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Work in Contemporary IT Teams

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“And now for something completely different.”

— Quote from Monty Python's Flying Circus.

Preface

In writing this thesis and the publications contained therein I have been very fortunate to receive support, guidance, and help from many people. I apologize in advance since this preface will not allow for covering each and everybody at the appropriate level of detail.

First and foremost, I would like to extend my sincere thanks to my supervisor Prof. Dr. Helmut Krcmar. I am deeply grateful for your continued advice, relentless support, and for helping me to really take my associative thinking to the next level. My time at the Chair for Information Systems, or the KrcmarLab, respectively, has been a really great experience: highly interesting projects and tasks, countless learning opportunities, and the certainty to never be bored. It is truly inspiring how you generously provide access to people and resources to help everyone grow and be the best they can. Thank you for instilling a unique collaborative environment for so much creative ideation, experimentation, and lastly: fun!

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Last, but certainly not least, I would like to thank my family and friends. My heartfelt thanks go to my parents for their curiosity to learn about the topics I have been working on, as well as their advice and unwavering support throughout writing this dissertation. Many thanks belong to all of my friends for their encouragement, providing necessary distraction, and for accepting the oddities of PhD life, such as paper deadlines conflicting with social appointments.

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Abstract

Problem Statement. Information Technology (IT) has become a widespread, if not ubiquitous, element of contemporary life. Considering this pronounced role, the question how IT artifacts, for example software, are conceived, developed, implemented, and maintained seems highly relevant. Extant research has portrayed such IT work as a specific context characterized by, for example, a particular organizational culture and the use of project teams to address knowledge-based tasks. To further elucidate details of this specific context of IT work, this thesis focuses on social and methodical aspects. Focusing on the composition of member characteristics as social aspects in IT teams, which are a typical organizational form of IT work, we studied the role of faultlines and subgroups as established constructs in general teams research. In the realm of methodical aspects, we investigated the potential of Design Thinking, which places humans and their needs at the center of innovation, to support IT work. Integrating the social and methodical focus of this thesis, we investigated Agile Software Development (ASD) as a now widespread approach to IT work.

Research Design. To investigate social and methodical aspects of work in contemporary IT teams, we followed a pluralist multi- and mixed methods approach. Our research into social aspects of IT work follows a post-positivist quantitative approach. To study the role of faultlines and subgroups in IT teams, which includes the potential moderating role of ASD, we analyzed survey and archival data using panel regression, negative binomial regression (NBR), and partial least squares structural equation modeling (PLS-SEM). Our research on methodical aspects followed a mostly qualitative mixed methods approach. To gain in-depth information on the potential of Design Thinking to support IT work, which includes suggestions for its relationship with ASD and for facilitating Design Thinking projects in a virtual setting, we adopted an interpretive qualitative approach based on the Critical Incident Technique (CIT), Design Science Research (DSR), and Case Study Research. Taking the inverse perspective, we studied the potential of a digital voice assistant as an IT artifact to support creative ideation based on hierarchical regression of an exploratory experiment.

Results. Considering social aspects, our results were partly in line with expectations. We observed a significant negative relation of perceived subgroups with team constructs and a positive, albeit insignificant relationship between the strength of knowledge-based faultlines and IT team performance. Surprisingly, we found the strength of diversity-based faultlines to be positively associated with IT team performance. Considering Open Source Software (OSS) projects, we found the effects of hypothesized subgroups to be contingent on the specific type of contribution behavior. Analogously, ASD practices may moderate effects of perceived subgroups contingent on the specific practice and team constructs. Considering methodical aspects, we found Design Thinking apt to support innovation in IT work, which includes a highly regulated health care context. We proposed combining ASD and Design Thinking as a promising approach to develop innovative IT solutions. However, we observed a digital context to give rise to both specific opportunities and challenges for applying Design Thinking. Considering the potential of IT artifacts to support creative ideation, objective performance measures exhibited no significant differences. However, the digital voice assistant rated significantly worse than a human facilitator on perceived helpfulness. To facilitate Design

Thinking projects in a virtual setting, we describe supporting creative ideation and assessing team morale as vital.

Contribution. Our results contribute to an increased understanding of the specific context of IT work, especially IT teams. By investigating the role of faultlines and subgroups, we follow the notion to consider social aspects as an important part of IT work. Our results imply faultlines and subgroups as established constructs in general teams research may be apt theoretical lenses to uncover additional contingencies of work in IT teams. In addition, by investigating the potential moderating role of ASD practices on effects of perceived subgroups, we heed calls to build ASD research on a theoretical basis. Our findings of ASD practices relating to established constructs from general teams research imply such constructs may help to increase our understanding of the effects of ASD. The observed effects of faultlines and subgroups combined with the potential moderating role of IT work methods imply potential levers to foster IT team performance through, for example, staffing and methodical adaptations. By investigating its potential to support innovation in IT work, we heed calls to further research into the role of Design Thinking in innovation. Our results support the case for Design Thinking to be a positive contribution to the methods applied in IT work. At the same time, our findings of opportunities and challenges specific to the digital context imply the potential need for and benefit of incorporating specific characteristics of IT work in applying Design Thinking. Our results on the potential of a digital voice assistant to facilitate creative ideation contribute to the discussion on the role of intelligent systems in teamwork.

Limitations. While purposefully adopting a broad and encompassing definition of IT work, we focused our investigation on specific subtopics of social and methodical aspects, which allows for only selective insights. Our investigations are set in several different individual contexts of IT work, which limits generalizability and introduces the risk of over-contextualization. Especially our quantitative investigations may benefit from a larger sample size. Moreover, applying different methods to the respective individual investigations may have resulted in additional or different insights. Similarly, other operationalizations of constructs, different approaches to analysis, or changes in model specifications may have resulted in different and, potentially, improved results.

Future Research. Beyond addressing the previously described limitations, our results imply several avenues for future research. To increase our understanding of the role of faultlines and subgroups in IT work, future research could investigate other operationalizations as well as include known characteristics of IT work. Similarly, additional research into the factors driving or limiting the applicability of Design Thinking in a digital context seems promising. To further heed the calls to build ASD research on a theoretical basis, future research could contextualize additional established constructs from general teams research. Both the application of Design Thinking in a digital context and ASD moreover harbor much potential to establish practical guidance on how to best facilitate IT work.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

ACIS	Australasian Conference on Information Systems
ACM	Association for Computing Machinery
AIS	Association for Information Systems
ASD	Agile Software Development
CAIS	Communications of the Association for Information Systems
CIT	Critical Incident Technique
CPR	ACM SIGMIS Conference on Computers and People Research
CSS	Creativity Support Systems
DSR	Design Science Research
DSU	Daily Stand-up Meetings
ECIS	European Conference on Information Systems
GCSS	Group Creativity Support Systems
GSS	Group Support Systems
HICSS	Hawaii International Conference on System Sciences
ICIS	International Conference on Information Systems
IEEE	Institute of Electrical and Electronics Engineers
IEEE TEM	IEEE Transactions on Engineering Management
IT	Information Technology
ITOC	IT Occupational Culture
NBR	Negative Binomial Regression
OSS	Open Source Software
PACIS	Pacific Asia Conference on Information Systems
PLS-SEM	Partial Least Squares Structural Equation Modeling
PVM	Projektmanagement und Vorgehensmodelle
SEM	Structural Equation Modeling
SIGMIS	Special Interest Group Management Information Systems
WI	Internationale Tagung Wirtschaftsinformatik
XP	eXtreme Programming

Part A
Introduction and Background

1 Introduction

1.1 Motivation

The paramount importance of information technology (IT) for modern society is evident at multiple levels. First and foremost, the role of IT itself has rather drastically morphed: “After merely a few decades, what once seemed to be glorified calculators have evolved into digital technologies that permeate our lives and work.” (Benbya, Ning, Tanriverdi, & Youngjin, 2020, p. 2) Adopting IT as a central element, second, implies changes in the design, function, or use of offerings, that is, products and services. There is no shortage of calls, proposals, and reports on “digitalization,” which range from considering the relationship of IT and service innovation in general (e.g. Barrett, Davidson, Prabhu, & Vargo, 2015; Böhmann, Leimeister, & Möslein, 2018), over a particular context, such as health care provision (Fichman, Kohli, & Krishnan, 2011), to concrete outcomes such as novel medical devices (Son, Brennan, & Zhou, 2020). At the organizational level, the evolution of IT implies established companies from all industries, including manufacturers of physical goods, have to embrace characteristics of IT to leverage opportunities and stave off challenges related to rapid technological change and new value propositions (Sebastian et al., 2017; Tiwana, 2014). Combining the nucleus of the pervasive role of IT with the widespread need for organizational reorganization leads to the third implication: Given the nearly all-encompassing use of IT in all strands of life, some argue that instead of mirroring physical reality, IT by now forms physical reality (Baskerville, Myers, & Yoo, 2020).

These far-reaching implications lead to the question how IT artifacts, for example software and its specific configurations, come into existence. This question, in turn, leads to several sub-dimensions, such as the individuals involved, the activities they carry out using which processes or tools, and the artifacts created. In this thesis, we broadly conceptualize IT work and the individuals taking part in these activities as “the entire continuum of workers who design, build, and manage application systems, who introduce them and other related IT into organizational environments, who operate, maintain, extend, and manage the IT, and who provide training, documentation, and support for the organizational context in which these systems are embedded.” (Niederman, Ferratt, & Trauth, 2016, p. 29)[1]. While this purposefully broad definition is meant to encompass anyone who has conceptual control over the design and use of IT, for example software developers and IT consultants, it excludes those who merely use IT without having control over its application, for example accountants using an Enterprise Resource Planning system.

IT artifacts as the outcomes of IT work, such as software, exhibit specific characteristics. They are frequently composed of individual components, which are interdependently linked to fulfill the desired overall function (Malone & Crowston, 1994). Further heightening the degree of interdependency, IT artifacts commonly draw on previously existing artifacts to achieve the intended outcome (Yoo, Henfridsson, & Lyytinen, 2010). Their intangible nature gives rise to

[1] While the publication referenced uses this definition to describe individuals engaged in IT work, we adopt it as a definition of IT work as such.

specific advantageous characteristics such as easy reuse as well as very low-cost transportation and reproduction (Tiwana, 2014).

These characteristics of IT artifacts translate to characteristic traits of activities, which portray IT work as a highly demanding endeavor and relate to a plethora of challenges. In this section we highlight challenges related to clarifying requirements, diverse needs for coordination, as well as the necessity to integrate knowledge in teams as a dominant organizational form of IT work. To accomplish its intended goals despite such manifold challenges, IT work heavily makes use of methods (Faraj & Sambamurthy, 2006), for example now highly popular agile approaches such as Scrum (G. Lee & Xia, 2010). Before dealing with the interdependence of IT artifacts (Malone & Crowston, 1994), determining *what* should be developed has posed issues in IT work already decades ago (e.g. Kling, 1977) and continues to be a relevant problem (e.g. Appan & Browne, 2012; Rosenkranz, Vranešić, & Holten, 2014). Especially considering the uncertainty in early project phases (Browning, Deyst, Eppinger, & Whitney, 2002), clarifying requirements, that is the goal and scope of IT work, is key to successful projects (Appan & Browne, 2012; Davis & Venkatesh, 2004). The interdependence of IT artifacts implies that teamwork is highly interdependent as well, which requires close coordination (Kraut & Streeter, 1995). In addition to technical dependencies, timing and processes require close coordination in IT work (Espinosa, Slaughter, Kraut, & Herbsleb, 2007b). Since it comprises mainly intellectual tasks, IT work is knowledge work with expertise as its main input (Faraj & Sproull, 2000). More specifically, IT work requires diverse expertise, which leads to teamwork as a dominant organizational form (Faraj & Sproull, 2000). Moreover, the mere presence of diverse knowledge is insufficient, but only its coordinated application (Faraj & Sproull, 2000; Kudaravalli, Faraj, & Johnson, 2017) and integration from multiple sources (Tiwana & McLean, 2005) lead to valuable outcomes in IT work. To satisfy these manifold needs for coordination, IT teams rely both on direct communication and implicit mechanisms such as knowledge shared by team members (Espinosa et al., 2007b). Such a focus on interpersonal communication and teamwork emphasizes the profoundly social nature of IT work, which is reflected in calls to investigate social aspects to understand drivers of successful IT work (Faraj & Sambamurthy, 2006).

To understand and address these challenges, extant research has treated a large number of topics related to, for example, social team processes as well as methods in IT work. As an example of a team-level social aspect, team member familiarity, that is how much team members have collaborated with each other before, benefits productive work in IT project teams (Espinosa, Slaughter, Kraut, & Herbsleb, 2007a; Huckman, Staats, & Upton, 2009). Concerning methods, the adoption of agile software development (ASD) practices may be considered the most encompassing development. Whereas “traditional” development is plan-driven, assumes predictability, and emphasizes planning to be in control, ASD deems change natural and favors iterative improvement based on interaction of all stakeholders (Nerur & Balijepally, 2007). The emphasis of ASD on self-managed teams that engage in direct interaction with users (G. Lee & Xia, 2010; Nerur & Balijepally, 2007), implies “Agile methods are people-centric” (Nerur & Balijepally, 2007, p. 81). In addition to ASD, which pertains to many tasks in IT work, “soft” social and subjective factors have also received attention concerning the specific activities related to requirements engineering. Examples include cultural and social effects (Hanisch &

Corbitt, 2007) or the proposition to draw on Design Thinking, which emphasizes human needs, as a method for requirements engineering (Vetterli, Brenner, Uebernickel, & Petrie, 2013).

In sum, IT work can be considered a complex endeavor that is profoundly shaped by human and social factors as well as the use of specific methods and tools. While the above overview implies a large body of extant research on enablers and inhibitors of IT work, there are relevant voids. First, the need for understanding social aspects in IT work is an enduring and often-voiced concern (Faraj & Sambamurthy, 2006). Despite a considerable amount of corresponding research, social aspects continue to be a relevant theme, for example considering structural traits in teamwork (e.g. Kudaravalli et al., 2017; Singh, Tan, & Mookerjee, 2011; Temizkan & Kumar, 2015). In the realm of requirements engineering, ASD is meant to address several issues of traditional practices, for example related to dynamic changes, considerable challenges remain, for example difficulties of users stating their requirements (Ramesh, Cao, & Baskerville, 2010). As stated in the previous paragraph, Design Thinking with its focus on human needs may present a valuable addition to requirements engineering (Vetterli et al., 2013). Notwithstanding widespread adoption and appraisal by practitioners, claims of the efficacy of ASD have for a long time lacked empirical corroboration (Dybå & Dingsøyr, 2008) and frequently continue to lack a theoretical foundation (J. Tripp, Saltz, & Turk, 2018). Against this backdrop, we seek to further the understanding of work in contemporary IT project teams. To this end, we focus on investigating the composition of member characteristics to elucidate the effects of social aspects on IT project teams, the potential of Design Thinking to support IT work, and both social and methodical aspects of ASD.

1.2 Research Questions

To update our understanding of contemporary work in IT project teams, we contribute threefold to research on social aspects and methodical aspects. First, we seek an improved understanding of the influence of member characteristics in IT project teams by adopting a structural approach based on the established constructs faultlines and subgroups. Second, we investigate the potential contribution of Design Thinking, which places human needs at the center of activities, as a method for innovation in IT work. Third, given the encompassing nature of ASD, see above, we investigate its role with regard to the preceding topics of social aspects and Design Thinking. In this section we briefly motivate each of the three research questions.

IT work profoundly relies on collaboration and interaction, which in turn rest on appropriate social processes. Based on the need for diverse expertise, work commonly takes the form of project teams (Faraj & Sproull, 2000). Such teamwork is, however, only successful if knowledge is applied in a coordinated manner (Faraj & Sproull, 2000; Kudaravalli et al., 2017) and integrated in a social process (Tiwana & McLean, 2005). Recent research highlights the role of structure for the performance of IT work, for example in distributed settings (Sarker, Ahuja, Sarker, & Kirkeby, 2011), in open source software (OSS) (Temizkan & Kumar, 2015) or in fulfilling the need for coordinated application of knowledge (Kudaravalli et al., 2017). Complementing this line of inquiry, research on teams in general has adopted the theory of faultlines, that is characteristics of team members aligning to create hypothetical dividing lines between member factions (Lau & Murnighan, 1998), and resulting subgroups to investigate the effects of differences in team member characteristics and their composition (e.g. Carton &

Cummings, 2012; Lau & Murnighan, 1998). Considering the observed effects of faultlines and subgroups on team processes and performance (e.g. Bezrukova, Jehn, Zanutto, & Thatcher, 2009; Carton & Cummings, 2013; Jehn & Bezrukova, 2010; Lau & Murnighan, 2005; S. Thatcher & Patel, 2011) and the previously outlined critical reliance of IT work on diversity as well as social processes, we seek to gauge the utility of faultlines and subgroups to better understand work in IT teams:

RQ1: What is the role of faultlines and subgroups in IT teams?

To address this research question, we analyze faultlines and subgroups in IT project teams in general and in the specific context of OSS and ASD. In general IT project teams, we investigate how the strength of faultlines and the number of potentially developing subgroups related to identity and knowledge affect team performance. In OSS teams, we operationalize subgroups based on OSS-specific measures such as reputation and contribution behavior. Lastly, in the context of ASD, we draw on the effects of perceptions of subgroups to investigate the moderating effect of ASD practices, see also RQ3. Our findings contribute to a better understanding how team composition and the resulting social processes can affect IT work. For practitioners, our findings can help to improve staffing and HR practices in IT project teams.

In addition to relying on social aspects, IT work makes extensive use of methods (Faraj & Sambamurthy, 2006). Requirements engineering, which basically means capturing user needs to inform *what* should be developed (Appan & Browne, 2012), has long been treated as a central issue in IT work (e.g. Hickey & Davis, 2004; Kling, 1977). Despite improvements in requirements engineering challenges remain. Specifically, establishing actual user requirements remains challenging (Davis & Venkatesh, 2004), for example due to the inability of users to state requirements (Ramesh et al., 2010) or failing to adequately capture requirements (Appan & Browne, 2012). Following previous suggestions (e.g. Vetterli et al., 2013), Design Thinking seems apt to resolve or at least ameliorate such issues. Following a human-centered approach based on, amongst others, iterative interaction with stakeholders to get a deep understanding of actual needs (Carlgren, Rauth, & Elmquist, 2016), Design Thinking is applicable to the type of "wicked," that is ill-defined, problems (Buchanan, 1992) presented by IT work (Nerur & Balijepally, 2007). At the same time, IT work presents a special type of context, which may influence how Design Thinking can be applied. For example, the knowledge-based nature of IT work (Faraj & Sproull, 2000), which implies artifacts are intangible, may be at odds with the key trait of Design Thinking to make results tangible (Carlgren, Rauth, et al., 2016; Liedtka, 2015). Given the potential of Design Thinking to inform requirements engineering in IT work and the potential of IT work affecting the applicability of Design Thinking, raises the question:

RQ2: *How can Design Thinking support work in IT teams?*

In investigating this research question, we focused on methodical or procedural implications of combining Design Thinking and IT work. Specifically considering the description of Design Thinking as applicable to a wide array of domains and topics (Beckman & Barry, 2007; Brown, 2008), we sought to assess the potential of Design Thinking to support the particular context of IT work. As an initial step, we harnessed Design Thinking in IT work as a human-centered means to elucidate requirements of digital innovation in a highly restricted health care context.

To understand the applicability of Design Thinking in IT work more comprehensively, we investigated how a digital context, that is, working on digital artifacts, enabled or constrained Design Thinking projects. As a last building block of our investigation how Design Thinking may contribute to IT work, we derived recommendations how Design Thinking may be used in conjunction with the popular ASD approach Scrum, see also RQ3. Complementing this investigation focused on applying Design Thinking to work on IT artifacts, we explored how well a digital artifact, that is a voice assistant, can facilitate creativity compared to a human facilitator. In addition, we provide recommendations how to facilitate Design thinking projects in a virtual context by ensuring creative ideation and assessing team morale. The results from investigating this research question improve our understanding how Design Thinking can form part of the methodical support of IT work. In addition to several opportunities, our results also underline that the specifics of IT work have to be dealt with adequately to achieve satisfactory results.

Whereas RQ1 seeks to further our understanding of work in contemporary IT teams by adopting a social perspective on teamwork, RQ2 explores how the human-centered approach Design Thinking can support IT work. Combining the two perspectives of social and methodical aspects leads to our third and final perspective on work in contemporary IT teams. Based on extant literature, ASD relates to methodical approaches, which have resulted in several incarnations (G. Lee & Xia, 2010) and emphasize social "people" aspects such as individual abilities (e.g. Nerur & Balijepally, 2007). Not least considering the proliferation of ASD (G. Lee & Xia, 2010) and the continued calls for further research on its efficacy (Dybå & Dingsøyr, 2008; J. Tripp et al., 2018), we deem it relevant to investigate how ASD as an overarching trend in IT work interacts with the social and methodical aspects investigated as part of RQ1 and RQ2. We thus pose the following research question:

RQ3: *How does agile development interact with perceived subgroups and can be combined with Design Thinking in IT teams?*

To shed light on the effects of ASD on social phenomena, we investigated how using ASD practices moderates the effects of perceived subgroups in IT teams. We specifically set out to link ASD practices to established constructs from teams research. Conversely focusing on the role of ASD as a method, we reflected on the relationship of Design Thinking and ASD. We thus were able to derive recommendations how Design Thinking may help requirements engineering before starting an ASD project for implementation. Our results underline how ASD can and arguably should be studied in relation to other constructs and methods as opposed to being treated as a monolithic social or methodical influence.

In summary, we sought to improve our understanding of IT work as a special work context by investigating several topics deemed relevant for contemporary IT teams. Following the reliance of IT work on social interaction in teams (e.g. Tiwana & McLean, 2005) and methodical support (Faraj & Sambamurthy, 2006), we investigated faultlines and subgroups as social phenomena and Design Thinking as a promising methodical contribution. By researching the role of ASD, which enjoys much popularity in IT work, related to subgroups and Design Thinking, we further linked our results to currently widespread practice in IT work. In the remainder of this thesis, we will present the results of our research and discuss it regarding the extant body of knowledge and avenues for future research.

1.3 Structure

This thesis comprises three main parts (A, B, C), which introduce the research topic and provide background information (A), provide an overview of the published research papers (B), and discuss our results regarding extant knowledge as well as suggest avenues for future research (C). Figure 1 depicts the structure of this thesis.

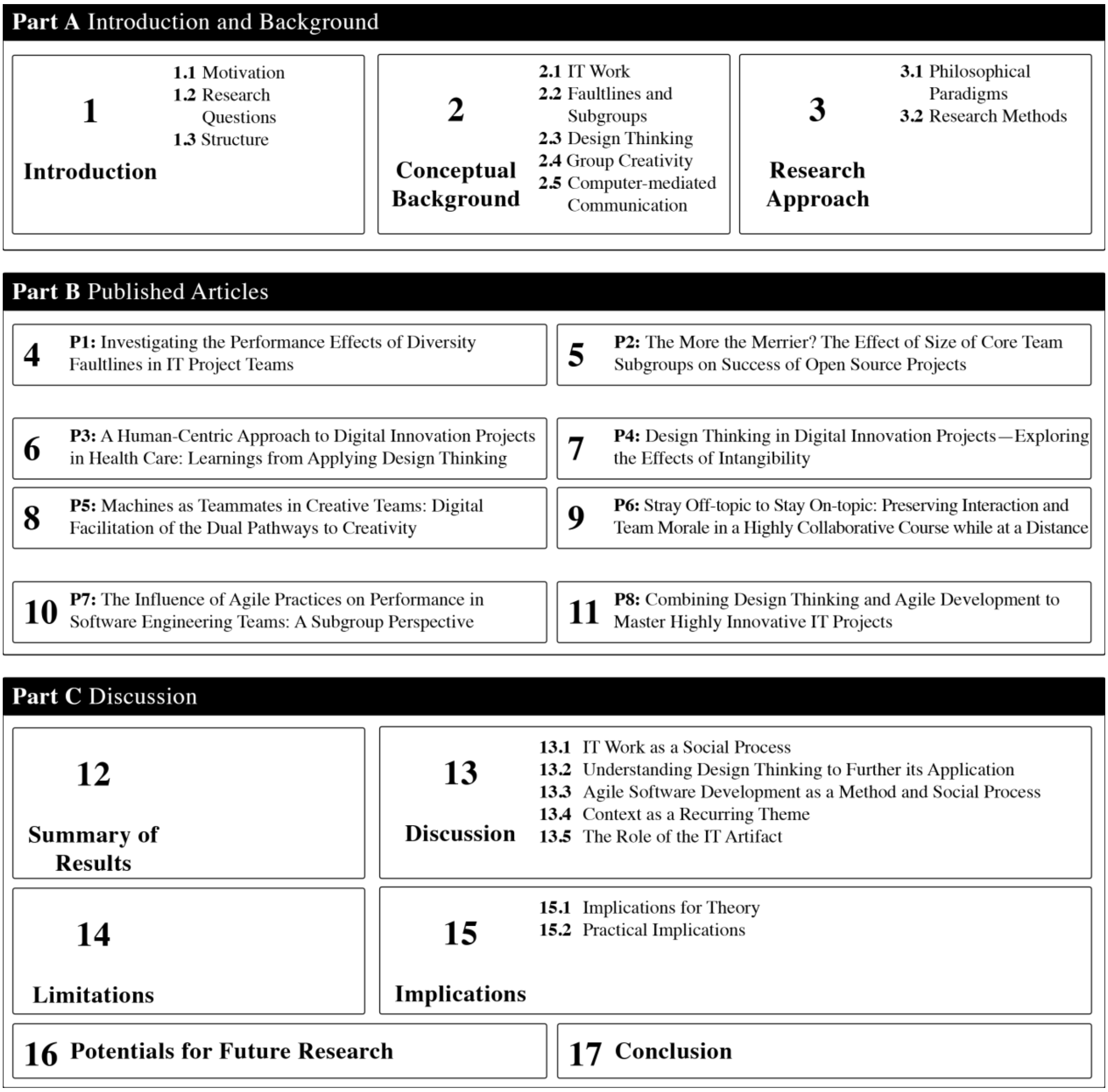

Figure 1 Structure of Thesis

Part A consists of three chapters, starting with an introduction to this thesis (current Chapter 1). Chapter 2 provides a summary of relevant background information on concepts central to this thesis: IT work including ASD, faultlines and subgroups, Design Thinking, group creativity, and computer-mediated communication. Chapter 3 describes our methodical approach to investigate work in contemporary IT teams.

Part B consists of the publications pertaining to the three RQ's guiding this thesis. P1 and P2 contribute to answering RQ1 concerning the role of faultlines and subgroups in IT teams (Chapters 4 and 5). P3-6 address RQ2 by investigating how Design Thinking can support work in IT teams (Chapters 6-9). P3 and P4 focus on applying Design Thinking in an IT context (Chapters 6 and 7), whereas P5 changes the perspective to how an IT artifact can facilitate Design Thinking (Chapter 8). P6 highlights the challenges of shifting a highly interactive Design Thinking course to a fully virtual setting and proposes potential interventions (Chapter 9). In combining the social and methodical perspective on IT work, P7 and P8 investigate how ASD affects work in IT teams (Chapters 10 and 11). P7 takes a social perspective on ASD by investigating it in conjunction with the social construct of subgroups (Chapter 10), which also helps to answer RQ1. Conversely, P8 focuses on integrating ASD with Design Thinking from a methodical perspective (Chapter 11), which adds to our answer to RQ2.

Part C focuses on reflecting and discussing our results regarding extant and future research. To this end, Chapter 12 provides a summary of key results of this thesis. Chapter 13 discusses our results concerning the main themes social and methodical aspects of IT work, as well as the characteristics and development of Design Thinking. We discuss contextualization as a characteristic common to all of the papers forming part of this thesis and reflect on the role of the IT artifact. Chapter 14 summarizes key limitations of this thesis before Chapter 15 outlines our contributions to both research and practice. Lastly, Chapter 16 proposes potential future research before Chapter 17 provides concluding remarks.

Table 1 and the following sections provide an overview and short summaries, respectively, of each of the publications (P) forming part of this thesis, see also chapters 4-11 in Part B. For each publication (P1-8), we summarize the research aim, the research approach we harnessed to fulfill this aim, and key results.

P1: Investigating the Performance Effects of Diversity Faultlines in IT Project Teams (Przybilla & Wiesche, 2019). Given the critical reliance of IT work on the joint application of diverse knowledge, the question how diversity in the composition of IT project teams affects their performance arises. To address this question, we drew on the theory of faultlines and subgroups to operationalize differences in member characteristics and the resulting group factions. We investigated the effects of identity-based faultlines, which we operationalized as demographics, and knowledge-based faultlines, which we operationalized as work experience, on project performance. In our sample of 424 projects, the number of identity-based group factions related significantly positively and knowledge-based ones insignificantly negatively to performance. Contrasting our expectations, we found only insignificant positive effects of knowledge-based faultlines, but a significant positive relation of the strength of identity-based faultlines with performance. We discussed how the specific characteristics of working in IT project teams may have contributed to this effect.

P2: The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects (Przybilla, Rahn, Wiesche, & Krcmar, 2019). In building software, OSS relies on mostly voluntary contributions from a community of developers. Given social structure is a known shaping force of work in OSS, we apply faultline and subgroup theory to understand how contributions in the core of an OSS project relate to its community appeal as a measure of success. We calculate the size of high- and low-value subgroups based on contribution characteristics related to reputation, extent and persistence of contributions, and issue focus. Including controls, neither reputation nor issue focus showed significant relations. Confirming our expectations, we found persistence in core contributions to significantly positively relate to community size, whereas extent was significantly negatively related. Based on these findings, we especially discuss the signaling effects contribution behaviors may have on outsiders and their potential influence in onboarding new members.

Table 1 Overview of Publications Embedded in Thesis

No	Authors	Title	Outlet	Type	RQ
P1	Przybilla, L; Wiesche, M	Investigating the Performance Effects of Diversity Faultlines in IT Project Teams	ICIS 2019	Conference	RQ1
P2	Przybilla, L; Rahn, M; Wiesche, M; Krcmar, H	The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects	WI 2019	Conference	RQ1
P3	Przybilla, L; Klinker, K; Wiesche, M; Krcmar, H	A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking	PACIS 2018	Conference	RQ2
P4	Przybilla, L; Klinker, K; Lang, M; Schreieck, M; Wiesche, M; Krcmar, H	Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility	IEEE TEM	Journal	RQ2
P5	Przybilla, L; Baar, L; Wiesche, M; Krcmar, H	Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity	CPR 2019	Conference	RQ2
P6	Przybilla, L; Klinker, K; Kauschinger, M; Krcmar, H	Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance	CAIS	Journal	RQ2
P7	Przybilla, L; Wiesche, M; Krcmar, H	The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective	CPR 2018	Conference	RQ1, RQ3
P8	Przybilla, L; Schreieck, M; Klinker, K; Pflügler, C; Wiesche, M; Krcmar, H	Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects	PVM 2018	Conference	RQ1, RQ3

Outlets	
CAIS	Communications of the Association for Information Systems
CPR 2018	ACM SIGMIS Conference on Computers and People Research, 2018, Niagara Falls, NY, USA
CPR 2019	ACM SIGMIS Conference on Computers and People Research, 2019, Nashville, TN, USA
ICIS 2019	40th International Conference on Information Systems, 2019, Munich, Germany
IEEE TEM	IEEE Transactions on Engineering Management
PACIS 2018	22nd Pacific Asia Conference on Information Systems, 2018, Yokohama, Japan
PVM 2018	Projektmanagement und Vorgehensmodelle, 2018, Düsseldorf, Germany
WI 2019	14. Internationale Tagung Wirtschaftsinformatik, 2019, Siegen, Germany

P3: A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking (Przybilla, Klinker, Wiesche, & Krcmar, 2018). The potential improvements digital innovation holds for health care in part have yet to be realized, not least because of characteristics specific to the health care context. To ameliorate this issue, we investigated how elements of Design Thinking can support such digital innovation projects. From a procedural perspective, learnings from two projects underlined the value of human-centered Design Thinking practices. Following an iterative, human-centered approach based on interaction with stakeholders was especially helpful for identifying requirements, which at times may not be salient or show only indirectly. Such an approach includes repeated testing with at first low-resolution prototypes, which are only gradually refined, to capture authentic and rich data. As an illustration of this approach, we summarized factors from several domains, which ranged from social and domain-related issues to the methodical approach, we observed as contextual elements digital innovation in health care should take into account. In discussing our results, we underlined the potential contribution of Design Thinking to improve Design Science Research.

P4: Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility (Przybilla, Klinker, et al., 2020). While Design Thinking does not assume a specific application context and has worked effectively in a number of domains, the increased relevance of digital artifacts for innovation leads to the question what may be specific to conducting Design Thinking in a digital context. Based on 21 projects, we found outcomes in the digital context to lie on a continuum from hardware-only to fully digital, e.g. software-based, innovation. Focusing on one mechatronic project incorporating hard- and software and one fully digital project, we detailed opportunities and challenges we observed for Design Thinking in digital innovation projects. Opportunities pertain to innovative business models, increased potential for individualization, and improved needfinding, prototyping, or testing. Challenges pertain to increased complexity in stakeholder management and difficulties in imagining, assessing, or prototyping digital features. We propose the intangibility of digital artifacts to be the common root cause of several opportunities and challenges we observed.

P5: Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity (Przybilla, Baar, Wiesche, & Krcmar, 2019). Research has established that both increased persistence and increased flexibility in ideation can lead to more creative outcomes. Given the current focus on “intelligent” information systems, this proposition leads to the question how well a virtual assistant can facilitate creativity compared to a human facilitator. Drawing on creativity research and the use of digital artifacts as facilitators, we built a digital voice assistant to facilitate flexibility or persistence in ideation. While a lab experiment showed no significant differences in objective outcome measures, digital facilitation rated significantly lower on perceived helpfulness. Our explorative results update extant knowledge on information systems in group settings and add to discussions on the role of digital assistants in teams. It seems especially relevant to study further which characteristics or context attributes contributed to nearly equal objective outcomes but perceived differences in helpfulness.

P6: Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance (Przybilla, Klinker, Kauschinger, & Krcmar, 2021). A Design Thinking course requires creative ideation, which in our experiences thrives on high levels of direct interaction. The constraints imposed to fight the Covid-19 pandemic forced us to conduct the second part of a two-semester course in a fully virtual setting. While adapting assignments was a necessary step, addressing the perceived reduction of creative interaction and constraints on assessing team morale in our experiences stood out as especially challenging. Incorporating the concept of social translucence in reflecting on our experiences, these difficulties may have resulted from a lack of visibility and awareness. Based on our experiences, we showcase possible measures to foster creative interaction by allowing for off-topic chit-chat as opposed to task-focused succinct communication. To mitigate the reduced ability to gauge team morale, we propose more explicit communication while ensuring team consent. Considering the specific context of our propositions, we reflect on lessons learned and discuss the applicability to other contexts. In summary, our observations are in line with extant publications highlighting the use of different media to be decisive as opposed to their basic characteristics.

P7: The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective (Przybilla, Wiesche, & Krcmar, 2018). Its emphasis on social aspects raises the question whether ASD moderates the effects of faultlines and subgroups in IT teams. We built a model relating the popular ASD practices daily stand-ups and retrospectives to the established social constructs elaboration of information and team reflexivity and tested their moderation of effects of perceived subgroups. We observed retrospectives to have a significant relation with either team construct, whereas daily stand-ups are only insignificantly related. In line with expectations, elaboration of information seems to attenuate, whereas team reflexivity surprisingly seems to further exacerbate conflict. Considering satisfaction, we found a similar, albeit insignificant, pattern. In addition to initial insight into the potential of ASD practices to moderate effects of subgrouping, our results help to understand the relation of ASD practices with social constructs. The resulting knowledge how ASD affects teamwork in turn can inform its effective use.

P8: Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects (Przybilla, Schreieck, et al., 2018). While ASD emphasizes iterative customer involvement and flexible reaction to changes, it assumes a goal for development has been set before. Based on our experiences in student and research projects, we propose to couple ASD with Design Thinking. Such an approach is meant to avert the risk of developing a solution that fails to address actual user needs. To this end, the detailed insights on stakeholders and their needs generated by Design Thinking can help to clarify what to develop using ASD methods such as Scrum. Focusing on the transition between Design Thinking and the subsequent implementation in ASD, we summarized key learnings related to human factors, knowledge management, and the need to challenge assumptions. We especially emphasize the value of having team members participate in both Design Thinking and ASD and of comprehensive, rich information moving from one phase to the other.

Beyond the eight publications forming part of this thesis, we authored several additional publications related to the topics under investigation. These complement the publications in this thesis by adding additional perspectives or through a different focus. Where RQ1 draws on faultlines and subgroups as theoretical constructs to study social aspects in IT work, we developed a theoretical model based on fluid team membership as a potential determinant of project success (Przybilla, Wiesche, & Thatcher, 2020), see entry P11. Closely related to P7 in addressing RQ3 and RQ1, entry P9 outlines a theoretical model how ASD could moderate the effects of faultlines through social constructs (Lassak, Przybilla, Wiesche, & Krcmar, 2017). Moreover, entries P10 and P12 draw on emergent leadership to understand work in ASD teams (Przybilla, Präg, Wiesche, & Krcmar, 2020; Przybilla, Wiesche, & Krcmar, 2019), which adds to both RQ1 and RQ3. Extending P10 and P12, P13 investigates perceptions of emergent leadership in two ASD teams (Biehler, Przybilla, & Krcmar, 2022).

Table 2 Overview of Additional Publications Relevant to Thesis

No	Authors	Title	Outlet	Type	RQ
P9	Lassak, S; Przybilla, L; Wiesche, M; Krcmar, H	Explaining How Agile Software Development Practices Moderate the Negative Effects of Faultlines in Teams	ACIS 2017	Conference [Research in Progress]	RQ1, RQ3
P10	Przybilla, L; Wiesche, M; Krcmar, H	Emergent Leadership in Agile Teams--an Initial Exploration	CPR 2019	Conference [Research in Progress]	RQ1, RQ3
P11	Przybilla, L; Wiesche, M; Thatcher, JB	Conceptualizing Fluid Team Membership and Its Effects in IT Projects: A Preliminary Model	ECIS 2020	Conference [Research in Progress]	RQ1
P12	Przybilla, L; Präg, A; Wiesche, M; Krcmar, H	A Conceptual Model of Antecedents of Emergent Leadership in Agile Teams	CPR 2020	Conference [Research in Progress]	RQ1, RQ3
P13	Biehler, J; Przybilla, L; Krcmar, H	"Primus inter Pares"?—The Perception of Emergent Leadership Behavior in Agile Software Development Teams	HICSS 2022	Conference	RQ1, RQ3
Outlets					
ACIS 2017	29th Australasian Conference on Information Systems, 2017, Hobart, Tasmania, Australia				
CPR 2020	ACM SIGMIS Conference on Computers and People Research, 2020, Nuremberg, Germany [virtual]				
ECIS 2020	28th European Conference on Information Systems, 2020, Marrakech, Morocco [virtual]				
HICSS 2022	55th Hawaii International Conference on System Sciences, Maui, HI, USA [virtual]				

2 Conceptual Background

In this chapter we will provide background information on concepts central to this thesis. First, we summarize our understanding of IT work, which includes the specifics of ASD and OSS. Having established our key object of inquiry, we introduce extant knowledge on faultlines and subgroups as social phenomena and Design Thinking as an innovation method that emphasizes human needs. Lastly, we briefly introduce research on creativity and computer-mediated communication.

2.1 IT Work

According to extant research, IT artifacts form the very basis of information systems research (Orlikowski & Iacono, 2001) but are not its sole focus (Benbasat & Zmud, 2003). While originally meant to define the IT artifact in its use context, we adapt the layered model of the IT artifact introduced by Benbasat and Zmud (2003) to structure our understanding of IT work. In this section, we will introduce our understanding of IT work, which includes the specific characteristics of IT teams, and outline ASD as well as OSS as specific contexts of IT work.

Based on Benbasat and Zmud (2003), we treat the IT artifact as the nucleus of IT work, which interacts with tasks. These elements are set within specific structures, which we see to include team states and processes, as well as the context specific to the respective development endeavor, for example country, industry, or business policies. Figure 2 illustrates this understanding of the elements of IT work. Following this structure, we adopt a deliberately comprehensive view of IT work to include a broad scope of activities from conceiving IT artifacts to educating users[2].

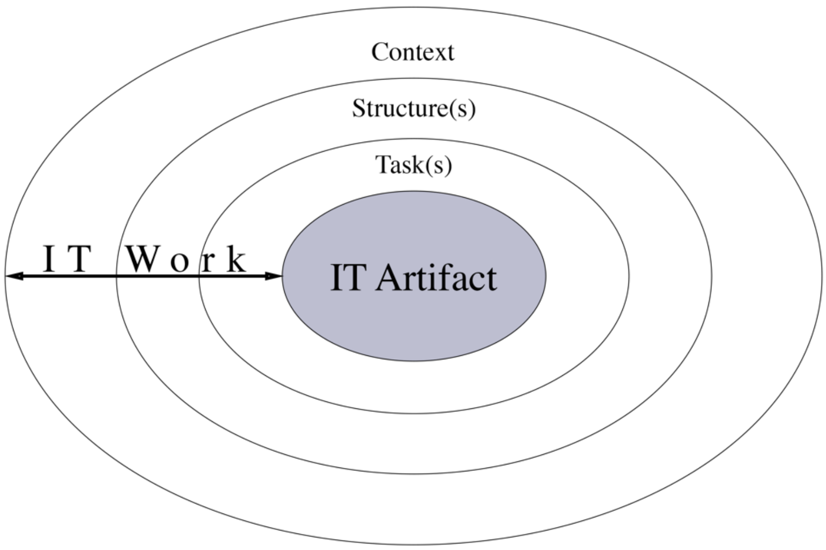

Figure 2 Layered Model of IT Work, adapted from Benbasat and Zmud (2003)

IT artifacts, that is "bundles of material and cultural properties packaged in some socially recognizable form such as hardware and/or software" (Orlikowski & Iacono, 2001, p. 121),

[2] See introduction section 1.1 for the definition of IT work, based on Niederman et al. (2016), adopted in this thesis.

have specific properties. In the following, we will focus on software as an IT artifact. A defining trait of IT artifacts is their interdependence: To achieve a certain goal, it is commonly decomposed into smaller instances, which in turn critically depend on each other to realize the overall functionality (Kraut & Streeter, 1995; Malone & Crowston, 1994). In addition, IT artifacts rely on preceding artifacts to function correctly, for example software requires appropriate computing hardware to be used (Yoo et al., 2010). Software is the object of knowledge work relying on expertise as primary input (Faraj & Sproull, 2000) and thus intangible compared to physical artifacts such as machinery. Consequently, intangible IT artifacts, that is software or information, can be combined without much effort as well as replicated and transported at very low cost (Tiwana, 2014; Yoo et al., 2010). Beyond characterizing IT artifacts, these traits have implications for organizations and society at large. Reliance on existing technology, easy integration and effortless transfer provide fertile ground for new business models or innovation, which may accelerate endogenously (Tiwana, 2014; Yoo et al., 2010). People using IT artifacts create a sociotechnical system, in which hardware, human actions, and digital features interact (Benbya et al., 2020).

Mirroring these characteristics of IT artifacts, *tasks* typical of IT work exhibit a combination of specific traits. First and foremost, IT work–specifically software development–is knowledge work (Faraj & Sproull, 2000) characterized as creative work on ill-defined problems that may have more than one solution (Tiwana & McLean, 2005), which in turn may only attenuate the problem (Benbya et al., 2020).

To attain its goals, IT work critically relies on the availability of diverse expertise, which is frequently brought together in teams (Faraj & Sproull, 2000; Tiwana & McLean, 2005).In such IT teams–as the central topic of this thesis–coordination across several topics is a key task to fulfill (Espinosa et al., 2007b; Kraut & Streeter, 1995). First, dependencies of IT artifacts require coordination (Espinosa et al., 2007b; Kraut & Streeter, 1995; Malone & Crowston, 1994). Beyond this artifact-related need for coordination, IT teams have to manage temporal dependencies, e.g. schedule overruns affecting downstream work, and process-related dependencies, e.g. following the order of steps prescribed in a mandatory process (Espinosa et al., 2007b). In addition, the diverse knowledge necessary for IT work has to be applied in a coordinated manner (Faraj & Sproull, 2000; Kudaravalli et al., 2017) and integrated (Tiwana & McLean, 2005). As an additional challenge, the phase and thus relative focus of IT work on design or implementation may make different coordination structures more effective (Kudaravalli et al., 2017). IT is, however, quickly evolving, which implies knowledge may become obsolete quickly (Zhang, Ryan, Prybutok, & Kappelman, 2012). To satisfy these diverse needs for coordination, IT teams rely on a number of mechanisms such as formal meetings, informal encounters in the office, and subconscious team processes (Espinosa et al., 2007b). The crucial need for coordination implies communication to be another critical task in IT work that, if insufficient, can contribute to subpar outcomes and project failure (Charette, 2005). Similarly, inadequate communication with users in determining requirements, for example by constrained communication or misinterpreting information, is a key issue in managing requirements (Appan & Browne, 2012; Ramesh et al., 2010).

Beyond coordination of expertise and work, a key task of IT work lies in correctly determining the requirements IT artifacts have to fulfill to generate value for users (Davis & Venkatesh, 2004; Hickey & Davis, 2004). While research has discussed the issue of failing to address actual user requirements already decades ago (e.g. Kling, 1977), it continues to be a relevant issue (e.g. Appan & Browne, 2012; Davis & Venkatesh, 2004; Ramesh et al., 2010; Schneider, Wollersheim, Krcmar, & Sunyaev, 2018). Issues in addressing requirements can arise from failing to capture actual requirements or from failing to incorporate the required functionality in the IT artifact (Davis & Venkatesh, 2004). While methodical support is said to have addressed the latter issue quite well, the issue of correctly defining requirements persists (Appan & Browne, 2012; Davis & Venkatesh, 2004). As a potential solution, the ability to adequately address changing user requirements is one of the proclaimed benefits of ASD (G. Lee & Xia, 2010; Ramesh et al., 2010). While ASD thus seems capable of attenuating some shortcomings of more traditional approaches, it is not adequate to address non-functional requirements, conflicting needs, or inability to state requirements on the side of users (Ramesh et al., 2010). To ameliorate the issue of failing to capture actual user needs, leveraging Design Thinking as a human-centered approach in requirements engineering has been proposed (Vetterli et al., 2013).

Traversing from typical *tasks* to *structures*, research has established a particular IT occupational culture (ITOC) (Guzman, Stam, & Stanton, 2008; Jacks, Palvia, Iyer, Sarala, & Daynes, 2018). Finding significant differences between IT workers and others on multiple but not all dimensions (Jacks et al., 2018), ITOC touches upon the specifics of IT work as well as differences to other professions. As examples from the former category, IT workers cherish technical knowledge, favor technical terms in communication, and appreciate technological change (Guzman et al., 2008; Jacks et al., 2018). Despite facing particularly high work demands (Guzman et al., 2008), IT workers emphasize the importance of "enjoyment at the workplace" (Jacks et al., 2018, p. 103). Moreover, ITOC underlines clearly established roles and responsibilities as well as unambiguous, exact communication (Jacks et al., 2018). Different communicative styles may contribute to somewhat tense relationships with other occupations (Jacks et al., 2018), which can comprise grumblings about others or a feeling of distinction (Guzman et al., 2008; Jacks et al., 2018). While statistically not significantly different from other occupations, autonomy is an important aspect of IT work, especially in ASD (Jacks et al., 2018; G. Lee & Xia, 2010; Tessem, 2014).

In addition to the previously elaborated characteristics of the IT artifact, tasks, and importance of ITOC, its profoundly social nature is a characteristic trait of IT work. To lead to successful outcomes, the integration of diverse knowledge in an IT team critically relies on social interaction (Tiwana & McLean, 2005). As team members work together over time, they become familiar with one another. Familiarity among members is conducive to IT project performance (Huckman et al., 2009), particularly when the team has a pronounced need for coordination (Espinosa et al., 2007a). Repeated interactions among team members also provide the basis for forming team cognition, that is team members having a shared understanding of elements such as tasks, processes, and who has which knowledge, which is an important ingredient of effective work in IT teams (Espinosa et al., 2007b; He, Butler, & King, 2007). Specifically, such team knowledge can help in coordination among members (Espinosa et al., 2007b).

Agile Software Development (ASD) shapes a specific context or environment for IT work, which comprises a specific relation to the IT artifact, particular tasks, and distinct emphasis on certain aspects of structure. A prominent root of ASD lies in a group of ASD supporters who put forth an "Agile Manifesto" to overcome the perceived shortcomings of then-current development approaches (Highsmith & Cockburn, 2001; G. Lee & Xia, 2010). The Agile manifesto proclaims an emphasis on functional artifacts, flexibly addressing change, and collaboration among developers as well as with customers (Beck et al., 2001; Highsmith & Cockburn, 2001). To attain these goals, agile principles include propositions such as a focus on customer satisfaction, iteration, direct interaction, and self-organization in teamwork (Beck et al., 2001). Based on these propositions, ASD is meant to outperform traditional development approaches, for example by better accounting for changes in the business context and the ensuing requirements (G. Lee & Xia, 2010; Ramesh et al., 2010).

To operationalize these propositions, there is a number of different ASD frameworks or methods such as Scrum, eXtreme Programming (XP), or feature-driven development (Highsmith & Cockburn, 2001; G. Lee & Xia, 2010). These methods in turn comprise ASD practices such as daily stand-up meetings (DSU) as joint short status updates, retrospectives for reflection and improvement, or pair programming as two team members jointly elaborating code (J. F. Tripp, Riemenschneider, & Thatcher, 2016). ASD generally emphasizes social collaboration such as direct interaction and self-organized decision marking in a cohesive team (Beck et al., 2001; McAvoy & Butler, 2009), which the preceding practices arguably reflect. Notwithstanding the assumed substantial benefits and much interest by practitioners, discussions of ASD had for a long time progressed without empirical studies (Dybå & Dingsøyr, 2008; G. Lee & Xia, 2010). While empirical studies partially support proclaimed benefits such as improved team communication (Pikkarainen, Haikara, Salo, Abrahamsson, & Still, 2008) or overall project success (Serrador & Pinto, 2015), results also highlight shortcomings and potential issues of adopting ASD. As an example from the social dimension of ASD, too much cohesion can negatively affect ASD teams (McAvoy & Butler, 2009). While ASD can ameliorate some issues related to requirements engineering, issues such as nonfunctional aspects and problematic input from users persist (Ramesh et al., 2010). Notwithstanding these empirical contributions to knowledge, proper theoretical footing is still scarce and remains a relevant potential in ASD research (J. Tripp et al., 2018).

Open Source Software (OSS)[3] development provides another specific context for IT work. OSS projects typically take place in internet communities whose members jointly produce software in an iterative manner (Singh et al., 2011; von Hippel & von Krogh, 2003). In producing OSS, which can be freely reused and changed (von Hippel & von Krogh, 2003),

[3] Considering this section is of key relevance to P2, it draws on the structure and argumentation of the original publication.

contributors effectively share information (Singh et al., 2011). Especially considering the in many cases voluntary contributions to OSS without an organizational affiliation (Hertel, Niedner, & Herrmann, 2003), the questions what drives such contributions, how OSS projects function, and what determines outcomes arise. Motivations for contributing to OSS include, for example, personal need for functionality, identity as a developer, pleasure of programming, personal skill development, or gaining status (Hertel et al., 2003; von Hippel & von Krogh, 2003). Considering the functioning of OSS projects, OSS communities exhibit a particular ideology, which comprises rules how work should be done, values, for example, activity over debates, defines status as a community construct, and appreciates, for example, community support and collaboration (Stewart & Gosain, 2006). OSS communities in many cases show a social structure akin to an onion with a set of core contributors surrounded by more peripheral, casual contributors (Amrit & Van Hillegersberg, 2010). Extant research has established such structural characteristics of OSS communities as an important consideration for functioning and outcomes. At a general level, changes between project core and periphery may, for example, indicate overall project status (Amrit & Van Hillegersberg, 2010). At a detailed level, diverse interactions of members benefit creative work in feature development, whereas tightly coupled members benefit targeted work on patches (Temizkan & Kumar, 2015).

2.2 Faultlines and Subgroups[4]

Intended as a theoretical lens to better understand effects of diversity in teams, the faultlines construct focuses on the distribution and (dis)similarity of member characteristics (Lau & Murnighan, 1998). Faultlines arise from one or several characteristics shared by some but not all team members, which lead to “hypothetical dividing lines that may split a group into subgroups based on one or more attributes.” (Lau & Murnighan, 1998, p. 328). Furthering the analogy with geological faultlines, faultlines in teams can remain passive or “dormant” or become active as subgroups perceived by team members (Jehn & Bezrukova, 2010; Lau & Murnighan, 1998). While originally conceived for demographic characteristics (Lau & Murnighan, 1998), more recent research has differentiated whether the formation of faultlines pertains to the identity of members or their specific expertise (Bezrukova et al., 2009). As a typology of subgroups, differences in identity, access to resources, and knowledge have been put forth as reasons for emergence (Carton & Cummings, 2012). These differences in formation consequently evoke different relations between subgroups (Carton & Cummings, 2012). In parallel with a more differentiated view on the emergence of faultlines and subgroups, multiple approaches to measurement, for example including the distance on attributes (Bezrukova et al., 2009), have developed (Meyer, Glenz, Antino, Rico, & Gonzalez-Roma, 2014).

The effects of faultlines and subgroups may vary based on the reason for formation and moderators. For example, demographic faultlines may reduce perceived performance, satisfaction, communication, and team cohesion while increasing conflict (Lau & Murnighan, 2005; S. Thatcher & Patel, 2011). Activated faultlines may further exacerbate such negative effects (Jehn & Bezrukova, 2010). Similarly, the number of identity-based subgroups may affect team performance (Carton & Cummings, 2013). Conversely to these quite consistent

[4] Considering this section is of key relevance to P1 and P7, it draws on the structure and argumentation of the original publications.

negative effects of faultlines and subgroups relating to identity, information- or knowledge-based faultlines and subgroups show more mixed results. While having more knowledge-based subgroups may positively relate to performance (Carton & Cummings, 2013), such positive effects may be contingent upon boundary conditions such as team identification, dynamism, or complexity (Bezrukova et al., 2009; Cooper, Patel, & Thatcher, 2014). As is evident from these results, the effects of faultlines and subgroups strongly depend on the specific context (Bezrukova et al., 2009), which is mirrored in several research efforts considering moderation. For example, reflexivity (Veltrop, Hermes, Postma, & de Haan, 2015), cross-cutting faultlines (Homan, Van Knippenberg, Van Kleef, & De Dreu, 2007), or the ability to directly share knowledge (van der Kamp, Tjemkes, & Jehn, 2015) have been found or proposed to improve work in teams with faultlines or subgroups.

2.3 Design Thinking[5]

Design Thinking does not denote a clearly defined construct but can pertain to several discussions in the Design field as well as multiple ones in Management (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). The breadth of the term is further evident from findings that Design Thinking may refer to a discipline, a mindset, or a method (Carlgren, Rauth, et al., 2016), which moreover comprises a multitude of processes and techniques (Liedtka, 2015). A key trait of Design Thinking is its suitability for addressing "wicked" problems, that is, problems without a clear definition nor solution (Buchanan, 1992). For the purpose of this thesis, we mostly focus on the managerial discussion on Design Thinking, which introduces approaches usually used in design to managerial practice (Johansson-Sköldberg et al., 2013). We specifically follow the view of Design Thinking as a method for problem-solving that promises innovation (Liedtka, 2015) by putting human needs at the core of a creative approach while safeguarding technological feasibility and economic viability (Brown, 2008).

To attain this goal, Design Thinking relies on several guiding principles. At a fundamental level, design work is described as abductive, that is, based on the generation of alternative ideas, which complements inductive and deductive ways of working (Carlgren, Rauth, et al., 2016; Dunne & Martin, 2006; Liedtka, 2015). Observing practitioners, Carlgren, Rauth, et al. (2016) found the following distinct principles in Design Thinking, which align closely with propositions by practitioners: Users and their needs are at the very center of Design Thinking, which is reflected in a human-centered approach emphasizing empathy and direct interaction (Brown, 2008; Carlgren, Rauth, et al., 2016). In seeking to address these needs, Design Thinking favors exploring the problem to gain a deep understanding as opposed to trying to solve the problem from the start (Carlgren, Rauth, et al., 2016). Ideas for potential solutions should be elaborated visually using prototypes of initially low-fidelity (Brown, 2008; Carlgren, Rauth, et al., 2016). Referring back to the core principle of involving users, these prototypes should be tested by stakeholders, which leads to the trait of an iterative approach based on trial and error (Brown, 2008; Carlgren, Rauth, et al., 2016). Beyond these typical tasks, Design Thinking favors diversity in team members and team-external information as well as an optimistic mindset (Brown, 2008; Carlgren, Rauth, et al., 2016). While these traits and

[5] Considering this section is of key relevance to P4, it draws on the structure and argumentation of the original publication.

principles may be an important contribution to the management of innovation projects (Mahmoud-Jouini, Midler, & Silberzahn, 2016), they at the same time may lead to challenges based on, for example, how to communicate during work (Carlgren, Elmquist, & Rauth, 2016).

The lack of a clear definition is mirrored in the number of proposed Design Thinking processes. Despite such variety, a comparison of processes deemed popular has resulted in a common core of three phases (Liedtka, 2015). An initial investigation of stakeholder needs in the first phase provides the underpinning for ideating on potential solutions in the second phase, which in turn lead to prototyping and evaluation based on testing (Liedtka, 2015). These phases are meant to be iteratively repeated by diverse teams, should encompass direct interaction with stakeholders, and can harness a number of tools (Liedtka, 2015). For the purpose of this thesis we focus on two Design Thinking processes: The Double Diamond model described by the Design Council ("What Is the Framework for Innovation? Design Council's Evolved Double Diamond,") and the Design Thinking Micro-cycle described by Uebernickel et al. (2020).

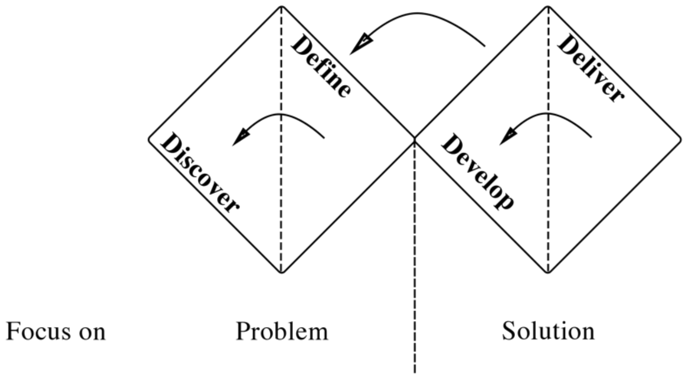

Figure 3 Double Diamond Model of Design, based on "What Is the Framework for Innovation? Design Council's Evolved Double Diamond")

The Double Diamond model, see figure 3, emphasizes the integration of dichotomous activities and perspectives. The first “diamond” emphasizes initially gaining a profound understanding of the problem to be addressed, whereas the second focuses on finding a potential, appropriate solution (Ball; "What Is the Framework for Innovation? Design Council's Evolved Double Diamond,"). The first, problem-focused, diamond comprises the *discover* step, which as a divergent activity aims at gathering detailed information about the issue to be addressed, and *define* step, which as a convergent activity condenses the previously gathered information in a precise statement of the problem to be solved (Ball; "What Is the Framework for Innovation? Design Council's Evolved Double Diamond,"). Mirroring the first, the second diamond comprises the *develop* step, which as the second divergent activity seeks to generate a variety of potential solutions to the previously identified problem, and the *deliver* step, which as a convergent activity narrows the set of potential solutions through testing and improvement (Ball; "What Is the Framework for Innovation? Design Council's Evolved Double Diamond,"). Notwithstanding its depiction as a sequence of steps, the Double Diamond model acknowledges iteration such that, for example, prototypes can increase the understanding of core issues to be addressed ("What Is the Framework for Innovation? Design Council's Evolved Double Diamond,").

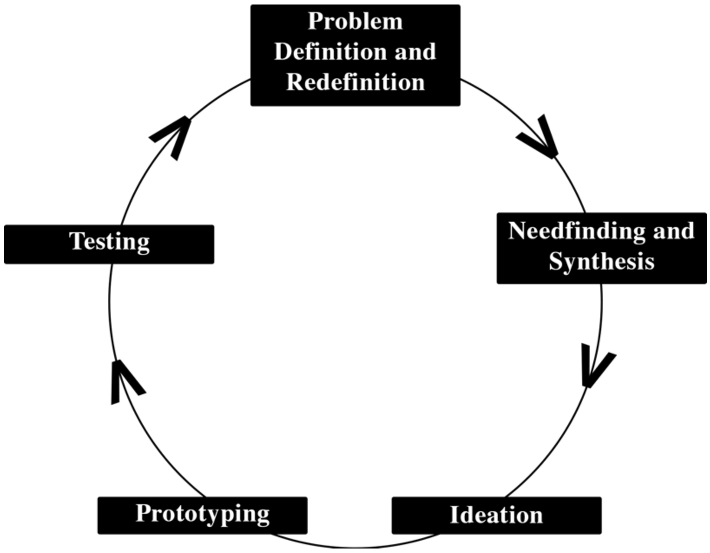

Figure 4 Design Thinking Micro-cycle, based on Uebernickel et al. (2020)

As a complement to the Double Diamond model, which emphasizes both problem and solution as key aspects of a project, the Design Thinking Micro-cycle, see figure 4, outlines the steps to be iteratively repeated (Uebernickel et al., 2020). Over the course of a project the relative focus on the individual steps shifts in accordance with the propositions of the Double Diamond, that is, early iterations emphasize gathering diverse information and pursuing alternative approaches, whereas later iterations emphasize detailed development (Vetterli, Uebernickel, Brenner, Petrie, & Stermann, 2016). Posing a good, that is specific to the goal but neutral regarding the solution, question starts the micro-cycle in the *Problem definition and redefinition* step (Uebernickel et al., 2020). *Needfinding and synthesis* aims at establishing a detailed understanding of stakeholders and their needs using activities, such as interviews, benchmarking, or ethnographic observations, and condensing these using tools such as personas (Uebernickel et al., 2020). This information on actual needs provides the basis for *Ideation* on potential solutions using methods such as brainstorming (Uebernickel et al., 2020). *Prototyping* comprises creating tangible embodiments of ideas, which not only aid testing with stakeholders but also help, for example, to ensure common interpretation in the team (Uebernickel et al., 2020). *Testing* these prototypes with stakeholders serves to (dis)confirm whether the proposed solutions address actual needs (Uebernickel et al., 2020). The knowledge gained in *Testing* can inform a more refined *Problem definition* (Uebernickel et al., 2020) and lead to a new iteration of the cycle.

2.4 Group Creativity[6]

Explicitly not seeking to provide a comprehensive overview of the decades-long history of research into creativity (e.g. Amabile & Pillemer, 2012), we will briefly introduce key traits relevant to this thesis. In addition, we will provide examples of the relation of creativity and information systems.

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[6] Considering this section is of key relevance to P5, it draws on the structure and argumentation of the original publication.

Basic issues of research lies in defining and measuring creativity (Amabile, 1983; Rietzschel, De Dreu, & Nijstad, 2009). Considering the baseline for evaluation, creativity can either relate to an individual's personal activities or to a universal assessment of all activities enacted by humanity (Rietzschel et al., 2009). At a more operational level, creativity has frequently been related to personal characteristics, processes, outcomes, or context factors (Amabile, 1983; Rietzschel et al., 2009).

Process-focused views research creativity based on thought processes, several of which describe the combination of elements to attain a solution (Amabile, 1983). During a considerable timespan, psychological research has studied creativity extensively based on personal traits or characteristics that allow people possessing these traits to be creative (Amabile & Pillemer, 2012). Regarded as especially useful, outcome-based views of creativity emphasize unforeseen, surprising elements that at the same time should be suitable in their context (Amabile, 1983). Diagnosing an overreliance of creativity research on traits, a component model of creativity considering context, which integrates elements such as specific skills, motivation, traits, and social influences, has been proposed (Amabile, 1983).

Considering the basic issue of measuring creativity, *originality, fluency,* and *flexibility* are frequently used, but potentially unrelated, measures to attain this aim (Rietzschel et al., 2009). To be *original* an outcome has to be unexpected or rare, whereas *fluency* denotes the quantity of unique outcomes (Rietzschel et al., 2009). *Flexibility* relates to harnessing different viewpoints and taking a broad approach using multiple cognitive categories (Nijstad, De Dreu, Rietzschel, & Baas, 2010; Rietzschel et al., 2009). Complementing this set of measures aimed at "the more the better," "The dual pathway to creativity model" (Nijstad et al., 2010, p. 34) proposes both *flexibility* and *persistence,* that is more exhaustive, meticulous elaboration within few cognitive categories, to be drivers of creativity (Nijstad et al., 2010). Drawing on the compositional model of creativity, the dual pathway model hypothesizes different context factors to support either *flexibility* or *persistence* (Nijstad et al., 2010).

Creativity, specifically brainstorming, in group settings has led to several specific observations and questions. First, the conundrum why groups perform worse than individuals in terms of number of ideas was in the focus (Stroebe, Nijstad, & Rietzschel, 2010). Second, the context of working in a group became a focal point, which was followed by a broader approach including an emphasis on the quality of outcomes (Stroebe et al., 2010).

Considering IT work, group creativity has a dual, reciprocal role. On the one hand, group creativity is a necessary part of IT work to address hard-to-grasp problems that may have more than one solution (Tiwana & McLean, 2005). On the other hand, there is a considerable amount of research into how IT artifacts can support group work, termed group support systems (GSS) (e.g. Dennis & Wixom, 2002; Liou & Chen, 1993), creative elaboration as creativity support systems (CSS) (e.g. Wierenga & van Bruggen, 1998), or creativity in groups as group creativity support systems (GCSS) (e.g. Voigt, Bergener, & Becker, 2013). Research has, for example, investigated how computer-mediated communication influences group creativity (e.g. Dennis & Wixom, 2002; Rosalie Ocker, Fjermestad, Hiltz, & Johnson, 1998; R. Ocker, Hiltz, Turoff, & Fjermestad, 1996), including how to design the physical environment of computer-supported group work (Lewe & Krcmar, 1991), or how IT artifacts support creativity (Massetti, 1996).

Moreover, structuring ideation (Dennis, Valacich, Connolly, & Wynne, 1996) or stimulating participants (Satzinger, Garfield, & Nagasundaram, 1999) may be able to shape creative performance. Specifically considering the dual pathway of both flexibility and persistence driving creative performance, stimulation using IT artifacts may outperform other means such as structuration (Althuizen & Reichel, 2016).

2.5 Computer-mediated Communication[7]

In addition to investigating effects of computer-mediated communication on group creativity, see previous section for examples, information systems research has covered the potentials and specific characteristics of computer-mediated communication from several different angles. Without the intent of being exhaustive, we will briefly highlight approaches pertaining to the characteristics of different communication media and those highlighting their actual use. This selection is in line with the general classification of research into the choice of different media, which may result from either traits or social factors (Carlson & Davis, 1998).

Media richness theory proposes different media, for example direct face-to-face interaction or text-based media, to differ in their "richness," that is, in characteristics such as delays in response or the ability to convey additional information, for example body language (Daft & Lengel, 1986). Consequently, using "lean" media may create issues, for example misinterpretations, in distributed work, (Kayworth & Leidner, 2002). However, expected interactions of media richness with task characteristics have not been confirmed (Dennis & Kinney, 1998). Likewise, team characteristics may decisively affect the role of media richness (Yoo & Alavi, 2001).

The concept of social translucence can be applied to describing electronic media and their use by evaluating the levels of *visibility*, *awareness*, and *accountability* (Erickson & Kellogg, 2000). *Visibility* as the ability to observe another person's presence or actions is a basic requirement for *awareness*, that is, knowledge of the respective person's presence, actions, or implied needs (Erickson & Kellogg, 2000). Lastly, *accountability* ensures supervision and implies people may face consequences for their actions (Erickson & Kellogg, 2000).

Traversing to use-based approaches, habits or their disruption may affect the use of media and subsequent outcomes (Bartelt & Dennis, 2014). Additionally, patterns in communication may affect performance (Espinosa, Nan, & Carmel, 2015). The multitude of factors potentially affecting the use of specific media over others can result in different combinations of multiple media to fulfill the intended communicative activity (Watson-Manheim & Bélanger, 2007).

[7] Considering this section is of key relevance to P6, it draws on the structure and argumentation of the original publication.

3 Research Approach

In this chapter, we outline our research approach to investigate work in contemporary IT teams. Reflecting our multi-faceted view of IT work, we followed a multi- as well as mixed methods approach. To test hypotheses based on established theory in the specific context of IT work, which draws on propositions by Hong, Chan, Thong, Chasalow, and Dhillon (2013) to conduct context-specific investigations, we harnessed quantitative methods while taking a post-positivist perspective. To openly explore phenomena and generate a rich, detailed understanding of them, we drew on qualitative methods, which frequently link to an interpretivist perspective. Using this approach, we follow suggestions to use mixed methods (Venkatesh, Brown, & Bala, 2013) and to combine methods beyond individual paradigms (Mingers, 2001) in information systems research. Against this backdrop, we will first outline the philosophical paradigms guiding our research before introducing the research methods we harnessed.

3.1 Philosophical Paradigms

For the purpose of this thesis, we construe a paradigm as a philosophical concept concerning, for example, the existence of phenomena, the role of knowledge, as well as related research methods (Mingers, 2001; Villiers, 2005). As part of this thesis, both the (post-)positivist and the interpretivist paradigm, which discussions repeatedly distinguish (e.g. Mingers, 2001; Venkatesh et al., 2013; Villiers, 2005), are relevant.

At its core, a positivist view construes research results to mirror an objective reality (Villiers, 2005). The positivist paradigm routinely accompanies tests of hypotheses (Orlikowski & Baroudi, 1991; Villiers, 2005) derived from extant theory (Orlikowski & Baroudi, 1991). Following a positivist view, social sciences follow the research approach of natural sciences (A. S. Lee, 1999). As empirical means, a positivist approach frequently harnesses quantitative methods (Orlikowski & Baroudi, 1991; Villiers, 2005), which complements the observation that information systems research oftentimes employs quantitative methods to test hypotheses (Venkatesh et al., 2013). As an extension to the positivist paradigm, post-positivism concedes that factors such as the operationalization of measures can influence results, which in turn limits objectivity (Gefen, 2019). A proclaimed advantage of a (post-)positivist paradigm lies in forcing researchers to clearly state their expectations in theory, which is subsequently the subject of (relatively) objective confirmation or disconfirmation based on empirical data (Gefen, 2019). In the scope of this thesis, we adopt a post-positivist stance and acknowledge inherent limitations to operationalizations, measures, or models of phenomena.

Where positivism assumes the existence of a single objective truth, interpretivism construes reality to be contingent on the context, timing, or involvement of actors, which implies there may be several interpretations (Orlikowski & Baroudi, 1991; Villiers, 2005). Consequently, interpretivist research results build on individual views and interpretations, which renders them subjective (Orlikowski & Baroudi, 1991; Villiers, 2005). Research following the interpretivist paradigm commonly harnesses qualitative methods to capture detailed information (Villiers, 2005), which frequently back explorative research in information systems (Venkatesh et al., 2013). While for a considerable time a positivist approach has been central in information systems research (Orlikowski & Baroudi, 1991), interpretivism has also become established (Klein & Myers, 1999). An interpretive approach is especially suited to research questions related to complex phenomena (Villiers, 2005), where “it has the potential to produce deep insights into information systems phenomena” (Klein & Myers, 1999, p. 67).

To attain the aim of studying work in contemporary IT teams, this thesis heeds the recommendation to follow a pluralist approach in information systems research (Mingers, 2001). Consequently, we extend our post-positivist view and the corresponding quantitative research methods by using qualitative methods, which typically relate to an interpretive view. Within our pluralist approach to investigate IT work, our specific foci on social and methodical aspects each follow a distinct approach.

To investigate social phenomena in IT work, which include the social aspect of ASD, we draw on faultlines and subgroups as theoretical constructs established in general teams research (e.g. Lau & Murnighan, 1998). Heeding calls to consider context, that is influencing factors contingent on the specific situation (Johns, 2006, quoted in Hong et al., 2013) or attributes of the technology and associated use case (Hong et al., 2013), in information systems research (Hong et al., 2013), we drew on established theory as a foundation to better understand social aspects in the specific context of IT work. By hypothesizing and operationalizing faultlines and subgroups based on IT-specific measures, such as industry experience (P1) or reputation in OSS (P2), incorporating context-specific control variables, such as project duration (P1), project age (P2), or adding context-specific moderators (P7), we sought to adequately contextualize extant theory to IT work (Hong et al., 2013). Our aim of generating and testing hypotheses based on theory thus corresponds to a positivist approach (Orlikowski & Baroudi, 1991; Villiers, 2005), which we extend to a post-positivist stance. By harnessing quantitative methods to test our hypotheses, our approach moreover corresponds to the widespread application of quantitative methods in information systems research to confirm theory (Venkatesh et al., 2013).

To study methodical aspects of contemporary IT work, which namely include the role of Design Thinking and ASD as a method, we extend our research approach to include qualitative methods, which frequently link to an interpretive approach. While there is extant research on a number of topics around Design Thinking, for example, the origins of the concept (e.g. Johansson-Sköldberg et al., 2013), its role in innovation is still poorly understood (Pitsis, Beckman, Steinert, Oviedo, & Maisch, 2020). Combining this lack of an established coherent body of research and the number of specific traits of IT work, see section 2.1, in our view constitutes a complex phenomenon. To understand the implications of Design Thinking for IT work, we draw on qualitative methods as a common means of exploratory research in information systems (Venkatesh et al., 2013). Given the frequent use of qualitative methods as operationalizations of interpretive research (Villiers, 2005), we thus extend our approach to include interpretive elements, which seems beneficial considering the potential of an interpretive approach “to produce deep insights” (Klein & Myers, 1999, p. 67). Extending the concessions of post-positivism, see above, we especially acknowledge that our individual perceptions and subsequent biases may influence results to be indicative of only one but not necessary “the” reality (Orlikowski & Baroudi, 1991; Villiers, 2005).

Within this general interpretive frame, two research projects of this thesis present special cases. Seeking to gauge the applicability of Design Thinking in the specific context of information systems in health care, we drew on Design Science Research (DSR, see P3 and section 3.2.2 for methodical details), which while allowing for several realities lies in the middle of (post-)positivism and interpretivism by exhibiting "a pragmatic, problem-solving approach that tolerates ambiguity" (Villiers, 2005, p. 37). While DSR exhibits traits of interpretivism (Villiers, 2005), its hybrid nature adds coherently to our pluralist research approach.

Compared to the other publications that are part of RQ2, P5 inverts the perspective on IT artifacts by investigating their potential to support creative ideation. Mirroring this thematic shift, P5 takes a pure post-positivist view using a quantitative, experimental approach. While our focus was on exploring the potential role of digital artifacts, our exploration footed on hypotheses based on extant theory, which closely aligns with a (post-)positivist approach (Orlikowski & Baroudi, 1991; Villiers, 2005).

3.2 Research Methods

Table 3 Research Methods in Publications Forming Part of Thesis

No	Authors	Title	RQ	Method
P1	Przybilla, L; Wiesche, M	Investigating the Performance Effects of Diversity Faultlines in IT Project Teams	RQ1	**Quantitative**: Panel Regression
P2	Przybilla, L; Rahn, M; Wiesche, M; Krcmar, H	The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects	RQ1	**Quantitative**: Negative Binomial Regression (NBR)
P3	Przybilla, L; Klinker, K; Wiesche, M; Krcmar, H	A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking	RQ2	**Qualitative**: Design Science Research (DSR) and Case Study Research
P4	Przybilla, L; Klinker, K; Lang, M; Schreieck, M; Wiesche, M; Krcmar, H	Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility	RQ2	**Qualitative**: Critical Incident Technique (CIT)
P5	Przybilla, L; Baar, L; Wiesche, M; Krcmar, H	Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity	RQ2	**Quantitative**: Hierarchical Regression
P6	Przybilla, L; Klinker, K; Kauschinger, M; Krcmar, H	Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance	RQ2	**Qualitative**: Case Study Research
P7	Przybilla, L; Wiesche, M; Krcmar, H	The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective	RQ1, RQ3	**Quantitative**: Partial Least Squares Equation Modeling (PLS-SEM)
P8	Przybilla, L; Schreieck, M; Klinker, K; Pflügler, C; Wiesche, M; Krcmar, H	Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects	RQ1, RQ3	**Qualitative**: Case Study Research

Within our research approach, we harnessed multiple quantitative and qualitative research methods. Our investigation into research questions two and three incorporates both quantitative and qualitative elements, which relates our work to the tradition of mixed methods research in information systems (see e.g.Venkatesh et al., 2013). Explicitly not seeking to provide a comprehensive account, we will briefly outline methods used as part of this thesis in the following. Quantitative methods encompass several subtypes of multiple regression using different sources of empirical data, whereas qualitative methods include the critical incident technique, case studies, and design science research. Table 3 provides an overview of the publications forming part of this thesis and which research methods they drew on.

3.2.1 Quantitative Methods

As the name suggests, quantitative methods (primarily) seek to capture phenomena in numbers, which subsequently provide the basis for statistical analysis and, potentially, inferences (Creswell & Creswell, 2018; Villiers, 2005). Both empirical observation, or data generation, as well as analysis can take different forms such as surveys, experiments, descriptive statistics or regression analysis (Creswell & Creswell, 2018; Venkatesh et al., 2013; Villiers, 2005). While quantitative observations can provide the basis for interpretive research (Mingers, 2001), they are frequently associated with positivism (Creswell & Creswell, 2018; Villiers, 2005). Based on the positivist assumption that harnessing methods originating in the natural sciences improves social science research, hypotheses regarding the relationship of variables frequently result in a graphic of "boxes-and-arrows (or ellipses-and-arrows)" (A. S. Lee & Hubona, 2009, p. 238) and the application of statistical means (A. S. Lee & Hubona, 2009).

To investigate social phenomena in contemporary IT work (P1, P2, P7), including social aspects of ASD, and the potential of IT artifacts to facilitate ideation (P5), we drew on several types of multiple regression. As a type of general linear model, multiple regression is applicable to investigate how a dependent variable, that is, the outcome of interest, relates to a set of independent variables (Cohen, Cohen, West, & Aiken, 2003). Within this very broad description, a variety of research endeavors, for example different types of variables or geometric forms of relationships, lend themselves to multiple regression (Cohen et al., 2003). Rooted in research into the relationship of traits observed in biology and social sciences, multiple regression is appropriate to test hypotheses using empirical data from sources such as experiments or surveys (Cohen et al., 2003). Harnessing multiple regression yields several advantages such as the ability to jointly consider multiple independent variables (Cohen et al., 2003). Results of multiple regression provide a wealth of information, such as the extent to which independent variables can explain values of the dependent variable or the magnitude of the relation of each independent variable (Cohen et al., 2003). It could, however, be the case that variables correlated with an independent variable in the model and affecting the dependent variable are left out, which leads to omitted variable bias and thus could potentially negatively affect results (Stock & Watson, 2014). Moreover, in interpreting results, care should be taken not to confound the correlations between variables that multiple regression establishes with an actual causal relation, which may only be inferred using specific research designs such as experiments (Cohen et al., 2003).

In the scope of this thesis, we drew on several types of multiple regression, that is panel-corrected regression (P1), negative binomial regression (NBR, P2), hierarchical regression

(P5), and partial least squares structural equation modeling (PLS-SEM, P7), which we will briefly introduce in the following.

Panel Regression: When a dataset contains multiple observations of entities over time, panel regression allows for considering a priori differences between the entities, which the included independent variables may not fully reflect (Stock & Watson, 2014). If unaddressed, these differences could result in omitted variable bias (Stock & Watson, 2014). To alleviate such concerns, panel regression controls for differences between entities that do not vary based on time (Stock & Watson, 2014). In our investigation of the relation of faultlines in IT teams with their performance (P1), our data contained customers with more than one project, which implied the risk of omitted variable bias based on differences between customers. To address this concern, we harnessed a fixed effects model, which controls for differences between entities by introducing a specific intercept for each entity (Stock & Watson, 2014).

Negative Binomial Regression (NBR): To relate the characteristics of hypothesized subgroups in OSS projects with their success, we used community size as dependent variable (P2). Community size expressed as the number of community members, represents count data, that is a dependent variable assuming “a counting number” (Stock & Watson, 2014, p. 469), that is non-negative integer values. While standard regression models are applicable in general, they do not harness the special data type, which consequently can lead to biased or illogical results (Cohen et al., 2003; Stock & Watson, 2014). To also account for overdispersion, that is the included independent variables do not explain all variance in the dependent variable (Cohen et al., 2003), we applied Negative Binomial Regression (NBR), which is frequently harnessed to analyze count data (Stock & Watson, 2014). Negative Binomial Regression extends a Poisson regression model by considering additional variance in the data (Cohen et al., 2003).

Hierarchical Analysis: To better understand the relation of individual independent variables, or specific groups of independent variables, with the dependent variable, we drew on characteristics of hierarchical analysis (see e.g.Cohen et al., 2003). We iteratively added independent variables to the regression models to compare results between and within models (Cohen et al., 2003). This approach specifically helped to compare the relations of different types of faultlines in IT teams (P1), the effects of controlling for project characteristics on the relation of hypothesized subgroup characteristics with success of OSS projects (P2), and to understand the relation of different characteristics of facilitation with creative ideation (P5).

Partial Least Squares Structural Equation Model (PLS-SEM): To investigate the moderating relation between ASD practices and effects of perceived subgroups (P7), we harnessed Structural Equation Modeling (SEM), which can calculate the relations between multiple constructs (Cohen et al., 2003). To this aim, SEM relates measured variables to the hypothesized latent constructs, which provides the basis for testing the hypothesized underlying structure of relations (Cohen et al., 2003). As a specific type of SEM, approaches based on Partial Least Squares (PLS) are akin to “standard” linear regression in seeking to explain variance in variables and determine whether effects exist (Gefen, Straub, & Boudreau, 2000). However, compared to other types of SEM based on defined models, PLS iteratively calculates estimates until a stopping criterion is fulfilled (Gefen et al., 2000).

The quantitative research in the scope of this thesis relied on multiple types of data sources, namely survey research, experimental research, and archival or secondary data. In the following, we provide a brief overview of each type of data.

Surveys are a nonexperimental means to collect quantitative research data (Creswell & Creswell, 2018). By administering a collection of items, i.e. questions, surveys are apt to gather information, e.g. perceptions, within a specific sample of participants, which is meant to extrapolate to a more general population (Creswell & Creswell, 2018). Response data from surveys subsequently allows for providing descriptive information on characteristics as well as investigating relationships (Creswell & Creswell, 2018). To research the potential moderation of perceived subgroup effects by ASD practices (P7), we implemented a cross-sectional design, that is the survey was administered once (Cohen et al., 2003; Creswell & Creswell, 2018) as an online survey (Creswell & Creswell, 2018). Additionally, our research into the potential of digital artifacts to facilitate creative ideation (P5) harnessed surveys to collect supporting data in the experimental design.

Experiments: Compared to asking participants for information in surveys, experiments allow for manipulating conditions and thus to study the effects of specific interventions (Creswell & Creswell, 2018). Given the ability to potentially eliminate confounding influences, experimental research thus is suited to infer causal relations between constructs (Cohen et al., 2003). As a between-subjects design, experimental conditions change for different participants, which consequently enables research into differences between these conditions based on the respective participants (Creswell & Creswell, 2018). In contrast, a within-subjects design varies experimental conditions over time (Creswell & Creswell, 2018). To explore the potential of digitally facilitating creative ideation by focusing on either flexibility or persistence (P5), we drew on a mixed design combining changes within- and between subjects (Creswell & Creswell, 2018). We changed the focus on flexibility and persistence within all groups and varied the use of human or digital facilitation between groups (P5).

Archival or Secondary Data: As opposed to collecting data for a specific research purpose, harnessing extant data, which can originate from sources such as preceding research or accessible data repositories, can be a viable alternative (Bryman, 2016). Notwithstanding potential downsides such as limited ability to influence scope and quality in capturing data or the need to become acquainted with the dataset, secondary data has specific advantages such as potentially including an extensive number of subjects and multiple points in time (Bryman, 2016). A particular advantage of data collected for other purposes than research is that as "unobtrusive methods" it may ameliorate potential biases arising from a conscious relation between researchers and study participants (Bryman, 2016). In obtrusive methods, such as surveys or interviews, respondents or participants are aware of being part of a research endeavor, which may lead them to change their demeanor or answers (Bryman, 2016). Conversely, in unobtrusive methods relying on data collected for other reasons than the specific research endeavor, for example archival data, participants obviously cannot respond to researchers (Bryman, 2016), which should eliminate this source of bias.

Leveraging the previously described advantages, we harnessed archival data to investigate the relation of faultlines in IT teams with their performance (P1) and to study the relation of hypothesized subgroups in OSS projects with their success (P2). In P1, we used archival project records from a large IT service provider containing detailed information on how employees participated in specific projects. In P2, we accessed publicly available datasets pertaining to activities in the OSS community GitHub.

3.2.2 Qualitative Methods

Compared to the aim of quantitative methods to capture research data in numbers, qualitative methods seek to investigate developing research questions on especially social phenomena (Creswell & Creswell, 2018; Villiers, 2005). Originating in social sciences such as anthropology, qualitative methods focus on research results inductively emerging from empirical data (Creswell & Creswell, 2018), which makes them a frequent choice in an interpretive paradigm (Villiers, 2005). In information systems research, qualitative methods are frequently harnessed to explore phenomena in detail and to derive novel contributions to theory (Venkatesh et al., 2013). In line with this common focus on exploration, we drew on qualitative methods to research methodical aspects of contemporary IT work. Qualitative methods allowed for insights into the potential role of Design Thinking in IT work, including its relation with ASD, (P3, P4, P8) and factors to improve computer-mediated teaching of Design Thinking (P6). In the scope of this thesis, we drew on the Critical Incident Technique (CIT, P4), Design Science Research (DSR, P3), and Case Study research (P3, P6, P8) as qualitative methods. Explicitly not seeking a comprehensive account, we will briefly introduce each of the qualitative methods in the following.

Critical Incident Technique (CIT)[8]: For our research on opportunities and challenges of Design Thinking in digital innovation projects (P4), we drew on the Critical Incident Technique (CIT). Now a popular method in research areas ranging from nursing to marketing, the CIT originated and has gained much traction in industrial and organizational psychology (Butterfield, Borgen, Amundson, & Maglio, 2005). With its strength "in generating a comprehensive and detailed description of a content domain" (Woolsey, 1986, p. 242), the CIT has originally developed to observe activities with the aim of using these observations to address practical issues (Flanagan, 1954). As the name suggests, the CIT focuses on incidents deemed *critical*, that is identifiable and with a pronounced effect (Flanagan, 1954). Information systems research has, for example, used the CIT to investigate requirements elicitation (Rosenkranz et al., 2014) or technology adaptation in virtual teams (Thomas & Bostrom, 2010). While the CIT prescribes flexible adaptation to the research context (Flanagan, 1954), it can be expressed in five steps: *general aims*, *plans and specifications*, *collecting the data*, *analyzing the data*, and *interpreting and reporting* (Flanagan, 1954). This sequence of steps will provide the structure for the subsequent brief overview of the general procedure. Determining decisive actions in specific jobs has originally propelled the development of the CIT (Flanagan, 1954), which the general steps reflect by emphasizing the analysis of an activity.

General Aims: First, establishing the scope of the activity to be studied is a foundational requirement (Flanagan, 1954). Matching the defined aim with the intended use of the study

[8] Considering this section is of key relevance to P4, it draws on the structure and argumentation of the original publication.

outcomes is especially important (Flanagan, 1954). Moreover, brevity and simplicity are key to aid universal understanding of the goal of the study (Flanagan, 1954).

Plans and Specifications: Defining the situations and actions to be included in the study is a second prerequisite (Flanagan, 1954). Specifically, researchers have to define the actors, environment and actions to be surveyed, as well as how and to what extent these actions relate to the general aim (Flanagan, 1954). In choosing who is to make observations including people familiar with the activity under study is usually advantageous (Flanagan, 1954).

Collecting the Data: The scope defined in *plans and specifications* informs data collection on critical incidents (Flanagan, 1954). While capturing data "on the spot" during observations would be ideal, retrospective accounts are more efficient and permissible (Flanagan, 1954). Retrospective data collection is especially admissible if observations are recent and the importance of observations was evident at the time, or the events under consideration had great importance (Flanagan, 1954; Woolsey, 1986). Data collection can take different forms such as one-on-one or group interviews, surveys, or forms (Flanagan, 1954). The quality of data collected is reflected in the ability to provide rich, detailed descriptions of incidents as well as their antecedents and consequences (Butterfield et al., 2005; Flanagan, 1954).

Analyzing the Data: Compressing the collected information in a succinct format, which is meant to increase their value for practical issues, is the main aim of analyzing the data (Flanagan, 1954). First, a frame of reference organizing the collected critical incidents should be established based on considerations such as usefulness or accuracy (Flanagan, 1954). Within this frame, categories of related incidents are iteratively established and refined, which constitutes an inherently subjective activity (Flanagan, 1954). Deciding on an appropriate level of granularity, which encompasses aspects such as practical utility, logical structure, or comprehensiveness, presents the last step for reporting results (Flanagan, 1954).

Interpreting and Reporting: To ensure appropriate utility, identifying potential biases and interpreting results is a crucial final step (Flanagan, 1954). In addition to clarifying limitations, for example related to generalizability or procedural choices, researchers should equally discuss the contribution of their results (Flanagan, 1954).

Design Science Research (DSR): To gauge the potential of Design Thinking to help create innovative IT solutions in the specific application context of health care (P3), we drew on Design Science Research (DSR). In contrast to a large share of information systems research focused on capturing and understanding observed phenomena, DSR seeks to create new artifacts with the purpose of addressing specific problems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Considering propositions that practical value should be a key outcome, information systems research may necessarily comprise both DSR and explanations of phenomena related to IT artifacts (Hevner, March, Park, & Ram, 2004). While positioned between (post-)positivism and interpretivism, the focus on generating potentially several realities through observation-based actions exhibits interpretivist traits (Villiers, 2005). Notwithstanding differences in individual activities, an integrative analysis of DSR processes has established six steps ranging from specifying the problem to be addressed to communicating results (Peffers et al., 2007). Figure 5 summarizes the process.

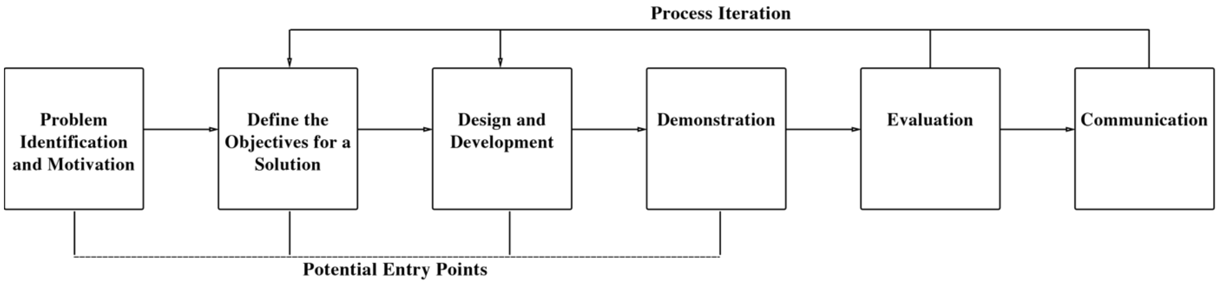

Figure 5 Design Science Research Process in Information Systems based on Peffers et al. (2007)

'Problem identification and motivation' sets out to clarify the problem to be addressed, which also underlines the benefit of finding a solution (Peffers et al., 2007). Based on the identified problem, '*Define the objectives for a solution'* details dimensions on which the solution should be superior (Peffers et al., 2007). Following these preparatory activities, '*Design and development'* aims to specify and generate artifacts, which "can be any designed object in which a research contribution is embedded in the design" (Peffers et al., 2007, p. 55), including, for example, models or changes in characteristics (Peffers et al., 2007). '*Demonstration'* seeks to establish the ability of the artifact to address the previously identified problem through, for example, case studies or simulation (Peffers et al., 2007). As a more comprehensive test, '*Evaluation'* contrasts the actual properties or effects of the artifact with the previously defined objectives using methods such as quantitative indicators or surveys (Peffers et al., 2007). By interpreting these results, researchers can either go back to refine the design or proceed to *'Communication,'* which is meant to publicize information on both the identified problem and the artifact, including its development (Peffers et al., 2007).

As implied by the option to repeat the design-related steps, the DSR process is not necessarily linear but can comprise iterations (Peffers et al., 2007). Moreover, starting at a different step, for example with design, is deemed admissible (Peffers et al., 2007). While these options provide some flexibility for the DSR process, further changes to the approach to evaluation have been suggested (Sonnenberg & vom Brocke, 2012). To better account for the successive realization of artifacts, including additional evaluation steps before fully implementing the artifact, which includes testing the relevance of the problem to be addressed, may be in order (Sonnenberg & vom Brocke, 2012). Sonnenberg and vom Brocke (2012) propose four distinct types of evaluations, which cover validating the problem, the conceptual design, a scaled-down artifact, and the fully implemented artifact (Sonnenberg & vom Brocke, 2012). To achieve their respective aim, each of these evaluations can harness a number of different approaches such as, for example, literature reviews, focus groups, benchmarks, experiments, or case studies (Sonnenberg & vom Brocke, 2012). Our research describes the potential contribution of Design Thinking based on this more extensive approach to evaluation (P3).

Case Study Research: Considering its specific ability to generate detailed insight into complex phenomena (Yin, 2009), we drew on elements of case study research in several publications contained in this thesis (P3, P6,P8). Case study research is appropriate to investigate complex, current occurrences in their actual environment if the focus lies on the drivers of such occurrences and their workings (Yin, 2009). However, researchers do not have to have control over these occurrences (Yin, 2009). While some instances consider case study research a qualitative method leaning towards interpretivism (e.g. Villiers, 2005), case studies can pertain to positivism or interpretivism in information systems research (Klein & Myers, 1999; Venkatesh et al., 2013). In the realm of this thesis, we drew on case study research for exploratory purposes, which follows the common use of qualitative methods in information systems research (Venkatesh et al., 2013). Not least considering our relatively direct involvement as participant-observers in the cases studied, which may have caused biases (Yin, 2009), we apply an interpretive view.

While following an iterative process, determining its applicability is the entry to case study research before defining the research question (Yin, 2009). Stating propositions on potential relations, or the purpose of exploratory studies, enable targeted data collection (Yin, 2009). The research question provides the basis for delimiting the scope of a case, or unit of analysis, and plans to gather suitable data (Yin, 2009). A key choice lies in deciding between a single or multiple case study (Yin, 2009): Single case studies may be useful to study, for example, unusual or extreme cases, whereas including multiple cases allows for cross-case comparisons at the expense of increased effort (Yin, 2009). This principal research design provides the basis for planning and collecting data, which can and preferably should originate from multiple sources (Yin, 2009). According to Yin (2009), case studies can use data gathered directly from participants, such as interviews or observations, as well as indirect sources, such as artifacts, documents, or archival records. As a special case, in participant-observations researchers take part in the occurrences to be studied, which grants them very direct and broad access to data at the expense of potential biases due to, for example, participation confounding observation (Yin, 2009). Notwithstanding the absence of a universally applicable approach, several common approaches can guide data analysis (Yin, 2009). Starting with a "playful," open exploration and sorting of data, analysis can, for example, follow the previously elaborated propositions or harness a newly developed thematic frame (Yin, 2009). In addition to these common approaches, analyzing data can follow several practices, such as comparing or relating patterns, studying changes over time, or combining information from several cases (Yin, 2009). The outcomes of data analysis provide the basis for the case study report, which can take different forms depending on the envisioned audience (Yin, 2009).

By incorporating multiple cases as empirical basis, several of our research inquiries forming part of this thesis drew on elements of case study research. Within the DSR approach in P3, see above, we harnessed a case study approach to identify potential applications of information systems to improve health care delivery (P3). We especially utilized ethnographic observations in hospital and elderly care settings, respectively, to identify potentials for improvement and to understand the specific characteristics of processes that could benefit from support.

Focusing on practical use, we drew on elements of case study research to compile recommendations for teaching Design Thinking in a computer-mediated setting (P6) and combining Design Thinking with ASD (P8). As participant-observers, we drew on a single iteration of our Design Thinking course to collect our observations how a computer-mediated setting influenced creative elaboration and to describe the perceived effects of our interventions (P6). To derive recommendations how Design Thinking can contribute to effective ASD (P8), we relied on observations we made as participant-observers in classroom and research projects, which relates to the characteristics of a multiple case study.

Part B

Published Articles

4 P1: Investigating the Performance Effects of Diversity Faultlines in IT Project Teams

Table 4: P1: Investigating the Performance Effects of Diversity Faultlines in IT Project Teams

Authors	**Przybilla**, Leonard[1] **Wiesche**, Manuel[2]
Author Affiliations	**1** - Technical University of Munich, Garching, Germany **2** - Technical University of Dortmund, Dortmund, Germany
Outlet	**ICIS 2019** 40th International Conference on Information Systems, 2019, Munich, Germany
Status	**Published**

Abstract. To complete complex and knowledge-intensive tasks, IT work critically relies on the interaction of team members. While heralded as a contribution to performance, diversity is also linked to negative team outcomes. Given the critical role of team collaboration, we investigate the effects of diversity on performance in IT projects. Drawing on faultline theory as a measure of diversity, we develop and test hypotheses on the performance effects of the strength of identity- and knowledge-based faultlines and the number of resulting factions in 424 IT projects. While insignificant, knowledge-based faultlines positively relate to performance. The number of potential group divisions has a positive effect if identity-based and a negative effect if knowledge-based. Unexpectedly, we find identity-based faultlines to significantly improve performance. Findings are of value to research by furthering knowledge on the specifics of IT work and effects of diversity. For practice, we provide important considerations for how teams can be designed to achieve superior outcomes.

5 P2: The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects

Table 5: P2: The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects

Authors	**Przybilla**, Leonard[1] **Rahn**, Maximilian[1] **Wiesche**, Manuel[1] **Krcmar**, Helmut[1]
Author Affiliations	**1 -** Technical University of Munich, Garching, Germany
Outlet	**WI 2019** 14. Internationale Tagung Wirtschaftsinformatik, 2019, Siegen, Germany
Status	**Published**

Abstract. Open source software (OSS) has become an important organizational form of building software. Given the desire to understand drivers of OSS project success and the known importance of social structure for team functioning, we investigate the effects of the relative size of contribution-based subgroups on community size of OSS projects. Drawing on extant research on OSS and faultline-based subgrouping, we investigate the relation with project community size of the relative size of subgroups based on reputation, issue focus, contribution extent and contribution persistence. While in several instances non-significant, results suggest a differential relation in which a large share of core members with high reputation, issue focus and persistent contributions positively relate to community size, whereas a large share of extensively contributing members in the core team is negatively related. Our findings are of value to research and practice by furthering the understanding of work in OSS projects.

6 P3: A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking

Table 6: P3: A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking

Authors	**Przybilla**, Leonard[1] **Klinker,** Kai[1] **Wiesche**, Manuel[1] **Krcmar**, Helmut[1]
Author Affiliations	**1 -** Technical University of Munich, Garching, Germany
Outlet	**PACIS 2018** 22nd Pacific Asia Conference on Information Systems, 2018, Yokohama, Japan
Status	**Published**

Abstract. Digital innovation is described to harbor great potential to improve health care. Yet, much of this potential has not been realized. A number of context-specific factors are described to limit implementation of innovative digital solutions. To attenuate these limits in development, we propose a human-centric approach using elements of Design Thinking. We follow a design science research approach using two cases of digital innovation in health care. Based on qualitative and quantitative evaluations performed with care givers we used an iterative prototyping approach to create digital artifacts aimed at improving the underlying health care processes. We detail the research processes of an augmented reality smart glass application for documenting chronic wounds and a smartphone application to support dispensing medication. Based on the exemplary cases, we derive process learnings on applying Design Thinking methods to digital innovation projects in health care.

7 P4: Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility

Table 7: P4: Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility

Authors	**Przybilla**, Leonard[1] **Klinker**, Kai[1] **Lang**, Michael[2] **Schreieck**, Maximilian[1] **Wiesche**, Manuel[3] **Krcmar**, Helmut[1]
Author Affiliations	**1 -** Technical University of Munich, Garching, Germany **2 -** msg nexinsure ag, Ismaning, Germany **3 -** Technical University of Dortmund, Dortmund, Germany
Outlet	**IEEE TEM** IEEE Transactions on Engineering Management
Status	**Published (Early Access)**

Abstract. The locus of innovation has shifted from mechanical advances to digital solutions. By emphasizing the importance of user needs, Design Thinking is apt to develop human-centered innovation, including digital solutions. Using two representative examples from 21 Design Thinking projects spanning the gamut of mechatronic to fully digital solutions, we report on critical incidents as opportunities and challenges of applying Design Thinking in a digital context. In the case of mechatronic solutions, we identified opportunities related to improved collaboration and higher quality prototyping as well as in innovative business models, which in turn created challenges in managing stakeholders. In the fully digital context, we observed opportunities in improved needfinding and the ability to offer individualized products. Conversely, we uncover difficulties in imagining digital features, estimating their feasibility, and correctly setting the fidelity of prototypes. Based on these observations, we discuss the intangibility of digital artifacts as enabler and inhibitor of Design Thinking in a digital context.

8 P5: Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity

Table 8: P5: Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity

Authors	**Przybilla**, Leonard[1] **Baar**, Luka[1] **Wiesche**, Manuel[1] **Krcmar**, Helmut[1]
Author Affiliations	**1 -** Technical University of Munich, Garching, Germany
Outlet	**CPR 2019** ACM SIGMIS Conference on Computers and People Research, 2019, Nashville, TN, USA
Status	**Published**

Abstract. Considering recent advances in information systems, we pose the question how well a digital facilitator can support the complex task of creative idea generation in teams–especially compared to a human one. Drawing on the dual pathway to creativity model and extant research in group creativity and information systems, we develop a set of interventions for both human and digital facilitation. We test the hypothesized effects in a 2x2 study design with 24 participants and a human or digital voice assistant as facilitators. We find that objective outcomes of digital facilitation are not significantly different from those of human facilitation. Digital facilitation is, however, significantly worse in subjectively perceived helpfulness. These results add to the scant research on the effects of intelligent systems on team interactions and help inform future research on group effects of intelligent information systems.

9 P6: Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance

Table 9: P6: Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance

Authors	**Przybilla**, Leonard[1] **Klinker**, Kai[1] **Kauschinger**, Martin[1] **Krcmar**, Helmut[1]
Author Affiliations	**1** - Technical University of Munich, Garching, Germany
Outlet	**CAIS** Communications of the Association for Information Systems
Status	**Published**

Abstract. The Covid-19 pandemic has prompted schools and universities to shift their teaching to virtual classrooms from one day to the other. As a unique example, we had to virtualize the second half of a two-semester course on human-centered innovation, which heavily relies on direct interaction of students in small groups. In going virtual, we have found that adapting assignments is only the tip of the iceberg. Despite being familiar with the students, the real challenges were preserving high levels of creative interaction as well as surveying team morale and status. Reflecting on our experiences, we detail solutions related to the lack of creative interaction by fostering off-topic chit-chat and surveying team morale by introducing more explicit communication and seeking team consent. To help teachers adapt to virtual teaching, we discuss how our mitigation approaches, which we developed in an extreme setting requiring close, creative collaboration, may apply to virtual teaching in general.

Copyright: Association for Information Systems

10 P7: The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective

Table 10: P7: The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective

Authors	**Przybilla**, Leonard[1] **Wiesche**, Manuel[1] **Krcmar**, Helmut[1]
Author Affiliations	**1** - Technical University of Munich, Garching, Germany
Outlet	**CPR 2018** ACM SIGMIS Conference on Computers and People Research, 2018, Niagara Falls, NY, USA
Status	**Published**

Abstract. This research explores the influence of the agile practices daily stand-ups and retrospectives on negative effects of subgroups, i.e. of having several smaller groups within a team, on group conflict, satisfaction, and performance. Based on extant literature in agile software development (ASD) and group research, a model of effects of ASD practices and the constructs elaboration, i.e. direct sharing, of information and team reflexivity, i.e. how much teams reflect on processes and outcomes, is developed and assessed using a survey of agile teams. Previous findings on negative effects of subgroups on conflict and satisfaction are corroborated in an agile setting. Retrospectives enhance team reflexivity and elaboration of information. As expected, elaboration of information significantly attenuates effects on conflict. Surprisingly, reflexivity is seen to further exacerbate the negative effects of perceived subgroups on conflict and satisfaction.

11 P8: Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects

Table 11: P8: Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects

Authors	**Przybilla**, Leonard[1] **Schreieck**, Maximilian[1] **Klinker**, Kai[1] **Pflügler**, Christoph[1] **Wiesche**, Manuel[1] **Krcmar**, Helmut[1]
Author Affiliations	**1** - Technical University of Munich, Garching, Germany
Outlet	**PVM 2018** Projektmanagement und Vorgehensmodelle, 2018, Düsseldorf, Germany Lecture Notes in Informatics (LNI)
Status	**Published**

Abstract. Agile development methods have become mainstream. Notwithstanding the improvements they bring about in implementation, they are of little help for deciding what exact features are needed to address the core needs of customers: they mostly rely on the competence and domain knowledge of the product owner. This is an issue of paramount importance in innovative projects with high ambiguity such as digitization projects because such projects require a detailed under-standing of customers and their needs. In order to address this gap, we propose to follow a Design Up Front approach and to integrate the Design Thinking methodology, which aims at human-centered innovation, with agile development. Drawing on 25 student and research projects, we report key learnings concerning human aspects, knowledge management, and challenging of assumptions. Moreover, we offer practical recommendations for the integration of the two methodologies.

Part C

Discussion

12 Summary of Results

Given our aim to increase the understanding of work in contemporary IT teams, we focused our research on social and methodical aspects. As a social phenomenon, we investigated the role of faultlines and subgroups in IT teams. With regard to methods, we explored the potential of the human-centered approach Design Thinking to support IT work. As a unification of these two lines of inquiry, we investigated agile software development (ASD) as a potential moderator of the effects of perceived subgroups and considered the potential joint application of Design Thinking and ASD. To outline our contribution to advancing knowledge in these areas, we will briefly summarize key results of the publications forming part of this thesis.

RQ1*: What is the role of faultlines and subgroups in IT teams?*

Relation of Diversity- and Knowledge-based Faultlines with IT Team Performance. To understand the relation between diversity in IT project teams with their performance (P1), we adopted faultlines, that is hypothetical lines of separation arising from the characteristics of group members (Lau & Murnighan, 1998), as a theoretical construct. Using archival data from a large IT service provider, we operationalized identity-based faultlines according to age and gender as well as knowledge-based faultlines according to previous experience in the same industry and at the IT service provider. As expected, we observe a positive relation of the strength of knowledge-based faultlines and performance, which is, however, insignificant. Examining the number of subgroups, the analysis supports our hypothesis of a positive relation of the number of identity-based factions with performance, whereas the number of knowledge-based factions unexpectedly exhibits a negative relation. Contrary to extant research and our expectations, we observed a significant positive relation between the strength of identity-based faultlines and performance. In discussing this unexpected result, we propose how specifics of IT work, for example its task characteristics, occupational culture and the typical homogeneity of IT teams, may lead to a virtuous circle of diversity facilitating productive elaboration, which provides a basis to perceive others as knowledgeable, which consequently leads to a positive attitude towards diverse input.

Relation of Subgroups in the Core Team with OSS Project Success. As a specific type of IT work, we studied the relation of hypothesized subgroups in the core team of Open Source Software (OSS) projects with their success as expressed by community size (P2). We operationalized subgroups based on characteristics relevant to work in OSS projects, that is reputation, a focus on issues, and the extent and persistence of contributions. Drawing on the shares of relatively higher- or lower-ranking members of the project core, we observe contrasting relations of the different subgroup measures with OSS project success. Partly as expected, larger shares of core team members with high reputation or a focus on issues show positive, albeit insignificant, relations to community size. We find a strong significant positive relation between the share of persistently contributing members and community size. Conversely, the share of members with extensive contributions exhibits a strong significant negative relation. Weighing these results, we discuss how the perception of these different potential subgroups may affect outsiders to join the project community. It may thus be the case that persistent contributors show an OSS project to be "worthy" of contributions, whereas extensive contributors may lead to perceptions of a “closed shop” and consequently discourage potential community members.

***RQ2**: How can Design Thinking support work in IT teams?*

Design Thinking to Support Digital Innovation in Health Care. To gauge its potential to support the development of innovative IT-based solutions in the specific context of health care (P3), we integrated Design Thinking with a Design Science Research (DSR) approach in two cases. These two projects allowed us to derive learnings on specific characteristics to consider in health care settings as well as methodical implications. Among others, we observed factors related to staff, for example the experience of staff with information systems or their fit with workflows, the domain, for example aseptic use, or the business model in health care, for example the relation between insurance and health care provider, to be important boundary conditions in devising innovative IT solutions in health care. From a process perspective, the two cases showed the value of exerting much effort to understand the actual problem to be solved. As a departure from many established DSR approaches, the two projects exemplified the benefit of iteratively evaluating prototypes with users, which includes tests of rudimentary early-stage prototypes, to avoid developing ill-suited solutions.

Implications of a Digital Context for Design Thinking Projects

While Design Thinking can be universally applied, the pervasive role of IT artifacts for innovation prompted us to explore the effects a digital context implies for conducting Design Thinking projects (P4). Drawing on 21 projects, whose outcomes range from fully digital to mechatronic solutions integrating hard- and software, we identified critical incidents related to opportunities or challenges originating in the digital context. Illustrated by a project representing the mechatronic end of the spectrum, we observed the digital context to improve collaboration, increase prototype quality, and make the fulfillment of more needs viable by enabling innovative business models. Notwithstanding its potential to extend viability, we found the digital context to create challenges due to an increase in networked stakeholders in the business model. Focusing on a project representing the fully digital end of the technology spectrum we observed, we found the digital context to facilitate immersive needfinding by allowing for engagement at a distance, and to ease the creation of individualized solutions tailored to specific needs. Conversely, we identified the fully digital context to create challenges in imagining intangible IT-based features, assessing feasibility, and choosing an appropriate medium as well as fidelity for prototypes. In summary, we discuss the intangibility of digital innovation as a potential cause underlying several of the opportunities but also challenges we observed.

Potential of Digital Facilitation of Creative Ideation

Complementing the preceding two publications on the methodical implications of Design Thinking in IT projects, we took the opposite perspective and explored the potential of a digital voice assistant to facilitate creative ideation (P5). We incorporated the dual pathway to creativity model, that is both persistent in-depth ideation as well as flexible changes between cognitive categories can engender creative outcomes, and previous knowledge on information systems as facilitators of creativity to inform our research model and build a prototype of a digital voice assistant. Using a 2x2 exploratory experiment, we found the respective facilitation strategies to relate positively to the intended outcomes of flexibility or persistence, respectively. Partly following our hypothesis, we observed only insignificant differences between physical and digital facilitation. Considering the judgment of participants, the digital treatment exhibited a significant strong negative correlation with the perceived helpfulness of facilitation. Reflecting the results of our initial exploration, we discuss potential implications of digital assistants taking an increasingly pronounced role in teams, which, for example, could reshape team processes.

Facilitating Design Thinking Projects in a Computer-Mediated Setting

As a further complement to our research on the methodical implications of Design Thinking in IT projects, we derived practical recommendations to facilitate creative ideation and safeguard team morale in computer-mediated Design Thinking projects (P6). Reflecting our experiences from shifting a highly interactive Design Thinking course to a fully virtual format against the theoretical construct of social translucence, we identified a lack of visibility and awareness to be the likely reason behind the observed drop in creative interaction. Moreover, we observed the lack of off-topic chit-chat as opposed to on-topic elaboration to reduce creative interaction. Summarizing our experiences, we described leading by (fun) example, drawing on shared experiences, as well as embracing and planning for going off-topic as potential interventions to foster creative interaction. Moreover, to overcome the limitations on surveying team morale in the virtual setting, which, for example, preempted serendipitous encounters at the office, we recommended more explicit communication, such as frequently inquiring on status, while at the same time avoiding intrusions on team privacy. To extend our experiences beyond our specific context, we discussed how they may apply to other settings such as courses with lower levels of collaboration or creativity.

RQ3: *How does agile development affect work in IT teams?*

ASD Practices as Moderators of Subgroup Effects

Drawing on the social aspects embedded in ASD, we investigated how the ASD practices daily stand-ups (DSU) and retrospectives may moderate the effects of perceived subgroups (P7). We proposed daily stand-ups and retrospectives to relate to the established team constructs elaboration of information, that is direct, joint information sharing, and team reflexivity, that is pondering and discussing e.g. processes. Based on extant research, we hypothesized both as potential moderators of effects of subgroups related to increased conflict and reduced satisfaction. Based on a survey of members of ASD teams, we observed an insignificant positive relation between perceived subgroups and conflict and a significant negative relation between perceived subgroups and satisfaction. Our analysis showed significant positive relations of retrospectives with both elaboration of information and team reflexivity. Conversely, DSU exhibited only an insignificant weak positive relation to elaboration of information and a positive relation with team reflexivity, which bordered significance. As expected, elaboration of information showed a significant negative moderation of conflict and a positive moderation of satisfaction, which was, however, insignificant. Surprisingly, team reflexivity exhibited a significant positive moderation of conflict and a negative, albeit insignificant, moderation of satisfaction. We discuss how elaboration of information may benefit teamwork in ASD by facilitating the accomplishment of tasks, whereas team reflexivity may render negative occurrences salient and thus exacerbate conflict and dissatisfaction.

Combined Application of Design Thinking and ASD

While there are numerous proclaimed benefits to harnessing ASD, it mostly assumes an established goal for development and is ill-equipped to identify underlying needs of users. To augment the benefits of ASD, which come to bear in *how* to attain a set goal, with in-depth understanding of *what* to develop, we propose to add Design Thinking in a Design Up Front step (P8). Reflecting on our experiences in academic projects, we derive recommendations on human aspects, knowledge management, and the need to challenge assumptions. Concerning human aspects, we emphasize the advantages of functional diversity in team members and the crucial importance of ensuring access to potentially tacit knowledge gained in the Design Thinking phase. In the best of cases, team members should thus participate in both the Design Thinking and ASD activities. In the realm of knowledge management, capturing in-depth information on the product vision and its rationale, for example observations or stakeholder maps, and ensuring a proper handover between Design Thinking and ASD, are key activities. Challenging assumptions regarding user needs as well as other areas, such as communication, provides a key opportunity to improve outcomes. Considering differences in project goals and contextual constraints, we propose to adapt the extent of Design Thinking to inform ASD development and to experiment throughout all projects.

13 Discussion[9]

Based on the preceding summary, we will discuss our findings in relation to extant research on IT work. We will specifically reflect on social factors as crucial drivers of IT work, the current state of research on Design Thinking and its application concerning IT work, as well as the role of ASD. In addition to discussing the individual social and methodical views, we discuss contextualization and the role of the IT artifact as two themes unifying several individual contributions forming part of this thesis.

13.1 IT Work as a Social Process

Considering the pervasive role of information systems in all strands of life (Benbya et al., 2020), the ensuing need of organizations to adopt digital technologies and strategies (Sebastian et al., 2017; Tiwana, 2014), and lastly the potential paradigmatic shift of digital systems shaping the physical world instead of reflecting it (Baskerville et al., 2020), IT work as the locus of creation and deployment of IT artifacts[10] ought to receive key attention. Following calls of extant research to investigate "soft" social aspects as critical factors in IT work (Faraj & Sambamurthy, 2006), we drew on the theoretical constructs of faultlines, that is, hypothetical divisions in groups arising from differences in member characteristics (Lau & Murnighan, 1998), and potentially resulting subgroups to understand the effects of member diversity in IT teams.

To this end, we researched identity- and knowledge-based faultlines in the context of a large IT service provider (P1), hypothetically derived subgroups specific to work in OSS (P2), and the role of ASD practices as potential moderators of the effects of perceived subgroups (P7). Taken together, our results imply faultlines may be a helpful theoretical lens to better understand social aspects in IT work. These effects may, however, be contingent on boundary conditions, which require further study. In investigating the relationship of the strength of faultlines, which were based on identity or knowledge, and the number of resulting group factions with performance (P1), results provided only limited support for our expectation that IT work, specifically work on software as a knowledge-intensive endeavor (Faraj & Sproull, 2000), should benefit from strong knowledge-based faultlines and increasing numbers of knowledge-based factions. As discussed in P1, this surprising result may originate in a number of factors ranging from the team size in our sample, over dynamism reducing positive effects (Cooper et al., 2014), to dispersed knowledge increasing coordinative effort akin to distributed teams (Espinosa et al., 2007b), or potentially increased effort for building team cognition, which specific practices in turn may attenuate (Carton & Cummings, 2012). The latter hypothesis links to our investigation of the potential moderating effect of ASD practices (P7), which showed retrospectives to significantly relate to elaboration of information, that is sharing and integration of information (Van Knippenberg, De Dreu, & Homan, 2004). Consequently, elaboration of information exhibited a significant negative moderation of the relation of perceived subgroups with conflict (P7).

[9] This chapter provides novel interpretations and draws on the publications forming part of this thesis.
[10] See introduction section 1.1 for the definition of IT work, based on Niederman et al. (2016), adopted in this thesis.

Contrary to our expectations and extant research, we observed a significant positive relation of the strength of identity-based faultlines with project success (P1). Following the discussion in the original publication (P1), the very nature of IT work and its specific occupational culture may help to explain this unexpected finding. As described in P1, dentity-based faultlines are expected to harm group dynamics through categorizing members and subsequent perceptions of threats to one's ingroup (Carton & Cummings, 2012; Hogg & Terry, 2000). Through commonly valued elements, such as specific terms and communicative styles or high regard for technical expertise (Guzman et al., 2008; Jacks et al., 2018), ITOC may, however, create an overarching IT-specific identity (P1). It could thus be the case that all team members honoring these cultural values form part of the ingroup, which members may contrast with other professions (Guzman et al., 2008; Jacks et al., 2018). As an extension to our hypothesis in the original publication how contributions driven by diversity may engender positive attitudes (P1), the potential mechanism of identity-based faultlines driving objective performance measured as profitability warrants further attention. Following our previous discussion (P1), gender diversity exhibits a positive link to the development of team cognition in IT teams (He et al., 2007), which facilitates coordination as a key contributor to IT work (Espinosa et al., 2007b). This line of argumentation may thus provide an additional explanation of the observed positive relation between the strength of identity-based faultlines and performance.

Our research into hypothetical subgroups based on activities in OSS projects (P2) further adds to the potential role of context-specific culture in determining effects of faultlines and subgroups. In our analysis (P2), the differential relationships of the shares of core members with extensive versus those with persistent contributions stood out. A larger share of persistently contributing core members related positively to community size (P2). Conversely, a larger share of members with extensive contributions exhibited a significant negative relation (P2). As discussed in the original publication (P2), the respective behaviors may signal different types of projects, which either attract or deter outsiders. Specifically, we hypothesized in P2 a larger share of persistently contributing core members to reflect core values of OSS such as learning (Stewart & Gosain, 2006).

Whereas we discussed ASD practices as fora for knowledge sharing, which may subdue the effects of perceived subgroups, see above and P7, these features may equally embody key agile principles. Following P7, ASD practices as concrete building blocks of ASD methods (J. F. Tripp et al., 2016) can thus operationalize the overarching values of ASD in daily work. For example, daily stand-ups as repeated operational information sharing or retrospectives as self-guided continuous improvement of processes (J. F. Tripp et al., 2016) arguably cater to a preference for communication and foster self-managed teams, which are central to ASD (Beck et al., 2001; G. Lee & Xia, 2010; Nerur & Balijepally, 2007).

In conclusion, the three publications taking a social perspective on IT work (P1, P2, P7) raise the question to what extent IT-specific cultural influences, such as ITOC, OSS culture, or ASD principles, are distinct from factors described in general teams research and to what extent they affect outcomes. Leveraging research on ITOC (e.g. Guzman et al., 2008; Jacks et al., 2018) or OSS culture (Stewart & Gosain, 2006) in conjunction with constructs from general teams research, such as faultlines (Lau & Murnighan, 1998), may thus provide a viable approach to attain the knowledge of social aspects in IT work researchers have called for (Faraj & Sambamurthy, 2006).

13.2 Understanding Design Thinking to Further its Application

As argued in P4, the prominence of Design Thinking in managerial discourse (Liedtka, 2015) is in juxtaposition to noteworthy open points in corresponding research. For starters, neither a common definition nor established root of Design Thinking can be identified (Johansson-Sköldberg et al., 2013; Liedtka, 2015). Notwithstanding several research endeavors (Liedtka, 2015), knowledge on the application of Design Thinking in innovation as well as its effects continues to be scarce (Pitsis et al., 2020). In the scope of this thesis, we contributed to filling this void by investigating the potential of Design Thinking to support IT work.

As outlined previously, see section 2.3, we follow the definition of Design Thinking as a method for problem-solving, which emphasizes human needs (Brown, 2008; Liedtka, 2015). Defining what to develop, that is specifying requirements for development, has been a long-standing issue in IT work (e.g. Kling, 1977), which despite progress in development methods continues to remain challenging (Appan & Browne, 2012; Davis & Venkatesh, 2004; Ramesh et al., 2010). As a specific example, ASD methods may ameliorate some issues but still exhibit deficiencies concerning, for example, conflicting statements by users or difficulties in stating requirements (Ramesh et al., 2010). Adding to extant propositions to harness Design Thinking to improve requirements engineering in IT work (Vetterli et al., 2013), we propose the combination of Design Thinking and ASD to attain innovative outcomes (P8) and explore boundaries of applying Design Thinking in IT work. Specifically, we describe the potential of Design Thinking to facilitate innovation in a highly restricted health care context (P3) and identify opportunities and challenges of Design Thinking in a digital context (P4).

Applying Design Thinking in a highly regulated context emphasized its potential to help in identifying important requirements and the value of iterative prototyping (P3), which relates the proposed benefits of Design Thinking (e.g. Brown, 2008) directly to observed issues in establishing requirements in IT work concerning stating and capturing requirements (e.g. Appan & Browne, 2012; Ramesh et al., 2010). Our investigation into the specifics of Design Thinking in a digital context resulted in a number of both opportunities and challenges, several of which may result from the intangibility of digital artifacts (P4). On the one hand, these contributions help to better understand the role and effects of Design Thinking in innovation, which is still lacking (Pitsis et al., 2020). On the other hand, as alluded to in P4, the observed challenges of Design Thinking in a digital context raise the question whether there are boundaries to the universal applicability of Design Thinking, which publications have emphasized (Beckman & Barry, 2007; Brown, 2008).

Applications of Design Thinking may range from the development of hard- and software products, services, or organizational culture (Beckman & Barry, 2007; Kolko, 2015), in all of which Design Thinking may specifically be concerned with wicked problems having neither a clear definition nor solution (Buchanan, 1992). Considering the observed benefits in IT work, which were evident even when operating in a highly regulated environment (P3), and the opportunities a digital context enabled (P4), we deem Design Thinking to be a very valuable approach to facilitate the development of innovative IT solutions. The challenges we observed in the digital context such as, for example, difficulties in imagining intangible digital artifacts or assessing their feasibility, raise, however, the question to what extent developing new practices or adapting extant ones to the digital context may improve outcomes. As discussed in our original publication (P4), such a specific toolset may position Design Thinking even better as a suitable approach for digital innovation. Considering the overall scope of Design Thinking, the specific adaptations and extensions would add to the extant "'basket' of tools and processes" (Liedtka, 2015, p. 925) observed in Design Thinking. While we were specifically concerned with implications of a digital context, we take our results as an indicator that adapting Design Thinking tools to the specific application context may harbor potential for improved outcomes. Inspired by the "Design-for-x" approach, which highlights specific aspects in the design phase (Kuo, Huang, & Zhang, 2001), devising a "Design Thinking-for-X" approach may be a beneficial endeavor. Such an approach naturally should not restrict creativity but suggest tools and collate hints that may help to circumnavigate potential pitfalls the specific application context may harbor.

13.3 Agile Software Development as a Method and Social Process

Our research into ASD as a contemporary topic in IT work mirrors the approach of this thesis to adopt both a social and methodical view. From a methodical point of view, we derived suggestions how ASD may be combined with Design Thinking to work on innovative IT solutions (P8). Emphasizing the implications of ASD for teamwork, we investigated how ASD practices may moderate the effects of perceived subgroups (P7). Below, we will discuss how both of these perspectives relate to extant research in ASD.

Our propositions to combine ASD with Design Thinking (P8) seeks to improve requirements engineering in ASD. As discussed in the preceding section on Design Thinking, despite improvements in some areas, lack of capabilities of users to articulate their needs remains a challenge in requirements engineering using ASD (Ramesh et al., 2010). Harnessing the focus of Design Thinking on understanding actual user needs (Brown, 2008), we proposed a sequential approach: Design Thinking provides information on "what" to develop, which subsequently can be implemented based on ASD methods describing the "how" of implementation (P8). Specifically focusing on the transition between the two phases, we add to previous work on integrating ASD with human-centered methods (e.g. Silva, Martin, Maurer, & Silveira, 2011). By combining ASD with Design Thinking, we effectively delimit the application scope of ASD and reiterate the potential benefits of adapting methodical support to the situation at hand. This line of thought relates to findings how communication structures may favor certain activities in IT work (Kudaravalli et al., 2017) as well as observed changes in the type of projects ASD is applied to (Dingsøyr, Moe, & Seim, 2018). While retrospectives aim at iteratively adjusting how work is done *throughout* ASD projects (J. F. Tripp et al., 2016), our combined approach extends this adaptation to *before* initiating an ASD project in the sense of a design up front approach (Silva et al., 2011).

Focusing on the social dimension of ASD, we investigated how the practices daily stand-ups and retrospectives may moderate effects of perceived subgroups through the established team constructs elaboration of information and reflexivity (P7). While partially supporting the expected positive implications of elaboration of information, reflexivity unexpectedly exhibits negative, albeit insignificant, implications (P7). Our results relate both to research on specific effects of ASD as well as discussions on how to further ASD research. Following the discussion in our original publication (P7), our research extends the body of knowledge on effects and contingencies of agile development (e.g. G. Lee & Xia, 2010; Serrador & Pinto, 2015; J. F. Tripp et al., 2016). The unexpected parts of our findings (P7) especially further the previously detailed proposition that ASD may lead to a complex pattern of effects (G. Lee & Xia, 2010). By drawing on established theoretical constructs, such as faultlines and subgroups, we heed the call to advance ASD research based on theory (J. Tripp et al., 2018). In our investigation, ASD practices exhibited relations to the team constructs elaboration of information and reflexivity, albeit not as expected (P7). Without the intent of generalizing from our single empirical dataset, this result leads to caution that the relation of ASD practices with extant constructs requires validation, even though a direct relation is palpable (P7). As alluded to in P7, while focusing on the moderation of effects of perceived subgroups, our results may exemplify a link between ASD practices and established constructs from teams research, which implies a set of extant, well-developed theoretical constructs may be apt as theoretical footing to understand the effects of ASD. Such an approach would especially further heed the call for a theory-driven and -backed investigation of ASD (J. Tripp et al., 2018).

13.4 Context as a Recurring Theme

The implications of a specific context for theoretical reasoning are a prominent theme in general management research, which is mirrored in information systems research including contextual features into research models (Hong et al., 2013). Several publications in the scope of this thesis follow the recommendation to consider context as a key factor in research (Hong et al., 2013) and thus add to the understanding of contingencies. We will detail the specific operationalizations and implications of context in our research on faultlines and subgroups as well as Design Thinking in the following.

All publications in the scope of this thesis on the role of faultlines and subgroups are set in the specific context of IT work. By using data from an IT service provider, our investigation of the relation of information- and knowledge-based faultlines with IT project performance (P1) targets the specific context of IT work. Drawing on the sample of IT projects, operationalizing experience based on previous work at the company and on projects in the specific industry (P1), which is comparable to previous measures of knowledge-based faultlines derived from organizational tenure (e.g. Bezrukova et al., 2009), captures the specific experience of project members with IT work to some extent. This approach especially relates to IT occupational culture holding technical knowledge derived from practice in high esteem (Jacks et al., 2018). Following the approach of creating contextualized variables (Hong et al., 2013), our investigation of hypothetical subgroups in OSS harnesses extant knowledge on OSS to operationalize subgroup measures and community size as a success measure of OSS (P2). In our investigation of the potential of ASD practices to moderate the effects of perceived subgroups (P7), we followed the approach to contextualization of including context-specific elements as moderators (Hong et al., 2013). In our case, the use of ASD practices and their relation to elaboration of information and reflexivity served as contextual moderating factors.

Our investigations of faultlines and subgroups in IT work, which comprised several different sub-contexts and were based on several operationalizations, imply some potential relationships with project outcomes, which in several instances deviate from previous expectations. These results arguably should add to a nuanced, contingency-based approach to faultlines. Following the discussion in our original publication (P1), the specifics of IT work and the IT workforce such as need for coordination (Espinosa et al., 2007b; Kudaravalli et al., 2017) or appreciation of technical terms and knowledge (Guzman et al., 2008; Jacks et al., 2018) may decisively shape the role and effects of faultlines and subgroups. As alluded to in P1, our results and these propositions relate, for example, to extant findings on the contingencies of faultline effects related to context such as complexity and dynamism (Cooper et al., 2014). To this end, as highlighted in our original publication (P1), perceptions as opposed to objective measures of diversity (Shemla, Meyer, Greer, & Jehn, 2016) may provide a useful tool to further the understanding of diversity effects.

Our investigations of Design Thinking relate to different aspects of the specific context of information technology. As stated in P4, extant publications emphasize the applicability of Design Thinking across different contexts, which can include hard- and software products, services, or organizational characteristics (e.g. Beckman & Barry, 2007; Brown, 2008; Kolko, 2015). Weighing these propositions of universal applicability with the known importance of contextual factors (Hong et al., 2013), we investigated the application of Design Thinking in digital innovation projects (P4) as well as how IT artifacts can facilitate creative ideation (P5) or change Design Thinking education (P6). Against the backdrop of digital technologies playing a pivotal role for innovation and the ensuing ramifications (Sebastian et al., 2017; Tiwana, 2014), we reported on opportunities and challenges to Design Thinking in digital innovation projects (P4). At a conceptual level, we identified the intangibility of digital artifacts as a likely cause of both opportunities and challenges. As argued in the original publication (P4), applying Design Thinking in IT work may thus benefit from context-sensitive guidance or adaptations. The proclaimed shift of digital solutions from reflections of the physical world to affecting it (Baskerville et al., 2020) may further amplify the implications of intangibility for Design Thinking in digital innovation projects. Specifically, the distribution of projects on the technology spectrum we observed (see P4) may change and even though hardware may still be a significant part of innovative solutions, they might increasingly follow the characteristics of software. Consequently, addressing the challenges potentially arising from intangibility may become both more difficult and more important.

Beyond the general opportunities and challenges of Design Thinking in digital innovation projects, we investigated specific contextual characteristics. In P3, we reported how Design Thinking can supplement Design Science Research to create innovative digital solutions that address actual user needs. In addition to evaluating the potential of Design Thinking in the general context of digital innovation, our investigation targeted a highly regulated health care context (P3). In P8, we reflected important considerations and derived recommendations for integrating Design Thinking with agile development. As a specific type of digital innovation projects, our publication targeted the context of IT projects based on ASD methods while emphasizing the handover between Design Thinking and ASD.

As opposed to applying Design Thinking in digital innovation, P5 and P6 treat the implications of IT in the context of facilitating creative ideation and teaching Design Thinking. P6 summarizes experiences from shifting a Design Thinking course to fully computer-mediated communication. Specifically reflecting on the change from a partly to a fully virtual context, we found the drop in creative interaction and limited ability to assess team morale to be the most challenging differences. Whereas P6 was set in the context of computer-mediated education on Design Thinking by humans, P5 was set in a face-to-face setting and compared facilitating creative ideation by a human instructor with a digital voice assistant. While in our small sample differences in outcomes were surprisingly small, participants rated digital facilitation lower on helpfulness (P5). Even though both P6 and P5 are only very limited forays to understand the potentials and limitations of IT in Design Thinking education, they imply the potential need and benefit of carefully considering the context and tools used.

13.5 The Role of the IT Artifact

A second overarching theme of the publications forming part of this thesis lies in the role of the IT artifact. As outlined in the background section, see 2.1, extant literature argues the IT artifact to have a central role in Information Systems research (Benbasat & Zmud, 2003; Hevner et al., 2004; Orlikowski & Iacono, 2001). While Information Systems research extends beyond the IT artifact (Benbasat & Zmud, 2003), its very own properties and traits may not have been considered at a level commensurate with its central role (Orlikowski & Iacono, 2001). Against this backdrop, we will discuss the role of the IT artifact in publications forming part of this thesis. Our research especially considers IT artifacts as the result of knowledge work and the implications of being intangible. Moreover, we specifically compared the implications of software-based compared to other implementations.

The publications P1, P2, and P7 draw on characteristics of the IT artifact to understand the potential role of faultlines and subgroups in IT work. P2 operationalized hypothetical subgroups based on the contributions of OSS project members, which arguably relate directly to the IT artifacts as outcomes of the underlying OSS projects but does not consider their specific properties that differ between projects. P1 and P7 relate to properties of IT artifacts as they reverberate in specific demands on IT workers[11]. Focusing on the application of development methods, P7 hypothesizes ASD practices to moderate the effects of perceived subgroups through reflexivity and elaboration of information, which relates to the proposition of frequent direct interaction put forth in ASD (Highsmith & Cockburn, 2001). Further developing this notion, P1 argues the character of IT artifacts and the resulting demands on IT work to be a possible explanation of the observed relations of faultlines with project performance. As outlined in P1, IT artifacts, specifically software, are the outcome of complex knowledge work (Faraj & Sproull, 2000; Kudaravalli et al., 2017) and frequently exhibit an interdependent structure (Malone & Crowston, 1994), which makes coordination across several dimensions a key requirement of IT work (Espinosa et al., 2007b; Faraj & Sproull, 2000; Kudaravalli et al., 2017). In P1, we argued the resulting need for interaction to coordinate and exchange

[11] See introduction section 1.1 for the definition of IT work, based on Niederman et al. (2016), adopted in this thesis. See section 2.1 for an overview of specific characteristics of IT work.

knowledge may explain the observed positive relation of identity-based faultlines with project performance.

In addition to the publications drawing on the specific characteristics of IT artifacts to understand social phenomena in IT work, we juxtaposed software-based IT artifacts with other instantiations to investigate the implications of their characteristics. Investigating the opportunities and challenges of using Design Thinking in digital innovation projects (P4), we identified the intangibility of software-based prototypes as key differences in project work compared to hardware-based artifacts. On the one hand, intangibility enabled, for example, improved collaboration, whereas on the other hand, it seems to have been a cause of challenges related to imagining digital features, assessing their feasibility, or choosing a medium and resolution for prototypes (P4). As discussed in P4, our results thus imply that the specific characteristics of software-based IT artifacts may affect the application of Design Thinking, which is referred to as virtually domain-agnostic (Beckman & Barry, 2007; Brown, 2008). Considering extant research in information systems, our findings relate to discussions on the role, use, and properties of boundary objects in information systems development (e.g. Doolin & McLeod, 2012).

Traversing from developing to using IT artifacts, P5 and P6 juxtapose digital to human-based facilitation of innovation. In P6, we reflected on the changes in teaching a highly interactive Design Thinking course using only electronic communication compared to a hybrid set-up. While neither explicitly naming the electronic communication tools nor listing their features or user experience, our reflections implicitly reference the availability of features such as live video, media sharing, or virtual backgrounds. In addition to referencing prior research on the characteristics and use of computer-mediated communication, we adopted the notion of social translucence (Erickson & Kellogg, 2000) to reflect on the specific changes and challenges computer-mediated communication brought about and our mitigation approaches (P6).

In P5 we investigated the potential of a digital voice assistant to facilitate creative ideation by comparing it to a human facilitator. While not focusing on specific features or details of implementation, we investigated differences in the process and outcomes between human and digital facilitation (P5). Our initial results of mostly insignificant differences between either type of facilitation but significantly less perceived helpfulness in the digital setting especially raised additional questions concerning the potential future role of digital artifacts in collaborative settings (P5). The expression “Machines as Teammates” used by Seeber et al. (2018), which we specifically referred to by including “Machines as Teammates in Creative Teams” in the title of P5, concisely summarizes the potential future role of IT artifacts.

While criticism of a lack of consideration for the IT artifact is not new (see Orlikowski & Iacono, 2001), the changing characteristics and role of IT artifacts may reshape this discussion. IT artifacts have become entrenched in many domains (Benbya et al., 2020), which leads to the argument that digital artifacts form the physical world as opposed to mirroring it (Baskerville et al., 2020). Considering the complexity of sociotechnical systems involving IT artifacts (Benbya et al., 2020), wide-ranging effects on how activities are carried out and subsequent implications such as how human values influence design (Baskerville et al., 2020), discussions of the IT artifact, its characteristics and role seem poised to continue if not intensify.

14 Limitations[12]

As a typical trait of research endeavors, this thesis and the publications contained therein are subject to limitations. In the following, the definition of the scope of this thesis, the methods chosen and their application, as well as the empirical data used, will be the focus.

A fundamental limitation lies in the definition of the topic of this thesis and its subtopics. As outlined in the introduction, we adopted a broad and encompassing definition of IT work, which is commensurate with studying a variety of its different characteristics. We chose to investigate social and methodical aspects of IT work, which we studied based on the specific methods Design Thinking and ASD as well as the social constructs faultlines and subgroups. Moreover, within each of these subtopics we focused on specific topics or effects. By making these specific choices, we naturally excluded other phenomena, constructs, or methods that can be of key importance for IT work. These exclusions can be exemplified by our investigation of ASD as a contemporary theme in IT work. We researched social aspects of ASD practices as potential moderators of the effects of perceived subgroups (P7) and offered recommendations on combining ASD as a development method with Design Thinking (P8), which are quite focused topics. Previous research has, however, suggested ASD to harbor a complex interdependent pattern of effects (G. Lee & Xia, 2010). The purposefully limited scope, which juxtaposes a broad array of contingencies, should be kept in mind in interpreting our results, which consequently may change in relevance when considered in a broader scope.

Further limitations are inherent to the research methods used. While following a pluralist, multiple method approach, see section 3.2, to investigate the topic of work in contemporary IT teams, we mostly used a single method to investigate individual subtopics. Except for P5 harnessing an experimental design, publications based on a quantitative analysis (P1, P2, P5, P7) exhibit the key limitation of observed relations being mere correlations, which do not necessarily indicate causality (Cohen et al., 2003). Moreover, by typically capturing data in numerical form (Creswell & Creswell, 2018) quantitative methods naturally restrict analysis to the previously specified variables. Conversely to this potential lack of breadth, the publications following an interpretive qualitative approach (P3, P4, P6, P8) seek to obtain in-depth knowledge, which is commensurate with the history of information systems research (Klein & Myers, 1999; Venkatesh et al., 2013). As a key limitation, results in these publications rely on interpretation, judgment, and inferences of the authors, which in line with the interpretive paradigm may be subjective (Orlikowski & Baroudi, 1991; Villiers, 2005). P4 exemplifies this limitation in the *analyzing the data step* of the critical incident technique, which acknowledges subjectivity in its procedural description (see Flanagan, 1954). In addition, as described in P4, the characteristics shared by projects studied may limit generalizability to other settings.

Beyond those inherent to the methods applied, our operationalization presents additional limitations. Commensurate with the post-positivist paradigm in our quantitative investigations (P1, P2, P5, P7), the definition of variables may not be adequate to represent the actual phenomena of interest (Gefen, 2019). For example, the sets of variables used may be subject to omitted variable bias, which describes how an empirically observed relation between variables

[12] This chapter provides novel interpretations and draws on the publications forming part of this thesis.

may in fact stem from an additional, missing variable (Stock & Watson, 2014). Across all studies, choosing alternative variables or other approaches to operationalization, e.g. different survey items or calculations, may potentially be better suited to describe the phenomena of interest. For example, while drawing on established scales, P7 drew attention to these scales as a potential limitation. In a similar vein, some limitations of the exploratory initial investigation in P5 could be addressed by validated scales and potentially different brainstorming tasks. The potentially extensive limitations arising from the definitions of variables and their calculation is especially evident in our investigations of calculated faultlines and subgroups (P1, P2). For example, as described in P1, choosing other criteria for calculating identity- or knowledge-based faultlines may naturally result in other strengths of faultline measures and consequently different magnitudes as well as directions of empirically observed relations.

In addition to the operationalization of variables, the specification and calculation of models presents potential limitations. At a conceptual level, akin to the false specification of measures acknowledged in post-positivism (Gefen, 2019), the hypothesized relations between variables may not be representative of actual relations even though empirical data supports the propositions. Transferring the argument of the omitted variable bias, see above, to relations between variables, alternative or more complex models, for example specifying different relationships of moderation or mediation between variables, may be more adequate to capture actual relationships. Additional limitations may arise from the calculation of the specified models. The choice of calculation method, e.g. the specific type of regression, as well as the preparation and transformation of data all present limitations since alternative methods and approaches may be better suited to describe the underlying actual relationships.

Lastly, the data used in analysis and its acquisition present additional limitations. While seeking to investigate quite specific subtopics, see above, we used data from contexts that may be more specific than required by the research question. Considering the importance of context in information systems research and the proposal to retest propositions across contexts as a means of identifying contingency factors (Hong et al., 2013), this fact may be considered over-contextualization and consequently further reduce generalizability. For example, P1 seeks to investigate the relationship of identity- and knowledge-based faultlines with performance in IT projects but is limited by using data from one IT service provider. In a similar vein, P4 raises the general question of opportunities and challenges of Design Thinking in digital innovation projects. While we drew on projects from three different categories (P4), all of them are set in an academic context, which may limit the ability to transfer results to other settings. In addition, our results may be limited by the size of the sample used. This limitation is especially evident in the exploratory investigation of digital versus human facilitation of creativity (P5) but also arose in the survey-based study of the potential of ASD practices to moderate the effects of perceived subgroups (P7).

15 Implications[13]

The research results described in this thesis have implications for theory as well as practical application. Taken together, the results contribute to an improved understanding of IT work concerning social and methodical aspects as well as their combination. This section outlines implications pertaining to faultlines and subgroups as constructs to investigate social phenomena in IT work, the potential role of Design Thinking in IT work, and ASD comprising both social and methodical aspects in IT work.

15.1 Implications for Theory

By researching faultlines and subgroups in IT work, we followed the call to investigate social phenomena to increase our understanding of the performance of IT projects (Faraj & Sambamurthy, 2006). Notwithstanding different research foci, dissimilar operationalization, and data sources, faultlines or subgroups exhibited significant relations with outcome measures of IT projects (P1, P2, P7). While neither formally comparing contexts nor conducting meta-analysis across contexts (Hong et al., 2013), the significant relations of faultlines or subgroups in IT projects (P1), OSS projects (P2), and ASD projects (P7) imply the theoretical constructs faultlines and subgroups may be apt to further our understanding of social phenomena in IT work. Specifically, faultlines and subgroups may be helpful to understand the effects of diversity on the dynamics and consequently performance of IT teams. As discussed in P1, the question whether identity- and knowledge-based faultlines and subgroups have specific implications in the particular context of IT work seems central. In this realm, the interaction of faultlines and subgroups with IT-specific aspects such as ITOC or ASD practices, as investigated in P7, seems to be a relevant consideration.

While highlighting a potential approach to better understand social aspects of IT work, our publications similarly have implications for research on faultlines and subgroups in general. Notwithstanding previously discussed limitations of operationalization, our research (P1, P2, P7) showed significant relations despite harnessing field data, which tends to lead to lower effect sizes compared to laboratory studies (S. Thatcher & Patel, 2011) (see also P1). By investigating and discussing faultlines and subgroups in several settings within the context of IT work, we additionally reiterate the importance of considering contextual factors for evaluating faultlines and subgroups described in extant literature (e.g. Bezrukova et al., 2009; Cooper et al., 2014).

Similarly to our investigation of faultlines and subgroups to better understand social aspects of IT work, our research into the potential role of Design Thinking in IT work has implications for both information systems and Design Thinking research. Considering information systems, we add to work on the long-standing issue of requirements engineering (e.g. Kling, 1977), which despite advances in managing requirements remains challenging concerning specification (Davis & Venkatesh, 2004). In P8 we outlined how Design Thinking may complement ASD to specify requirements in highly innovative projects without a clearly established development goal. By proposing to clearly separate “what” to develop from “how”

[13] This chapter provides novel interpretations and draws on the publications forming part of this thesis.

it should be implemented, we suggest a potential means to ameliorate the issues related to specifying user requirements, which persist in ASD (Ramesh et al., 2010). While P8 focuses on harnessing Design Thinking to determine requirements and their handover into subsequent ASD, P3 evaluates the potential of Design Thinking to complement a Design Science approach to develop innovative solutions. Our application of Design Thinking approaches, which rely on involving stakeholders (Carlgren, Rauth, et al., 2016; Liedtka, 2015), to develop digital solutions in a health care context implies its applicability may be quite universal and include other highly regulated contexts.

In addition to exploring the potential of Design Thinking to develop innovative IT solutions, we investigated the specific implications of digital innovation projects for applying Design Thinking (P4). While we observed several opportunities related to digital innovation, for example improvements in prototyping or the potential for highly individualized products, challenges equally became apparent. Not least, imagining digital features, assessing their feasibility, and settling on an adequate medium and resolution for prototypes may present difficulties for Design Thinking in digital innovation projects (P4). As discussed in P4, the intangibility of digital features may be at the root of these observed challenges. Consequently, taking account of its specific implications may be a worthwhile approach for developing Design Thinking in digital innovation (P4).

As complements to our research on Design Thinking to develop innovative digital solutions, we investigated the potential of a digital assistant to facilitate creative ideation (P5) and the challenges of switching to a fully computer-mediated setting for teaching Design Thinking (P6). While the explorative nature of our study requires caution, the observation of differences between digital and human facilitation being especially pronounced concerning perceptions of helpfulness (P5) implies further research and development regarding the collaboration of digital artifacts and humans may help make digital assistants at least a beneficial addition to foster creativity. In a comparable realm, our impressions described in P6 imply that a computer-mediated setting may require only comparably little adjustment to content and deliverables, whereas ensuring adequate creative interaction and gaining knowledge of team morale may be impaired. Notwithstanding the crucial importance of course content, our results imply increased attention to “softer” factors may further the use of digital tools to support creative teamwork—even while at a distance.

In summary, our publications on Design Thinking further knowledge on its actual implications for innovation projects, which has been described to be lacking (Pitsis et al., 2020). Our observations of Design Thinking being well applicable to digital innovation while at the same time giving rise to specific opportunities and challenges imply the specific application context of Design Thinking may be worth considering.

By investigating both social and methodical aspects of IT work, the publications forming part of this thesis have implications for research on ASD. Our investigations of ASD as a potential moderator of subgroup effects (P7) harnessed several established constructs from general teams research, which contributes to ameliorating the observed scarcity of empirical research on ASD (Dybå & Dingsøyr, 2008; G. Lee & Xia, 2010). As discussed in P7, while the relation of the ASD practices daily stand-ups and retrospectives with the constructs elaboration of information and team reflexivity did not fully match expectations, the observed links imply these team constructs may provide a useful lens to further our understanding of ASD. Moreover, our focus on ASD practices as potential moderators of subgroup effects implies a specific view of ASD as embedded in and explained by constructs established in general teams and psychological research. Taken together, these implications may contribute to building a theoretical basis for ASD research as called for by J. Tripp et al. (2018).

Our proposition of establishing “what” to develop using Design Thinking before engaging in ASD to determine “how” to accomplish this goal (P8) reemphasizes extant knowledge of adaptations to ASD based on contextual necessities (e.g. Dingsøyr, Moe, Fægri, & Seim, 2018; Ramesh, Mohan, & Cao, 2012). In combination, these findings and our propositions emphasize that despite its advantages, ASD is no panacea. As a resulting implication, treating ASD as part of a more encompassing methodical toolkit seems promising to capitalize on its advantages without falling prey to known remaining issues, for example concerning the management of requirements (Ramesh et al., 2010).

15.2 Practical Implications

Beyond the implications for research described in the preceding section, our results have implications for understanding and improving IT work in practice. In the following, we will describe implications for HR and project management and the context-specific application of methods.

Our investigations into social aspects of IT work (P1, P2, P7) underline the importance of HR and project management. As described in the original publication (P1), the observed relationships between different types of faultlines and IT project performance imply staffing projects with the right composition of people may benefit project performance. The unexpected but observed significant positive relationship between the strength of identity-based faultlines and performance implies staffing teams to have very distinct identity-based faultlines may be beneficial (P1). While the observed positive relationship between knowledge-based faultlines and performance was insignificant (P1), creating teams with distinct differences in knowledge may still be worthwhile. If, however, teams harbor perceived subgroups as opposed to measured faultlines, they may adversely affect team dynamics such as reducing satisfaction (P7). In a similar vein, we observed hypothetically defined subgroups based on contribution behavior in OSS to have both significant positive and significant negative relations with success (P2). While directly applying these observations in practice may be difficult, they draw attention to the potential role of team composition for effective work in IT teams beyond the mere presence of core competencies. We hope the ensemble of our observations may be helpful to practitioners as a frame of reference to better understand–and subsequently manage–the performance of IT teams—whether it be exceptionally good or fall short of expectations.

While anticipating team dynamics and staffing projects accordingly may be of much theoretical appeal, this scenario does not seem universally feasible. The observation of ASD practices potentially moderating the effects of perceived subgroups on team properties through established constructs from general teams research (P7) thus carries additional practical implications. Extending the discussion in P7, based on our initial results engaging in adequate

ASD practices could provide an approach to managing known influencing factors of teamwork and thus to address effects of subgroups.

Our research into methodical aspects of IT work provides additional practical implications. Taken together, P3, P4, and P8 imply Design Thinking is worth considering in innovative IT projects. P3 and P8 highlight how Design Thinking can potentially support development efforts. The promising results from applying Design Thinking in a health care context (P3) imply it may be apt for other highly regulated contexts as well. In addition to this general consideration on Design Thinking, our suggestions in P8 imply appropriately combining Design Thinking with ASD may be particularly well suited to define and implement innovative digital solutions. We thus encourage practitioners to experiment whether Design Thinking is apt to foster innovation in the context at hand, even if it may be constrained by regulations or very specific demands. The observations described in P4 suggest that a digital context may have particular implications for applying Design Thinking. Our observations (P4) may enable practitioners to assess whether a project may be able to reap benefits from opportunities enabled by a digital context or whether a project may have to deal with challenges arising from a digital context.

16 Potentials for Future Research[14]

While contributing to our understanding of several facets of IT work, the publications forming part of this thesis similarly allow for identifying potentials for future research. In this chapter we will exemplarily outline some topics we see as fruitful subjects of future investigation.

A major set of potentials for future research arises from the limitations inherent to the publications forming part of this thesis, see chapter 14. Addressing or at least ameliorating these limitations seem to be fruitful goals for future research. For example, as discussed in P1, the implications of alternative theoretical operationalization and calculation of faultlines and subgroups may be the subject of future research. As stated in P1, we thus add to previous propositions of additional research into the specification of faultline and subgroup models concerning aspects such as weights of individual characteristics (Meyer & Glenz, 2013).

Beyond addressing limitations inherent to operationalization, exploring the potential of faultlines and subgroups to increase our understanding of IT work seems worthwhile. Great potential may lie in combining existing information concerning contingency factors of faultlines and subgroups with known characteristics of IT work as a basis for future empirical investigation. For example, as initially discussed in P1, the specific characteristics of IT work can be related to known contingencies of faultline effects (e.g. Cooper et al., 2014). Timing concerning the team and project, specific methods and practices as well as ITOC as a fundamental influencing factor seem to be promising examples. Time as indicated by the extent of a team's joint working history may be a fruitful approach to further our understanding of IT work and faultlines. Extant research proposes diversity effects to be contingent on time (e.g. Joshi & Roh, 2009), which extend to specific calls for additional research concerning faultlines (S. M. Thatcher & Patel, 2012). Combining these propositions with the observation of coordination needs in IT work depending on the task at hand (Kudaravalli et al., 2017), investigating the role of faultlines considering team and project phase including the relative need for specific types of tasks seems promising to advance research on both faultlines as well as IT work. Picking up the key theme of P7, the potential of specific IT work methods and associated practices to shape group dynamics and thus moderate faultline effects seems promising. Extant research has identified several facets of ITOC (Guzman et al., 2008; Jacks et al., 2018), which may be helpful in investigating faultline effects in IT work. First, these characteristic traits of IT work may provide the basis for defining faultlines relevant to the specific context of IT work. Second, as discussed in P1, ITOC may shape faultline effects in IT teams and thus could present a moderating factor.

To further elucidate the potential role of Design Thinking in IT work, additional research seems fruitful. While we observed Design Thinking to be helpful in fostering digital innovation in a restricted health care setting (P3) and reported on specific opportunities and challenges for Design Thinking in a digital context (P4), additional research into the factors and drivers underlying these results seems worthwhile. Such an investigation might draw on extant work seeking to explain the efficacy of Design Thinking on a more theoretical basis. Initiatives to more accurately understand the basis for the efficacy of Design Thinking has taken several

[14] This chapter provides novel interpretations and draws on the publications forming part of this thesis.

forms (Pitsis et al., 2020). For example, research proposes Design Thinking to be effective by reducing biases in decision-making (Liedtka, 2015) or, in a broader sense, to affect several factors as a "social technology" (Liedtka, 2020, p. 53). Knowledge on the "inner workings" of Design Thinking additionally may provide a basis for addressing the described void in our understanding of the application of Design Thinking and related outcomes (Pitsis et al., 2020).

In addition to these theory-driven considerations, future research with the specific aim of helping practitioners benefit from Design Thinking seems fruitful. The previously mentioned call to increase our understanding of the usage of Design Thinking (Pitsis et al., 2020) should arguably also result in implications for its future application. Our observations on applying Design Thinking in a restricted health care context (P3), its potential role in conjunction with ASD (P8) as well as opportunities and challenges for its application in a digital context (P4) may inform future work on how Design Thinking can help digital innovation projects. As alluded to in P4, a potential boundary condition may be acknowledging the need to address context-specific characteristics and issues while maintaining the general, broad applicability of Design Thinking, which extant works describe (Beckman & Barry, 2007; Brown, 2008). In addition to helping the application of Design Thinking, our research on supporting creative ideation using digital means (P5) and teaching Design Thinking in a fully computer-mediated setting (P6) highlights the opportunity for future research on the potential of digital technology in Design Thinking education. Considering all of our publications on Design Thinking are set in an academic context, combining our deliberations on context-specific influences with learnings from industrial applications (e.g. Carlgren, Elmquist, et al., 2016), seems worthwhile to increase generalizability and thus derive implications and related guidance for practical use.

As with Design Thinking, future research may seek to solidify our understanding why and how ASD influences work in IT projects. Adding to previous calls to increase the theoretical base of research into ASD (J. Tripp et al., 2018), we see much potential in increasing our understanding of ASD by adopting theoretical lenses from general group research. For example, future research may follow up on our study of links between ASD practices and the established constructs elaboration of information and reflexivity (P7). Considering we observed links between ASD practices and established constructs, which were, however, only partly in line with expectations, further research to detail the relationships between ASD practices and established team constructs could be fruitful (P7).

Further future research might draw on the rich heritage of teams research, which spans several decades (Mathieu, Maynard, Rapp, & Gilson, 2008). Investigating the relationship of ASD practices with established constructs proposed to affect work, e.g. voice (see Chamberlin, Newton, & Lepine, 2017 for an overview), could speed up developing a theoretically grounded understanding of ASD: Extant research and knowledge may provide a fruitful basis for general future research strategies as well as specific hypotheses. We see such an approach in line with the call for a more theoretical basis in ASD research (J. Tripp et al., 2018) by contextualizing extant research in a specific scope (Hong et al., 2013), namely ASD. This may equally help in delimiting the properties related to the use of ASD, which has been proposed as a fruitful direction for ASD research (J. Tripp et al., 2018). Considering our observations of cross-cut relations between ASD practices and established team constructs, which we discussed in P7, and extant research reporting complicated, contingent relations of constructs in ASD (G. Lee & Xia, 2010), such an investigation of ASD and its role in IT work may be a complex endeavor in and of itself. We see, however, much potential to gain insight into the “inner workings” of ASD and how it may influence IT work.

As discussed in the section concerning Design Thinking, see above, research aiming to achieve practically useful insight is equally worthwhile in ASD. The academic understanding of ASD and its role in IT work should provide a basis to derive practical implications. For example, as discussed in P7, ASD practices may moderate effects of perceived subgroups in IT teams. As discussed in the original publication (P7), knowledge on such effects and their applicability may provide the basis for enhancing teamwork by purposefully harnessing ASD practices to manage team properties. Transferring the call to study characteristics related to ASD (J. Tripp et al., 2018), see above, to the practical realm leads to the question when and to which extent ASD and its related practices can foster IT work. Our propositions to combine ASD with Design Thinking to determine “what” to develop before using ASD to determine the “how” of implementation (P8) contribute to this line of inquiry, albeit in a quite specific and limited scope. Future research identifying boundaries to the practical applicability of ASD and suggesting potential methods or approaches to fill voids and supplement ASD thus seems fruitful.

17 Conclusion

Information technology has become a part of (nearly) every strand of life. This pervasive presence and the subsequent importance of information technology for the functioning of modern life lead to the question how information technology is conceived, developed, implemented, and maintained. Consequently, knowledge on the specifics of IT work–among them IT teams as a dominant form of organizing IT work–arguably ought to be a key concern for research. To increase our understanding of work in contemporary IT teams, this thesis investigated select social and methodical aspects. Taking a social perspective, we drew on the theoretical constructs faultlines and subgroups. As an example of methodical aspects, we investigated the potential role of Design Thinking in IT work. In addition, we investigated Agile Software Development (ASD) from both a social and methodical perspective.

To investigate social aspects in IT teams, we drew on the theoretical constructs faultlines and subgroups as an operationalization of objective or perceived differences in team members. Across the different contexts and operationalizations studied as part of this thesis, we found significant relations of faultlines or subgroups with team properties such as satisfaction or performance. For example, in line with expectations, we observed perceived subgroups to lead to adverse outcomes (P7), whereas , the strength of diversity-based faultlines unexpectedly exhibited a significant positive relation with performance (P1). Drawing on hypothetical subgroups based on contribution behavior (P2), our observations imply the specific type of contribution behavior to have a differential effect. In summary, our results imply faultlines and subgroups may be apt as theoretical lenses to investigate the role of team composition in IT work. Increased knowledge in this realm may uncover potential levers to improve teamwork regarding performance and member perceptions.

Considering the long-standing issue of requirements engineering, we investigated the potential role of Design Thinking, which places human needs at the center of activities, to support innovation in IT work. In the specific setting of a highly restricted health care context, we found Design Thinking to be a valuable addition to develop innovative digital solutions (P3). However, we observed the digital context to give rise to both specific opportunities and challenges for applying Design Thinking (P4). In summary, we deem Design Thinking apt to augment the ability to create innovative digital solutions but at the same time deem further research into how Design Thinking practices may best be applied and potentially adapted to the digital context a fruitful endeavor.

Reversing the role of Design Thinking and IT, we investigated the potential of IT artifacts to facilitate Design Thinking. In comparing a digital voice assistant to a human facilitator in creative ideation, a significant difference in perceived helpfulness stood out (P5). Our experiences from shifting a highly interactive Design Thinking course to a fully virtual setting highlight sustaining creative interaction and assessing team morale as even more important than adjusting course content (P6). In summary, digital tools may be apt to support education in Design Thinking. However, how they might be used best, which includes establishing limits to their application, remains a fruitful potential for future research.

Now a widely used approach in IT work, Agile Software Development (ASD) includes both social and methodical elements. Considering the social aspects of ASD, we observed ASD practices to be related to established constructs in group research and, consequently, to potentially moderate the effects of perceived subgroups (P7). Referring to its application as a method for IT work, we proposed combining ASD with Design Thinking to develop innovative digital solutions (P8). Based on our project experiences, we focused on the handover between the two approaches and suggested harnessing Design Thinking to determine "what" to develop, whereas ASD should guide "how" to implement the sought outcome. In summary, we suggest the specific application of ASD practices may be apt to effectively manage and improve team dynamics. In a similar vein, the benefits of ASD may be further amplified if its specific strengths are acknowledged and combined with additional methods such as Design Thinking.

By investigating several facets pertaining to social and methodical aspects, this thesis contributes to our understanding of contemporary IT work. While the purposefully broad coverage of topics underlines the multi-faceted nature of IT work, it equally creates several avenues for future research. Not least, future research may improve on the results contained in this thesis by addressing limitations such as potentials for different operationalizations. Further research into both social and methodical aspects may gradually increase our knowledge of the "inner workings" of IT work. Considering the crucial role of IT in many domains, such knowledge may provide a helpful basis for improving or developing management approaches to make IT work more effective, efficient, and satisfactory for team members.

D
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Appendix

[redacted] P1: Investigating the Performance Effects of Diversity Faultlines in IT Project Teams

Table AX1: P1: Investigating the Performance Effects of Diversity Faultlines in IT Project Teams

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Investigating the Performance Effects of Diversity Faultlines in IT Project Teams

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Abstract

To complete complex and knowledge-intensive tasks, IT work critically relies on the interaction of team members. While heralded as a contribution to performance, diversity is also linked to negative team outcomes. Given the critical role of team collaboration, we investigate the effects of diversity on performance in IT projects. Drawing on faultline theory as a measure of diversity, we develop and test hypotheses on the performance effects of the strength of identity- and knowledge-based faultlines and the number of resulting factions in 424 IT projects. While insignificant, knowledge-based faultlines positively relate to performance. The number of potential group divisions has a positive effect if identity-based and a negative effect if knowledge-based. Unexpectedly, we find identity-based faultlines to significantly improve performance. Findings are of value to research by furthering knowledge on the specifics of IT work and effects of diversity. For practice, we provide important considerations for how teams can be designed to achieve superior outcomes.

Keywords: IT work; teams; diversity; faultlines; performance; project; collaboration

Introduction

Information Technology (IT) projects are commonly carried out by teams as collections of employees brought together to contribute their individual competences (Faraj and Sproull 2000). Working in IT exhibits specific traits: IT work is highly knowledge-intensive and critically depends on the ability of team members to coordinate work on interdependent objects, as well as to process and exchange information (Faraj and Sproull 2000; Kudaravalli et al. 2017; Malone and Crowston 1994). Consequently, constant interaction of team members is needed (Espinosa et al. 2007; Faraj and Sproull 2000; Kudaravalli et al. 2017). In addition to the task, IT work exhibits a characteristic, homogeneous workforce with a continuing minority proportion of females (Armstrong et al. 2018; Korrigane 2019). The typical worker in IT is male, 35 years old, and has a high level of education (Korrigane 2019). Further solidifying the homogeneous nature of IT workers, the rapid evolution of required technical skills implies the emergence of clusters of employees of similar ages and with similar backgrounds (Zhang et al. 2012).

To reap benefits from different competencies of employees, teams are frequently assembled specifically to draw on diverse capabilities (Tiwana and McLean 2005). Whether due to differences in education or demographics, diversity is expected to increase the pool of knowledge and experiences the team can draw upon to develop cognition, solve problems, and to come up with creative solutions (DeChurch and Mesmer-Magnus 2010; Lau and Murnighan 1998). Diversity specifically enables team members to apply their knowledge individually and then integrate their outcomes in the group (Van Knippenberg et al. 2004). Such group-level integration of knowledge is the key driver of positive effects of diversity in IT work (Tiwana and McLean 2005).

While teams seek diversity to achieve the benefits mentioned above, diversity has also been frequently found to cause negative effects, thus being called “a double-edged sword” (Milliken and Martins 1996, p. 403). While relations are complex, diversity can lead for example to conflictive behavior, which in turn may inhibit effective teamwork (De Wit et al. 2012; Pelled et al. 1999). On an affective level, diversity can reduce satisfaction and the sense of belonging to a particular group (Milliken and Martins 1996). Moreover, diversity can increase turnover intentions (Jehn et al. 1999).

Social faultlines are a popular and corroborated approach to investigating diversity. Analogously to faultlines in the crust of the earth, they are hypothetical schisms in teams created by attributes that align to form a distinct division between members on either side of the faultline (Lau and Murnighan 1998). If, for example, a team is comprised of five young male programmers and two middle-aged female managers, age, gender, and job title form a distinct faultline. Embraced by many researchers, results on the effects of diversity using the faultline concept mirror the varied findings on diversity in general. Results see faultlines causing both positive and negative outcomes, from group clashes and animosity to improved knowledge processing (Carton and Cummings 2012; Cooper et al. 2014; Thatcher and Patel 2011). Faultlines based on identity attributes such as gender and age likely lead to negative outcomes through categorization in subgroups, whereas faultlines based on differences in knowledge can propel performance by making information processing more efficient (Carton and Cummings 2012).

This recollection of results in general team research gives rise to the question how faultlines affect work in the specific context of IT projects. As outlined above, IT work is highly knowledge-intensive to conduct complex interdependent tasks, which results in a constant need for team coordination and joint interaction (Espinosa et al. 2007; Faraj and Sproull 2000; Kudaravalli et al. 2017). With communication issues being key contributors to failure of IT projects (Charette 2005), ensuring a smooth flow of communication is thus a key concern in increasing project success. We thus expect to find identity-based faultlines to disrupt teamwork based on negative categorization, whereas knowledge-based faultlines as conduits of information sharing likely increase performance (Carton and Cummings 2012).

To shed light on the effects of faultlines on the performance of IT work, we investigate the prevalence and effects of faultlines based on identity and knowledge using data on 424 IT projects. First, we present background information on IT work and faultlines in general. Based on this theoretical background, we develop hypotheses on the performance effects of the strength of identity- and knowledge-based faultlines and the number of resulting group factions. After detailing the empirical method, we present and discuss results. We end with a conclusion of our results and their contributions to research and practice.

Background

In the following, we provide background information on IT work and its critical reliance on team interaction. Secondly, we introduce the faultline concept and summarize key results on observed effects.

IT Work

Work in IT is a special context shaped by factors such as task-based work practices, organizational aspects, as well as traits of teamwork and individual characteristics. In the following, we will detail these aspects as they relate to the challenge of effective teamwork. As opposed to goods in manufacturing, tasks in IT work require knowledge as their primary input (Faraj and Sproull 2000). Since IT artifacts are in a modularized structure with interdependent elements, IT workers have to coordinate the structure of the artifact as well as the tasks and interactions needed to create it (Kraut and Streeter 1995; Malone and Crowston 1994). Given the diversity of knowledge required in IT work, the requirement to coordinate transcends to the diverse expertise of members (Faraj and Sproull 2000). In order to address these organizational issues, IT work relies on methods and intense levels of collaboration between individuals (Faraj and Sambamurthy 2006).

To bring all required competences and areas of knowledge to bear, IT work is often organized around projects, which are frequently carried out in teams (Faraj and Sproull 2000). While teams are a dominant theme of current organizational practice in general (DeChurch and Mesmer-Magnus 2010), the fast-paced and project-dependent nature of IT work has specific effects. To bring in even more diverse competencies, membership may change or external parties may be involved (Espinosa et al. 2003). The observation that

IT workers are overall highly empowered to make decisions in their work (Tessem 2014) can be readily understood since much of the complexity in IT projects stems from the underlying tasks and artifacts, which require team members to draw on their individual knowledge. As a result, members have to interact to align their work (Espinosa et al. 2007; Faraj and Sambamurthy 2006; Kudaravalli et al. 2017).

The individual knowledge and cognitive abilities of team members are a prerequisite to carrying out these complex tasks. While individual cognition is the basis for performance, integration of individual abilities is critical in achieving creative outcomes (Tiwana and McLean 2005). Preceding integration, coordinating the application of distributed knowledge is of key importance (Faraj and Sproull 2000). These considerations are also at the heart of development methods. As a prominent example from agile development, pair programming requires joint elaboration of information (Balijepally et al. 2009). Moreover, integrating different methods requires knowledge sharing (Przybilla et al. 2018a). In addition to the expected technical coordination, "softer" aspects such as the timing of activities and process issues are areas that require team members to coordinate and align (Espinosa et al. 2007). As a further complication, no single interaction mechanism is universally optimal, but IT work is always trying to dynamically strike a balance between planned structure for "getting things done" and more emergent interaction between members to foster creative outcomes (Kudaravalli et al. 2017).

Work in such a challenging context critically depends on effective team processes. As a group construct, shared cognition of the task to be conducted or who in the team possesses which knowledge is a critical success factor in IT work by enabling e.g. quick coordination (Espinosa et al. 2004; He et al. 2007). As an antecedent to shared cognition, knowledge sharing as meaningful interaction between members depends on a diverse number of drivers ranging from heterogeneity in team members to incentives (Ghobadi 2015). A further critical factor are team perceptions: For example, conflict is an important concern in achieving performance (Sawyer 2001). Paying attention to such "soft" perceptual outcomes has thus been emphasized to improve project performance (Dingsøyr et al. 2016). In addition, IT work exhibits a distinct occupational environment with a number of characteristic traits. By driving positive aspects such as affective commitment, professional conduct is an important aspect in IT work (Dinger et al. 2015). As a characteristic cultural trait, members highly value technical competence and use a specific technical jargon (Guzman et al. 2008; Jacks et al. 2018).

Proceeding to a more granular level of analysis, processes at the personal level are important antecedents of productivity as well. "People aspects," i.e. how team members interact with each other, relate to a number of work practices and are thus decisive in achieving productive outcomes. Such personal interactions complement formal means of aligning work (Espinosa et al. 2004) and enable knowledge sharing (Ghobadi 2015). Interaction as such does not, however, lead to project success. For one, the content of communication is important for its effectiveness (Marlow et al. 2018). Secondly, the alignment of communication between team members with dependencies in the underlying task has been proposed as an important indicator of effective coordination (Sosa 2008).

On the most detailed level, considering the individuals working in IT project teams is worthwhile for understanding how teams work effectively. As stated before, IT work teams have been criticized to be quite homogeneous on demographic dimensions: The recurring obsolescence of technical skills can lead to marked age clusters (Zhang et al. 2012), and female members continue to be a rarity (Korrigane 2019). This compositional view gives rise to the question which individual traits make a team member an important contributor. Historically, technical and analytic abilities have been emphasized (Balijepally et al. 2006). More recently, this narrow focus grew wider to recognize the importance of teamwork and exchanging information. While the relevant characteristics still include cognitive ability and knowledge, they now also consider concepts such as motivation and communicative abilities (Siau et al. 2010). This finding on the individual level aligns with the team-level proposition that integrating information is more important than individual cognition (Tiwana and McLean 2005).

In sum, IT work exhibits a number of characteristic traits ranging from the task to be fulfilled, to typical team organization, characteristic team processes, and lastly characteristics of team members. Emanating from the complexity of the task, continuous exchange of information and interaction between members is of key importance for productive outcomes.

Team Faultlines as Explanations of Diversity Effects

As outlined above, IT work as a knowledge-intensive endeavor heavily relies on a diverse skill set, knowledge, and abilities, which have to be brought together, coordinated, and integrated to achieve the desired outcomes (Faraj and Sproull 2000; Kudaravalli et al. 2017). Diversity in members concerning their specialized knowledge and experiences is thus expected to bolster performance by allowing for more creative problem-solving (Tiwana and McLean 2005). Translating this belief into actual results hinges on group-level integration of information (Van Knippenberg et al. 2004), which necessitates productive communication within the team.

Assessing the effects of diversity on team processes and work outcomes is a longstanding issue in general group research (Bell et al. 2011). A prominent approach to explaining the effects of diversity is the faultline concept. While in geology a faultline describes a crack in the soil, in a more general sense, the term captures "a problem that may not be obvious and could cause something to fail" (Cambridge English Dictionary 2019). In group research, faultlines are hypothetical dividing lines splitting teams into several smaller entities (Lau and Murnighan 1998). Faultlines emerge based on specific differences in one or multiple characteristics that members on one side of the faultline share but distinguish them from all others (Lau and Murnighan 1998). Faultlines and the potentially perceived subgroups (Jehn and Bezrukova 2010) affect a wide range of team processes and outcomes. For example, conflict may be exacerbated by one faction strongly acting in opposition to all others (Jehn and Bezrukova 2010; Lau and Murnighan 1998). Opposition between groups moreover reduces effective communication across group boundaries (Lau and Murnighan 2005). Considering joint problem-solving abilities, activated faultlines relate negatively to creativity (Pearsall et al. 2008). In addition, satisfaction as a key enabler of effective teamwork tends to be reduced by faultlines (Thatcher and Patel 2011). Last but not least, faultlines lead to lower overall team performance (Thatcher and Patel 2011). As a concrete example, stronger faultlines negatively affect decision-making (Rico et al. 2007). Overall, the faultline concept has been found to outperform the analysis of individual diversity characteristics by taking interaction effects of multiple dimensions into account (Thatcher and Patel 2012).

Faultlines have originally been put forth to explain negative effects of demographic diversity, e.g. based on age and gender, in work teams (Lau and Murnighan 1998). Building on social categorization and social identity theory, splits based on characteristics shaping the identity of members are likely to lead to negative processes between the resulting factions (Carton and Cummings 2012). Social identity theory describes each individual to know about and estimate the value of membership in certain groups, which in turn leads to self-categorization. Self-categorization leads members to classify others as either part of their *in*group or as a "foreigner" from an *out*group (Hogg and Terry 2000). Consequently, team members repeatedly perceive and ponder their relative (dis)similarity with others. Such considerations can lead to negative effects such as biases and stereotypes, not least because of a desire to protect the own identity (Bezrukova et al. 2009; Hogg and Terry 2000).

Since its original inception, the faultline concept has been extended to other grounds for emergence. For example, knowledge-based faultlines may emerge based on e.g. differences in training and experience (Bezrukova et al. 2009; Carton and Cummings 2012; Carton and Cummings 2013). Being due to differences in knowledge, processes between the resulting factions are likely positive and focus on objectively exchanging information instead of clashing over identity (Carton and Cummings 2012). Especially in uncertain tasks, theory describes the need for more intensive information processing (Galbraith 1974). The categorization-elaboration model proposes processing task-relevant information to be the key mechanism of positive effects of diversity (Van Knippenberg et al. 2004). Based on these theories, knowledge-based faultlines thus make different pools of knowledge accessible to the team, which engenders positive effects if the knowledge is related to the task at hand and embraced by the team (Bezrukova et al. 2009; Carton and Cummings 2012).

Given the different reasons for emergence, a single team may exhibit several faultlines based on multiple dimensions (Carton and Cummings 2012). Effects of faultlines moreover depend on the magnitude of differences in the characteristics: Large differences in age are likely more impactful than having slightly different educational backgrounds (Bezrukova et al. 2009). Additionally, the number and configuration of faultline-based factions is of relevance: If teams are split into two equal factions, clashes are likely fiercer than if there are numerous factions, which may cross-cut each other (Carton and Cummings 2012;

Homan et al. 2007). More knowledge-based factions imply that achieving shared cognition may become more effortful (Carton and Cummings 2012). At the same time, an increasing number of knowledge-based factions implies more pools of knowledge to draw upon, which based on information processing theory aids elaborating uncertain tasks (Carton and Cummings 2012; Galbraith 1974).

In addition to the reason for emergence and subsequent team dynamics, faultline effects moreover depend on the context in which teams operate (Lau and Murnighan 1998). At an abstract level, effects depend on the team setting as such. As a small, yet significant influence, the type of industry moderates effects (Thatcher and Patel 2012). Moreover, the effects of diversity depend on the relevance to the task (Bezrukova et al. 2009). High autonomy of teams in decision making moderates faultline effects (Rico et al. 2007) and high task complexity can make information-based faultlines a valuable asset (Cooper et al. 2014). In addition, team structures that foster joint achievement can help cross-cut faultlines, i.e. team members feel attached to several factions (Homan et al. 2007), which attenuates negative effects.

Additionally, team-level processes moderate faultline effects. Having a shared, overarching identity is instrumental in drawing attention away from faultline differences and thus to lessen their effects (Bezrukova et al. 2009). Similarly, a shared goal can refocus members on the task instead of personal differences (Van Knippenberg et al. 2011). Lastly, the very process of sharing information in the group and elaborating project outcomes is likely to support performance and to attenuate negative faultline effects (van der Kamp et al. 2015; Van Knippenberg et al. 2004).

Hypothesized Effects of Faultlines on the Performance of IT Projects

Integrating the preceding information on IT work and faultline effects, we derive hypotheses on the effects of identity- and knowledge-based faultlines on the performance of IT project teams. We especially seek to link characteristic traits of IT work to factors influencing faultline effects such as team context and task. As introduced before, IT work heavily depends on the integration of information and knowledge of individual team members (Faraj and Sproull 2000; Kudaravalli et al. 2017). The complex tasks and resulting dependencies in timing and processes frequently require coordination of team members (Espinosa et al. 2007; Faraj and Sproull 2000; Malone and Crowston 1994). Consequently, communication figures among the decisive factors in determining project success (Charette 2005). Misunderstandings or not talking to others in the first place are a common point of failure. Moreover, communication is a key antecedent to important team-level constructs such as shared cognition (He et al. 2007).

The need for constant interaction translates into a need for effective and smooth overall teamwork. Both positive influences such as shared cognition and professionalism (Dinger et al. 2015; Hsu et al. 2012) and negative ones such as increased levels of conflict (Sawyer 2001) are decisive. We expect changes in group processes brought about by identity- and knowledge-based faultlines to affect the team processes in IT projects, and thus their performance. While the faultline concept is applicable to multiple attribute types, we distinguish these two classes as they lead to different team processes (Carton and Cummings 2012).

Effects of Identity-based Faultlines

Starting with the original introduction of the concept, faultlines based on attributes that can stimulate perceptions of identity have been related to changes in group processes and outcomes (Lau and Murnighan 1998). In meta-analysis, such faultlines have consistently resulted in adverse consequences such as increased conflict, reduced satisfaction, and lower team performance (Thatcher and Patel 2011). Moreover, faultlines inhibit communication between the resulting team factions (Lau and Murnighan 2005). Effects are more pronounced when members are further apart on the underlying characteristics, which translates into stronger and more distant faultlines (Bezrukova et al. 2009; Rico et al. 2007).

At their core, identity-based faultlines cause negative team processes based on self-categorization and the social identity of team members (Carton and Cummings 2012). By surveying whether or not others are part of their *in*group or different based on e.g. gender and thus part of the *out*group, team members change their behavior to protect the *in*group identity (Hogg and Terry 2000). As a result, exchanging knowledge across faultline divisions, i.e. to the *outgroup*, is inhibited (Lau and Murnighan 2005). A lack of exchange of knowledge removes the basis for elaboration and integration of information from multiple sources in the group (Van Knippenberg et al. 2004). Moreover, the ensuing hostility may strengthen group conflict, lower satisfaction, and reduce overall performance (Thatcher and Patel 2011).

The observed influences of identity-based faultlines relate directly to findings from IT work, which describe issues such as the difficulties of diversity in establishing knowledge sharing (Ghobadi 2015) or the negative effects of unmanaged group conflict on performance (Sawyer 2001). The specific context of IT work is, however, likely to influence faultline effects. IT projects are complex and usually exhibit a large degree of autonomy of members (Faraj and Sproull 2000; Tessem 2014). High autonomy emphasizes strong faultline effects (Rico et al. 2007), whereas complexity increases the need for joint work and makes knowledge-based faultlines a positive influence of team performance (Cooper et al. 2014). While the latter two observations relate to knowledge- instead of identity-based faultlines, we deem the effect transferable: Autonomy implies team members are in charge to make decisions (Tessem 2014), which implies that member interaction is needed to agree on how to proceed. Discussing how to proceed is moreover highly likely since IT work exhibits a high need for coordinating actions (Espinosa et al. 2007; Faraj and Sambamurthy 2006). Such interactions harbor potential for perceiving differences in others and thus to emphasize faultline effects (Rico et al. 2007). Analogously, complexity increases the need for communication and thus the basis for faultline effects. Given the relatively homogeneous workforce in IT (Korrigane 2019), differences in demographics may be especially salient and thus trigger negative effects. This expectation is bolstered by findings that revealing additional information on team members critically changes outcomes (Windeler et al. 2015). Moreover, the potential for cross-cutting and thus attenuating faultline effects may be limited if attributes of individual "outliers" align, which likely exacerbates effects. Considering the consistently corroborated negative effects of identity-based faultlines on team outcomes and the reliance of IT work on team-based information exchange, we put forth:

> **H1a**: The strength of identity-based faultlines negatively relates to performance in IT project teams.

As introduced above, the configuration of faultlines is an important consideration for their effects (O'Leary and Mortensen 2010). For identity-based faultlines, negative categorization is expected to be less pronounced when the number of potential factions increases since there is less direct opposition and threat to one's own *in*group (Carton and Cummings 2012). If factions based on identity clash, teams with two factions effectively opposing each other perform worse than teams with any other number (Carton and Cummings 2013). If there are multiple factions, members may perceive similarities with others that allow cross-cutting faultlines, which in turn reduces the likelihood of coalitions (Homan et al. 2007). At the same time, more potential factions may reduce the perception of the team as a coherent whole (Carton and Cummings 2012), which could lessen overall team identity. Since having one identity-based faction corresponds to having no faultline, we exclude this case and build our hypothesis on the case of two opposing factions as a minimum number, which implies a positive relative effect of additional factions:

> **H1b**: The number of team factions due to identity-based faultlines positively relates to performance in IT project teams.

Effects of Knowledge-based Faultlines

Drawing on the proposition that the reason for the formation of faultlines critically influences the direction of effects (Bezrukova et al. 2009; Cooper et al. 2014), we seek to investigate the effects of knowledge-based faultlines. As opposed to differences in identity, knowledge-based faultlines engender positive team dynamics (Carton and Cummings 2012). The group processes emerging from differences in knowledge help efficient information processing by enabling teams to consider more sources of knowledge (Carton and Cummings 2012). This proposition of positive effects of diversity in knowledge draws on the categorization-elaboration model, which proposes an increase in task-relevant information to bolster team performance (Van Knippenberg et al. 2004). According to information processing theory such increased processing is especially important in uncertain environments (Galbraith 1974).

Considering an overall dearth of research on knowledge-based compared to identity-based faultlines (Cooper et al. 2014), empirical results have validated claims of positive effects to some extent. Knowledge-based faultlines are positive under the conditions that distance on the underlying attributes is not excessive and team identification is high (Bezrukova et al. 2009). In addition, knowledge-based faultlines are positive for performance in complex tasks, especially if much information has to be processed, and without dynamism in the environment (Cooper et al. 2014).

The preceding description of the theoretical and empirical findings on when knowledge-based faultlines are positive readily relates to the specifics of IT work. Considering the work context, the high autonomy in IT teams (Tessem 2014) is likely to strengthen effects since more direct interaction is required (Rico et al. 2007). The complexity and interdependence of artifacts, uncertain tasks, and knowledge in IT work require much coordination and interaction (Espinosa et al. 2007; Faraj and Sambamurthy 2006; Faraj and Sproull 2000; Malone and Crowston 1994). A large extent of interaction provides a broad basis for perceiving other's competences and thus to enable the efficient information-processing aided by knowledge-based faultlines. The most suitable form of such interaction is not static and clearly defined but may well depend on the specific task conducted (Kudaravalli et al. 2017). This implies that not only the content discussed but also meta-coordination concerning expertise, as well as the process and timing of activities is crucial (Espinosa et al. 2007; Kudaravalli et al. 2017).

In this sense, the value of shared cognition for conducting IT work (He et al. 2007) needs to be emphasized: The dimension of knowing who holds which knowledge effectively provides the foundation for the efficient knowledge processing enabled by knowledge-based faultlines. Given the large amount of information to be processed and since IT work is inherently complex (Faraj and Sproull 2000), the findings on positive aspects of knowledge-based faultlines in complex tasks (Cooper et al. 2014) are directly applicable. Considering the breadth of expertise required in IT work (Faraj and Sproull 2000), we expect strong knowledge-based faultlines to help with integrating more diverse knowledge. According to the categorization-elaboration model, integrating diverse task-relevant knowledge leads to productive team outcomes (Van Knippenberg et al. 2004). Considering extant knowledge on the effects of faultlines and the specific characteristics of IT work, we hypothesize:

> **H2a**: The strength of knowledge-based faultlines positively relates to performance in IT project teams.

Analogously to the considerations on the number of identity-based factions, we also expect the number of knowledge-based faultlines to influence team performance. A larger number of knowledge-based factions is proposed to improve information-processing since more diverse pools of knowledge can be accessed (Carton and Cummings 2012), which add to the productive elaboration of information (Van Knippenberg et al. 2004). At the same time, an increasing number of individual knowledge pools may provide obstacles to reaching a shared mental model (Carton and Cummings 2012), which given its importance in IT work (Hsu et al. 2012) is likely to negatively affect team performance. This proposition relates to the frequently discussed issue of transaction costs incurred by considering alternative sources of knowledge (Ghobadi and Mathiassen 2016). If there is an abundance of different knowledge sources, considering different sources may be too costly and thus lead to team members not considering any outside sources. However, it does not seem logical to assume that having three or four specialized knowledge-based factions would exclude them from consideration, especially since IT work relies on heterogeneous knowledge with communicating results and knowledge being a key trait of effective team members (Siau et al. 2010). Empirically, a larger number of knowledge-based factions has been found to positively affect performance (Carton and Cummings 2013). We thus expect positive effects of the number of knowledge-based faultlines within reasonable bounds. Taking extant knowledge on the number of knowledge-based faultlines into account, we posit:

> **H2b**: The number of team factions due to knowledge-based faultlines positively relates to performance in IT project teams.

Method

To investigate the proposed hypotheses on the effects of identity- and knowledge-based faultlines, we conducted an empirical analysis of the performance of IT project teams. We have chosen a quantitative approach using archival data, which we analyzed in multiple stages: First, we acquired the raw data, on which we secondly calculated the faultline measures. Lastly, we used the faultline information to calculate the effect of identity- and knowledge-based faultlines on project performance.

Data Acquisition and Operationalization of Faultline Measures

As a data source, we have been given access to the project records of a large IT service provider, here named ALPHA, that conducts projects of different scopes for customers in various industries. This dataset provides fine-grained information on the involvement of employees in particular projects as well as general project information. For the current analysis, we limited the dataset to projects beginning in the timeframe 2009-2012. In addition, we excluded any projects for which at least one employee had data missing on any of the dimensions used to operationalize faultlines. Checking for unreasonable extreme values and outliers, we excluded five projects with durations of less than 15 days. Since faultline and group dynamics may change over time (Thatcher and Patel 2012), these projects may behave quite differently. Moreover, 15 projects had to be excluded for computational reasons as the faultline algorithm could not establish a faultline measure. Applying this strict filtering criteria, we obtained a sample of 424 projects.

To operationalize identity- and knowledge-based faultlines, we followed extant research, which draws on general literature on diversity and social identity. We operationalized identity-based faultlines using the demographic attributes *gender*, coded as male or female, and *age* (Bezrukova et al. 2009; Carton and Cummings 2013). *Age* has been assessed at the beginning of the project using the birthdate and the project start date. Knowledge-based faultlines are meant to capture differences in knowledge and expertise. While previous research has used tenure at a company (Bezrukova et al. 2009), we deem this measure somewhat imprecise given its likely high correlation with age. We thus operationalize the grounds for knowledge-based faultlines using two measures of work experience: The sum of hours an employee had worked at ALPHA when the project under consideration started, and the sum of hours an employee had worked on projects in the same industry as the project under consideration. In both sums, we considered projects completed before the project under consideration started. These measures should capture both general knowledge acquired by working at ALPHA and industry-specific knowledge.

Calculation of Faultline Measures

The data on identity- and knowledge-based characteristics provides the foundation for calculating faultlines in the project teams. An early form of measuring faultlines is assessing strength using Thatcher's Fau as the percentage of group variation accounted for by the strongest division (Thatcher et al. 2003). As an extension, the additional measure of faultline distance captures the extent of differences within characteristics (Bezrukova et al. 2009). These measures are, however, not suitable for identifying more than one potential division (Meyer and Glenz 2013). Since we hypothesize the number of resulting factions to affect performance, we employ the cluster-based Average Silhouette Width (ASW) approach (Meyer and Glenz 2013), which is deemed applicable to all potential faultline configurations (Meyer et al. 2014). Moreover, the ASW algorithm is proposed as especially robust in cases of missing or incorrect data (Meyer et al. 2014), which increases our confidence in the results.

We calculated the strength of faultlines and the likely number of resulting factions based on the ASW algorithm using the accompanying R package asw.cluster. Since we expect differential effects, we calculated identity- and knowledge-based faultlines separately using automatic rescaling of values. Since experience at ALPHA may correlate with experience in the project industry, we chose mahalanobis distance, which can be applied to correlated characteristics (Meyer and Glenz 2013), for calculating knowledge-based faultlines.

Dependent and Control Variables

As dependent variable and operationalization of performance, we use data on the profitability of projects. Due to reasons of confidentiality, the data has been anonymized but enables a true-to-reality comparison between projects. Defining how performance of a project can be assessed is a topic of debate (Neely et al. 2005). Companies may value a host of project outcomes such as quality, yet profitability arguably is the key deciding factor (Gopal and Koka 2012; Hoermann et al. 2015). Not least, project profitability provides a proxy for firm profitability (Ethiraj et al. 2005). Influences on such highly valued outcomes are thus more likely to trigger actions or decisions that allow for improvements (Gopal and Koka 2012). Given this argumentation, we deem overall profitability apt for expressing the interests of ALPHA. Since the dataset contains projects for the same customer at different points in time, we chose a panel-corrected multiple regression analysis. A Hausman test determined a fixed effects model to be appropriate.

Beyond the four faultline variables, strength and number of likely factions based on identity and knowledge, we included control variables to account for systematic differences in projects. To control for the potential of more group splits, we added *team size*. Team size is frequently discussed as an important factor for performance since the coordination of larger teams may constitute an impediment (Ethiraj et al. 2005). To control for outliers, we logged *team size*. Moreover, we include *project volume* as a control since previous research has established it to significantly increase profitability (Gopal and Koka 2012). We operationalize *project volume* as the overall revenue generated by the project. To control for outliers, we logged the variable. In addition, we controlled for *project duration* since prolonged projects make forecasts and planning more difficult (Ethiraj et al. 2005), and changes in between are more likely (Gefen et al. 2008). Projects with a longer duration thus exhibit lower performance (Sauer et al. 2007). We operationalize *project duration* as the number of days a project has been marked as active. To control for outliers, we logged the variable.

In addition, the project setting has to be controlled for. The overall business confidence is likely to affect project outcomes. We control for this influencing factor by including the current value of the ifo business climate index (CESifo 2019), which is applicable since ALPHA is mostly based in Germany.

With the expectation of employees building knowledge for ALPHA in industry projects, we control for overall learning effects at ALPHA by including the *project start year* as a control variable. In addition to learning effects, this variable controls for other general influences (Ethiraj et al. 2005).

Results

To judge the overall sample of projects and employees, we provide descriptive statistics in Table 1. Following guidance on checking for multicollinearity in fixed effects panel models, we calculated variance inflation factors (VIFs) on linear regression equivalents of the model. *Strength of knowledge-based faultlines* exhibited the highest value of 8.09, followed by the logged *team size* at 5.17. Since both values are below the recommended threshold value of 10 (Chatterjee and Hadi 2012), we kept them in our model. All other variables exhibited VIFs of 3.52 or less. Moreover, we observe typical traits of IT work in the sample: A large majority of 81.73% of employee observations indicated gender as male. The average project duration of 176.26 days justifies our operationalization of knowledge and age since intervals of less than a year are not likely to have much influence on overall experience.

In Table 2, we detail results of the panel-corrected multi-level regressions. We used Arellano-type robust standard errors to control for any potential issues with heteroskedasticity. The first model including control variables yields an R^2 value of .142. Adding the strength and number of potential factions due to identity-based faultlines increases the amount of variance explained slightly to 15.9%. Similarly, adding the variables related to knowledge-based faultlines increases the variance explained. Model four combining the control variables and both types of faultlines achieves the highest R^2 value of 16.9%. As expected, adding the faultline variables explains additional variance. In all of the models, the control variables *project volume*, *project duration*, and *team size* are significant. As expected, *project volume* is positively related, whereas *project duration* and *team size* show negative relations.

Of our four hypotheses on the effects of identity- and knowledge-based faultlines on the performance of IT projects, only one, H1b, is supported statistically in all models. For two, the direction of effects is as expected, whereas the other two show a reversed direction.

Hypothesis 1a on the negative effect of the strength of identity-based faultlines in IT projects could not be supported. To the contrary, both in the individual model and when considered jointly with knowledge-based faultlines, the strength of identity-based faultlines is significantly positively related to project performance.

Hypothesis 1b on the positive effect of the number of identity-based faultlines could be supported. We observe a significant positive weight both in the individual and joint model.

Hypothesis 2a on the positive effect of the strength of knowledge-based faultlines in IT projects could be supported to some extent. The direction of the effect is positive, as expected, albeit insignificant.

Hypothesis 2b on the expected positive effect of the number of knowledge-based factions could not be supported. The direction of the effect is, contrary to our expectations, negative and insignificant.

Descriptive Statistics					
Projects [n=424]	**Min**	**Mean**	**Median**	**Max**	**sd**
Team Size [persons]	3	3.86	3	9	1.18
IFO Index	84.5	102.77	103.55	115	7.35
Project Volume	445.00	41289.84	17371.50	835459.56	77203.94
Project Duration [days]	15	176.26	134.50	1024	148.34
Strength of Identity-Based Faultlines	0.17	0.49	0.50	0.90	0.16
# of Identity-based Faultlines	2	2.07	2	5	0.30
Strength of Knowledge-Based Faultlines	0.00	0.17	0.00	0.79	0.21
# of Knowledge-based Faultlines	1	2.35	2	4	0.57
Project Members [n=1637]					
Age [years]	20.49	41.18	41.13	63.47	9.06
Experience at ALPHA [h]	1	9331.47	7979.75	32187.40	7647.75
Experience in Industry [h]	1	7969.60	5672.44	32105.15	7503.18
Male	81.73%		Female		18.27%

Correlations	T. Size	IFO	P. Vol.	P. Dur.	Str. ID	# ID	Str. KN	# KN	Prof.
Team Size	1	0.01	**0.11***	**0.24*****	**0.48*****	**0.47*****	**0.82*****	**0.62*****	-0.01
IFO Index		1	0.03	-0.05	0.07	0.01	0.03	-0.01	0.01
Project Volume			1	**0.29*****	0.09.	**0.12****	0.05	0.01	0.09.
Project Duration				1	**0.16*****	**0.18*****	**0.21*****	**0.14****	0.01
Str. Identity Faultlines					1	**0.16*****	**0.46*****	**0.34*****	**0.10***
# Identity Factions						1	**0.33*****	**0.27*****	0.04
Str. Knowledge Faultlines							1	**0.83*****	-0.05
# Knowledge Factions								1	**-0.11***
Profitability									1

Table 1 Descriptive Statistics and Correlations of Sample

Discussion

IT projects as endeavors of knowledge work conduct complex, dynamic tasks and critically depend on the coordination of the work and expertise of team members (Espinosa et al. 2007; Faraj and Sproull 2000; Kudaravalli et al. 2017). Smooth teamwork is thus a prerequisite to effective work. Based on this assertion, we have investigated the effects of faultlines, a widely-applied concept to explain effects of diversity in groups (Lau and Murnighan 1998), in IT project teams using panel-corrected multiple regression. Contrary to expectations, we have found the strength of identity-based faultlines due to age and gender to have significant positive relations with performance. As expected, the number of group factions due to identity-based faultlines has a positive effect. In addition, the expected positive effect of the strength of knowledge-based faultlines on performance has been insignificant. Lastly, the number of knowledge-based factions has negative, insignificant relations with performance.

Multiple Panel-corrected Regression (Fixed Effects) with Arellano-type robust standard errors								
Model	**1**		**2**		**3**		**4**	
Team Size (log)	**-0.482**	**0.000*** **	**-0.713**	**0.000*** **	**-0.639**	**0.002** **	**-0.862**	**0.000*** **
IFO Index	0.001	0.774	0.000	0.917	0.001	0.859	-0.000	0.998
Project Volume (log)	**0.323**	**0.000*** **	**0.320**	**0.000*** **	**0.326**	**0.000*** **	**0.323**	**0.000*** **
Project Duration (log)	**-0.170**	**0.001*** **	**-0.180**	**0.000*** **	**-0.170**	**0.001*** **	**-0.180**	**0.000*** **
Strength of Identity-Based Faultlines			**0.744**	**0.043* **			**0.749**	**0.036* **
Number of Identity-based Factions			**0.108**	**0.027* **			**0.121**	**0.000*** **
Strength of Knowledge-Based Faultlines					0.719	0.192	0.713	0.167
Number of Knowledge-based Factions					-0.228	0.177	-0.236	0.123
Year 2012	**0.165**	**0.019* **	**0.168**	**0.033* **	**0.147**	**0.043* **	0.149	0.067.
R^2	0.142		0.159		0.151		0.169	

Table 2 Results of Multiple Regression Models

In the following, we discuss these findings, starting with characteristics of the dataset and analysis. Next, we elaborate on the effects of knowledge-based faultlines before turning to identity-based ones. We especially highlight how the special context of IT work may have contributed to the observed positive effects of identity-based faultlines.

Characteristics of Dataset and Analysis

As objective archival data from the field, our measures capture faultlines as such as opposed to subgroups perceived by members (Jehn and Bezrukova 2010). While we relied on data from a single company, we leveraged a real-world context compared to much extant analysis of faultlines, which has been conducted in laboratory settings with the ability to create strongly aligned faultlines and larger overall effect sizes (Thatcher and Patel 2011). This finding implies that we may be under- instead of overestimating effects, which strengthens our confidence in our results.

We analyzed data using the ASW method to calculate faultlines and used a panel-corrected regression analysis since there may be more than one project per customer. The choices made in operationalization and analysis naturally influence results. Using different operationalizations may have changed results and improved some statistical properties. Investigating the effects of faultlines on other dependent variables of interest in IT projects, e.g. quality (Gopal and Koka 2012), is a fruitful avenue for future research. Different combinations of parameters in operationalizing faultlines and the effects of calculation methods are important open questions (Meyer and Glenz 2013), which we encourage as future research.

Effects of Knowledge-based Faultlines on Performance

While the regression weight of the strength of knowledge-based faultlines is positive as expected, it is insignificant, which leads us to reject the corresponding hypothesis on statistical grounds. Unexpectedly, the number of potential knowledge-based factions is not positively but insignificantly negatively related to performance. Previous studies have found knowledge-based faultlines to improve performance, especially if there are many factions and complexity is high (Carton and Cummings 2013; Cooper et al. 2014).

We have expected faultlines based on differences in knowledge to engender positive effects since different areas of expertise in teams likely stimulate team members to consider alternative knowledge repositories (Carton and Cummings 2012). The categorization-elaboration model predicts the amount of task-relevant information processing to be a key driver of positive effects of diversity (Van Knippenberg et al. 2004). Considering the proposition in information processing theory that especially large amounts of information are to be processed in uncertain contexts, and the key characteristic of IT work as processing complex uncertain tasks (Faraj and Sambamurthy 2006), our result is even more surprising.

A possible explanation lies in the work characteristics: In the dynamic context of IT work, the specific need to exchange information and to coordinate expertise, task- and process-related information very much depends on the task at hand (Espinosa et al. 2007; Kudaravalli et al. 2017). However, dynamic environments inhibit positive effects of knowledge-based faultlines (Cooper et al. 2014), which in our observed cases may have reduced positive effects to insignificance. Additionally, our operationalization of knowledge as working experience at ALPHA and within the industry of the project may not have captured enough differences in knowledge to become a significant influence.

In addition, given the average group size of 3.86, drawing on the number of potential group splits may have limits. This proposition is supported by the significant negative effect of team size on performance and findings in extant literature. Akin to geographic distribution, splitting a group into factions increases the effort needed for coordination (Espinosa et al. 2007) and may exceed the benefits of additional sources of knowledge. Additional factions may thus inhibit the emergence of a shared cognitive model of the task and transactive memory of who holds which expertise, which are influential factors in IT work (Carton and Cummings 2012; He et al. 2007; Hsu et al. 2012). Moreover, specific mechanisms of knowledge sharing may overpower the influence of knowledge-based faultlines as indicators where knowledge can be obtained (Carton and Cummings 2012). By using methodical approaches (Faraj and Sambamurthy 2006), IT work institutionalizes knowledge sharing in, for example, practices such as pair programming (Balijepally et al. 2009). It would thus be interesting for future research to consider knowledge-based faultlines interacting with development methods and shared cognition.

Understanding the Positive Effects of Identity-based Faultlines

Contrary to our hypothesis, the strength of identity-based faultlines has shown positive relations with performance. This finding is in opposition to extant literature, which has found negative relations to several team outcomes including performance (Thatcher and Patel 2011). While more recent works on the faultline concept have proposed to differentiate group factions based on the characteristics underlying their emergence, they have still made the case for negative effects of identity-based faultlines (Carton and Cummings 2012). Such a proposition rests on the expectation of negative categorization leading to perceived threats to each group's social identity (Carton and Cummings 2012; Hogg and Terry 2000). This gives a possible explanation to why we observed positive effects: Following self-categorization theory (Hogg and Terry 2000), there may have been no perceived threat to the identity of members' perceived *in*group and thus no negative repercussions. Differences may have been perceived as valuable task-relevant information, which can drive positive team performance (Van Knippenberg et al. 2004).

To understand this lack of identity threat, we have to consider the context-dependent nature of faultline effects. Starting with the initial proposition of the concept, faultlines are expected to have different effects based on the context and its moderating factors (Lau and Murnighan 1998). Subsequent research has analyzed a number of moderating factors such as team identification (Bezrukova et al. 2009) or task autonomy and complexity (Cooper et al. 2014; Rico et al. 2007). Many of these moderators are conceptually similar or at least closely related to known characteristics of IT work, which we expect to have been present in the project teams at ALPHA, and discuss in the next section.

Characteristics of IT Work Turning Demographic Diversity into Positive Influence

Given the dependence of faultline effects on context factors, assessing the characteristics of IT work as shaping forces seems worthwhile to interpret our results. While IT work is a broad concept without clearcut boundaries (Guzman et al. 2008), there are several characteristics that shape the working context. We argue that characteristics related to tasks, composition of the workforce, and teamwork explain how identity-based faultlines can engender the positive effects of a repertoire of diverse knowledge.

Key task-related aspects of IT work are complexity and knowledge-intensity (Faraj and Sproull 2000), as well as constant change in the underlying technology and skills required (Gallivan et al. 2004). These characteristics require close and dynamic coordination of tasks, timing, processes, and expertise held by team members (Espinosa et al. 2007; Kudaravalli et al. 2017). While investigated specifically for information-based faultlines, the high complexity of IT work may drive positive effects of diversity (Cooper et al. 2014). The multitude of content-based foci relating to expertise and complex decision-making provides an explanation to the positive effects of identity-based faultlines: The effect of diversity in work contexts depends on the degree to which differences are related to the task (Bezrukova et al. 2009). Since tasks in IT work do not relate to age and gender, there may be no negative repercussions on these dimensions. Moreover, since exchanging knowledge is a prerequisite in IT work (Ghobadi 2015; Kudaravalli et al. 2017), members have to interact, which implies negative perceptions may be cross-cut and thus rendered ineffective (Lau and Murnighan 1998). Drawing on social identity and self-categorization theory, team members thus might not perceive differences in identity as threats to their group identification (Hogg and Terry 2000) but come to embrace the different viewpoints in information processing. This interpretation draws attention to how perceived diversity can act as an important explanatory variable (Shemla et al. 2016). The uncertainty of tasks in IT work (Faraj and Sambamurthy 2006) strengthens this mechanism since information processing theory implies a heightened need for deliberation (Galbraith 1974). Supporting this interpretation, pronounced faultlines have been shown to be positive for team learning when interaction is high (Rupert et al. 2016).

Beyond task-related characteristics, the workforce stands out as a special factor. The IT workforce has been frequently described to be mostly composed of male members (Armstrong et al. 2018; Korrigane 2019). With 18.27% of employees in the projects we analyzed identified as 'female,' our sample is comparable with the overall representation of women in IT, which is at 17.2% (Korrigane 2019). Moreover, based on changes in technology and skill, distinct age clusters may emerge (Zhang et al. 2012). Considering these observations, differences in either age or gender should markedly stand out and may seem excessive in a typical IT project team. The resulting strong faultline is likely to engender direct opposition and conflict (Lau and Murnighan 1998). On the other hand, the minority status of those of different age or gender may inhibit the emergence of marked splits among or open conflict within the team (Carton and Cummings 2012; Lau and Murnighan 1998). In this peculiar case, the marked difference in characteristics might not lead to negative self-categorization as the resulting opposing party is too small to be perceived as a threat.

Lastly, the teamwork typical in IT warrants discussion. IT work is characterized by high levels of work autonomy (Tessem 2014), which implies much exchange of information through interaction and thus strengthens faultline effects (Rico et al. 2007). In addition, IT work draws on a set of shared professional attitudes and behaviors, that in turn significantly influence employee behavior, perceptions, and performance (Dinger et al. 2015). In addition to fostering professionalism, IT work has a distinct occupational culture, which comprises for example the use of technical jargon (Guzman et al. 2008) and much appreciation of technical knowledge (Jacks et al. 2018). These characteristics imply that any difference in characteristics of teammates might not be perceived as negative as long as they adhere to the IT occupational culture by e.g. exhibiting domain knowledge. In the context of self-categorization theory, this proposition implies that adhering to the ruleset of IT occupational culture may suffice to be perceived as part of the *in*group of team members (Hogg and Terry 2000), which starves off negative consequences. Going one step further, the value of technical knowledge (Jacks et al. 2018) and reliance on knowledge exchange (Ghobadi 2015; Kudaravalli et al. 2017) make a realistic case for perceiving any difference as a potential further source of information, which can help elaborating task-relevant information (Van Knippenberg et al. 2004). Our explanation thus describes a self-reinforcing circle: Bringing diverse knowledge helps in elaborating information, which in turn leads to perceptions of knowledge, which lead team members to welcome contributions. The possibility of such an "objective" approach to identity-based faultlines is supported by findings that gender diversity relates positively to performance through creating shared mental models in an IT context (He et al. 2007).

Contributions and Conclusion

To complete knowledge-intensive and complex tasks, IT work requires the constant exchange of information and coordination between team members. Since diversity critically influences such team processes, we investigated the effects of diversity related to identity and knowledge on the performance of 424 IT projects. We drew upon extant knowledge in IT work and faultlines as a widely discussed measure of diversity to develop hypotheses on the effects due to the strength of faultlines and the resulting number of factions. Contrary to our expectations, identity-based faultlines exhibited significant positive effects on performance. Conversely, the expected positive effect of knowledge-based faultlines was insignificant. Increasing the number of resulting factions showed significant positive effects for identity-based and negative effects for knowledge-based faultlines. We proposed an explanation to how the specific context of IT work may engender positive effects of identity-based faultlines by providing a common identity.

These results contribute to research in IT work and group diversity in general. For IT work, we contribute to the body of knowledge on contingency factors that are beyond directly visible elements such as development methodologies, yet critically influence outcomes. By integrating corroborated theory from general group research with the specifics of IT work, we particularly contribute to understanding the frequently described "people aspects" in IT work (Faraj and Sambamurthy 2006), which are a prerequisite to building a healthy workforce. Our surprising result of a positive influence of identity-based faultlines is testament to the specific work context in IT. Specifics of IT work such as agile practices may influence work characteristics (Prommegger et al. 2019), including those related to faultlines (Lassak et al. 2017; Pflügler et al. 2018; Przybilla et al. 2018b). Combining these factors provides interesting avenues for future research. By investigating the effects of team composition on outcomes, we add to the discussion of collaboration and coordination in IT work. Specifically, we added initial insight to an antecedent to how teams can optimally coordinate knowledge and tasks (Espinosa et al. 2004; Kudaravalli et al. 2017).

Moreover, our results based on a large sample of project data contributes to the body of research on faultlines. First, we added to research distinguishing faultlines based on their grounds for emergence (Carton and Cummings 2012; Carton and Cummings 2013), which helps in further teasing apart the complex phenomenon of group diversity. Contrary to extant findings (Bezrukova et al. 2009), we observed the strength of faultlines to positively affect outcomes. Our explanations of the surprising findings draw attention to the criterion of whether faultlines are perceived (Jehn and Bezrukova 2010). The present results thus provide a basis to further develop the proposed field of perceived diversity (Shemla et al. 2016). Future analysis could also benefit from combining our results on diversity with other (emergent) factors shaping teamwork such as the use of digital intelligent systems (Przybilla et al. 2019). Furthering our work while considering both characteristics of IT work and general team research can help to develop an in-depth understanding of how faultlines as measures of diversity shape IT work. While we see much potential in further empirical analysis, we see the long-term goal in developing a theory of faultlines in IT work.

For practitioners, our results are of interest by providing insights into an aspect of the dynamics underlying IT project work. Our results imply that it may be good practice to pay close attention to team composition in terms of the potential for faultlines based on either identity or knowledge. If the context is appropriate, staffing teams to draw on identity-based faultlines may provide another tool for success in IT project management. The observed effects can thus help with making precise staffing decisions and contribute to the governance of IT projects as a work endeavor characterized by very unique traits.

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[redacted] P2: The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects

Table AX2: P2: The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects

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The More the Merrier? The Effect of Size of Core Team Subgroups on Success of Open Source Projects

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Abstract. Open source software (OSS) has become an important organizational form of building software. Given the desire to understand drivers of OSS project success and the known importance of social structure for team functioning, we investigate the effects of the relative size of contribution-based subgroups on community size of OSS projects. Drawing on extant research on OSS and faultline-based subgrouping, we investigate the relation with project community size of the relative size of subgroups based on reputation, issue focus, contribution extent and contribution persistence. While in several instances non-significant, results suggest a differential relation in which a large share of core members with high reputation, issue focus and persistent contributions positively relate to community size, whereas a large share of extensively contributing members in the core team is negatively related. Our findings are of value to research and practice by furthering the understanding of work in OSS projects.

Keywords: Open Source Software, Subgroups, Community Size, Team Governance.

1 Introduction

Open source and related concepts such as libre or free software development (in the following summarized as Open Source Software or OSS) have gained much traction in the beginning of the century [1] and continue to garner research attention recently [2].

Since most of the members of OSS projects contribute during their spare time and without monetary remuneration, the questions what motivates people to join, to contribute over longer periods of time and how such informal communities are managed have emerged as topics of research. Such issues are all the more relevant since despite overall success of OSS, a large majority of projects is defunct and not maintained [3]–leading to the issue how success in projects can be propelled.

OSS development is characterized as a virtual, distributed form of teamwork in which theoretically anyone can contribute [4]. This implies that developers are likely to differ on a number of attributes. OSS team members' motivations have been found to be manifold–ranging from personal gain such as programming knowledge [1] or reputation [4] to philanthropic intentions [1]. Moreover, OSS team members embrace

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a common set of specific values and attitudes, which directly relate to work practices [5]. As may be expected from the clique-like description of OSS team interactions, the onboarding process of new members can be riddled with challenges [6].

The notion of positive effects of diversity in members on problem-solving [7] is only to some extent replicated in OSS [8], leading to the questions when and how diversity is conducive to outcomes. Based on characteristics shared by some members of a team and thus separating them from others, diversity can lead to so-called faultlines [7], which in turn may lead to perceivable subgroups [9]. Contingent on the specific reason for formation and configuration of faultlines and subgroups, the direction, i.e. enhancing or harmful, and strength of effects may differ [10, 11].

OSS teams as inherently open entities with a diverse set of members harbor much potential for faultlines and subgroups. Despite the critical importance of joint work in OSS, subgrouping and the resulting configuration as influential phenomena in general group research have, to the best of our knowledge, not received any research attention. We take a first step to addressing this void by investigating the following research question: Does the configuration of contribution-based subgroups in OSS teams relate to success as indicated by community size?

We first provide background information on extant research on OSS as well as faultlines and subgrouping before discussing specific implications in the context of OSS. We then introduce our hypotheses and the method used before reporting results of analysis and discussing implications. Lastly, we provide concluding remarks.

2 Background

In the following, we will briefly introduce extant research on OSS development and subgrouping before discussing the implications of subgroups in the context of OSS.

2.1 Work in Open Source Software Development

The success of OSS is astounding given its organizational challenges. Howison and Crowston (2014) report that organizing OSS is especially difficult for at least three reasons: Challenges presented by distributed work are exacerbated by relying on volunteers, which renders traditional incentive mechanisms ineffective. In addition, the work undertaken in OSS is complex with the associated difficulties [12]. Against the backdrop of previous research on the personality of developers [13], these assertions give rise to the questions which mechanisms help achieve valuable outcomes and why developers join and continue participating in OSS projects in the first place.

The motivations to join OSS projects are manifold. Given its characterization by voluntary contributions [1] and the ensuing absence of monetary remuneration, other causes such as personal motivations prevail. As private benefits, personal need for the developed functions, fun derived from working on the task and learning are key [1]. Membership in the community, the ability to gain reputation, and the possibility to receive job offers are also recurring themes [4]. The strong sense of community is mirrored in OSS participants sharing a common set of beliefs and values [5].

Assuming members assemble in a project, the issue of how work is organized arises. While OSS can be compared to several paradigms of work organization, unique differences are highlighted. Due to its inherently distributed nature, OSS can arguably be related to such teams, albeit results on governance may not be directly transferrable [12]. The voluntary and thus indeterminate nature is mirrored in elements that OSS development shares with agile projects [14]. More testament to the specific type of work accomplished in OSS is given by structural investigations. Typically, a relatively small core of developers contributes the majority of work, which is augmented by the smaller contributions of peripheral members [15]. Considering team composition, strong network ties of developers have been observed to bolster success [16]. For embeddedness of developers and projects, differential effects on success have been observed [17]. Moreover, the proficiency of projects at either developing new features or improving upon existing code has been observed to depend on the structure of collaboration [2].

The presence of a strong sense of community coupled with findings that a core of developers contributes differently than a periphery of developers gives rise to the question on how the configuration of the core relates to success in the larger community. To determine such possible effects, we propose to draw on faultline and subgroup theory.

2.2 Faultlines and Subgrouping

Diversity, i.e. differences in team members regarding attributes such as gender or functional background is found to be conducive to performance in teams by enabling the integration of diverse viewpoints [7]. In OSS, diversity of members has been found to improve some but not all outcomes [8].

Effects of diversity can be explained by so-called faultlines: Latent divisions among members based on characteristics shared by only some [7]. If perceived by members, faultlines are activated and lead to subgroups [18], i.e. several smaller entities within the overarching work teams [11]. For the purpose of this research, the term “subgroup” refers to activated faultlines and is rooted in faultline theory–notwithstanding its use in other contexts.

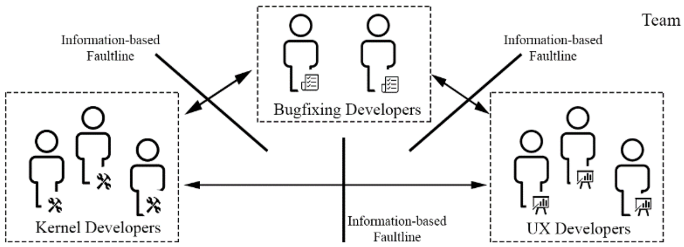

Figure 1: Example of Subgroups based on Information Processing, adapted from [19]

Faultlines and to a larger extent active subgroups have been found to affect team outcomes [9]. Recently, it has been proposed that the reason for subgroup formation may lead to different types of subgroups with different internal processes and thus different effects on group outcomes [11]. Identity-based subgroups due to e.g. differences in age are expected to trigger mostly negative processes, resource-based subgroups due to e.g. status differences harbor the potential for conflict but can boost efficiency, and information-based subgroups due to e.g. different expertise can engender team effectiveness by supporting information processing across groups. Given the need to coordinate knowledge in software development [20], the implications of information-based subgroups could be especially positive. Figure 1 exemplifies the emergence of subgroups based on information-triggered faultlines. The number of subgroups and their balance in terms of membership size, i.e. equally split versus imbalanced subgroups, also influence subgroup effects with e.g. an imbalanced configuration of geographically dispersed members leading to negative effects [10, 11]. Empirically, a complex interaction of subgroup formation, configuration and team outcomes has been observed [21]. In particular, software engineering practices may change subgrouping and its effects [19, 22].

2.3 Faultlines and Subgroups in Open Source Software

Considering the importance of commonly held values and community in OSS [5] and the observed effects of subgrouping raise the question whether harmful or positive effects of subgrouping occur in OSS. To this end, we provide an initial, non-exhaustive assessment of faultline types in OSS development.

By communicating through electronic means, members of OSS projects have limited possibilities to observe characteristics of their peers [8]. Faultlines based on *demographic attributes* may not be perceivable and thus irrelevant–unless members include demographic information in their public profiles. In fact, demographic attributes have not been found to be prominent among members [23].

Motivations to join OSS projects are manifold and thus harbor potential for splitting groups along identity-based faultlines. It could, however, be the case that like-minded individuals cluster in homogeneous groups. Motivations have been found to differ also based on project characteristics, i.e. size [24], which then would attract a specific type of developer. Since membership may not be fully determined by a single motivating factor and projects may cater to more than one need, e.g. enabling learning and at the same time providing opportunities to build reputation, motivation is likely to lead to identity diversity and thus faultlines in OSS projects.

Experience in OSS development in general and the specific project is expected to present an information-based faultline. Differences in professional experience are documented as faultlines [25], additionally in the context of OSS distinct differences in knowledge, which arguably is related to experience, are described [8].

Reputation as an individual’s social status is important in the social fabric in OSS [26]. Reputation as the congruence of promised actions and actual behavior [27] is multi-faceted such that positive views in technical aspects can be coupled with negative social evaluations. Given this multidimensionality and basis for authority [8], reputation is likely to differ for an individual between projects and for individuals within one project. These differences are expected to lead to a hierarchical structure and thus resource-based subgroup [11].

Differences in *activity type* are well-established differentiators in OSS projects and thus a likely faultline item. First, users and developers differ, where users mostly consume and at most make small contributions such as bug reports or minor changes, whereas developers contribute all major code advancements [8]. Within the set of developers, a hierarchy consisting of a core and more peripheral developers has been described: A set of core developers has a disproportionate share of contributions, which entails more influence and reputation, whereas a large number of peripheral developers contributes relatively little code [15].

The *extent and persistence of contributions* is another potential faultline. The overall amount of activity is expected to be an influential member characteristic. Abstracting from the specific contribution behavior, the core-periphery structure of OSS projects [15] is based on the extent of contributions. Activity is an antecedent to previously discussed characteristics such as experience and hierarchy. In addition, by contributing continually, members can build knowledge, which is a key criterion for advancing to more central roles [15]. Drawing on research into other open collaborative processes, roles are expected to be identifiable but flexible over time [28]. A subsequent reduction in activity may thus demote members from the core to peripheral contributors.

3 Hypotheses

We propose a set of hypotheses to investigate the correlation of the relative size of subgroups based on high reputation, issue focus, high contribution extent, and high contribution persistence and success of OSS projects as defined by community size.

3.1 Success in OSS

Success in OSS is not dependent on a single characteristic. The multi-faceted nature of OSS success is evident from the proposition of frameworks to assess success based on diverse indicators [29]. Following previous application [29], we use the size of the non-core OSS project community as an indicator of its external success since contributions of peripheral members are valuable to maintain the project [8]. The onboarding mechanism, i.e. to integrate new developers into the project has been described to be a difficult issue in OSS [6]: Community size is thus apt to indicate how well a project cannot only garner attention but recruit contributors, who potentially can advance to the core team. Based on the preceding discussion of characteristics prone to lead to faultlines and subgroups, we derive hypotheses on the relations of a selected subset of bases for subgrouping that are deemed relevant for community size.

3.2 Hypotheses on the Configuration of Subgroups in OSS Core

For the hypotheses on the relations of the relative size of subgroups defined by faultlines, we draw on findings concerning the stable yet dynamically changing roles in open collaboration [28]. Discussions on the type of potential subgroups and their related effects draw on the typology suggested in [11].

Reputation has been described as an individual's social status in OSS projects [26]. Drawing on extant research in subgrouping, differences in reputation can be related to hierarchical differentiation, which can lead to negative outcomes as resource-based subgroups [11]. At the same time, without perceptions of unfair distribution, a hierarchy can facilitate information processing and thus aid group performance [30]–which relates to potentially positive information-based subgroups. In the context of OSS, reputation has been found to increase trust and satisfaction in members [27, 31]. Considering virtual teams, trust in turn has been observed to increase participation and community activity [32]. Reputation may also facilitate the progression from observing user to contributor with decision power [8] through satisfaction, which leads to participation intentions [27]. In addition, since we focus on the size of the peripheral community as dependent variable, the presence of high-reputation individuals in the project core may signal credibility [27], which may help to attract new members.

H1: The relative size of the subgroup of high-reputation individuals in an OSS project will be positively correlated with community size.

Issue Focus: Different activity backgrounds lead to the potential of information-based subgroups, which can be positive [11]. A large share of issue-focused contributors, i.e. with most activity in creating and commenting on issues, is expected to foster community size. Reporting issues is a known pathway to transition from user to core contributor [33] since issue reports require less specific technical and project-related knowledge than code contributions. With commenting also being part of issue focus, a large share of issue-focused members implies many members may still be starting out as contributors or many people are helping others into the project by sharing knowledge through comments. Core members commenting on issues of newcomers is comparable to mentoring, which has been found to aid onboarding [34]. In addition, a large subgroup based on such behavior may send positive signals of a collaborative culture to outsiders and consequently make the project more attractive.

H2: The relative size of the subgroup of issue-focused individuals in an OSS project will be positively correlated with community size.

Contribution Extent: While rather general, the extent of contributions in projects is expected to foster success and to generate follow-up activity. Similar to reputation, past contributions in a project act as an outside signal of activity and maintenance–as opposed to a majority of OSS projects that are effectively abandoned [3]. Such signals may sway outsiders to become part of the peripheral network. Activity in and of itself is positive in OSS, which is witnessed by an emphasis on practical work in core beliefs [5]. The importance of activity for community building is mirrored in the finding that updates on activity are a key reason for following other members [35]. In addition, for acquiring new casual contributors, a large share of highly active contributors can make it easier for newcomers to identify who to turn to and ask questions and whose work to study to overcome issues related to a lack of replies found in onboarding [6]. In this sense, a large share of members in a high-activity subgroup may foster efficient processing as a knowledge-based subgroup [11].

H3: The relative size of the subgroup of extensively contributing individuals in an OSS project will be positively correlated with community size.

Contribution Persistence: Analogously to contribution extent, we expect a large share of persistent developers to aid community size. The presence of persistent contributors shows a project is actively developed and thus increases its attractiveness. Past activity may inform future activity [36] and thus benefit future contributions. In addition, persistent developers may be easier to identify and the likelihood of responses are increased, which can address the onboarding issue of receiving no reply from core members [6].

H4: The relative size of the subgroup of persistently contributing individuals in an OSS project will be positively correlated with community size.

Control Variables: To control for systematic differences in OSS projects, we include project age and the existence of previous releases as control variables. Project age is used to control for lifecycle aspects [37] and to capture related effects such as integration in the OSS community, access to resources and progress [38, 39]. As a binary control, the previous existence of releases is used to control for projects that while being actively developed do not declare official releases.

4 Method

4.1 Sampling

Data on OSS projects was obtained from GitHub Archive and a copy of the GHTorrent data on Google BigQuery. We included projects that had at least 100 pull requests or at least 500 commits and at least 2000 comments between January 1st 2014 and August 31st 2017, yielding 6037 projects of which we drew a 10% random sample. Controlling for name changes, the sample contained 580 projects. Since success is expected to be the result of collaboration we followed extant OSS research [37] and applied a lagged structure: Independent variables are collected from a six month timeframe in the middle of the project lifetime, community size in the following six months and control variables in the preceding six months. Sample size was reduced to 482 based on a sufficient level of activity in the reference period and the removal of two outliers showing an extreme level of activity not representative of the majority of projects.

4.2 Operationalization of Measures

Community size as a measure of external interest and thus success, see section 3.1, is operationalized as the extended development community [29] and implemented as the count measure of individuals associated with the project without being part of the project core. *Reputation of developers* is calculated as the prestige actor proximity index [40] by measuring how connected and how close an individual is to other members. This is a more elaborate approach than the one used by [26] to assess OSS reputation. Links between members are inferred by analyzing the sequence of users' comments, their quotes and direct references in discussions. The index increases with the number of reachable developers and if developers, which are directly or indirectly connected, get closer. *Contribution extent* is operationalized as an individual's share of overall project activity during the period of investigation, in terms of comments, issues, commits, and pull requests. This measure is inspired by previous constructions of developer-activity pairs in networks [2]. *Persistence* of an individual is operationalized as the share of periods with activity in all periods since the individual's first contribution. Following previous research classifying contribution types in OSS [2], *issue focus* shows the relative share of issue-related activity in an individual's contributions. It is operationalized as the ratio of the number of issue-related contributions to a project, e.g. issue reporting and commenting, compared to an individual's overall contributions to the project. We were, however, unable to reliably distinguish comments from issues to those to pull request, which may skew results.

Table 1 Operationalization of Measures

Measure	*Operationalization*	*Calculation*
Community size [Success]	Extended Development Community of p as sum of non-core members i_p^{nc}	$S_p = \sum i_p^{nc}$
Reputation	Connectedness and closeness of developer i to other developers j through comments, quotes, and direct references	$P_{ip} = \frac{I_i/(g_P - 1)}{\Sigma_j d(j,i)/I_i}$ I_i Number of nodes reachable from i g_P nodes in project p $d(j,i)$ distance of j to i
Contribution Extent	Share of i of overall activity in project p	$CE_{ip} = \frac{C_{ip}}{\Sigma_i C_{ip}}$ C_{ip} *Number of Contributions of i to p*
Contribution Persistence	Share of periods with activity since initial activity.	$CP_{ip} = \frac{A_{ip}}{S_{ip}}$ A_{ip} *# of periods with activity of I in p* S_{ip} *# of periods since first contribution of i to p*
Issue Focus	Share of issue-related activities in an individual's contributions	$R_{ip}^{issue\ focus} = \frac{C_{ip}^{issue}}{C_{ip}^{total}}$ C_{ip}^{issue} *# of issue-related contributions of i to p*

4.3 Analysis

For the independent faultline measures, we restricted analysis to the core project based on an activity threshold of twenty contributions. Since the count-based raw scores are prone to project-specific skews, values of faultline measures are normalized first. Drawing on previous findings concerning the specific effects of the relative size of subgroups [10], we operationalize the size of theoretically derived subgroups as the share of team members deviating more than half a standard deviation from the project median. Core members of projects can thus belong to either the high or low-value subgroup on the respective measure. This calculation is done for each independent variable. With the dependent variable being a count measure, Negative Binomial Regression (NBR) has been chosen as regression method.

5 Results

Table 2 Correlations of Variables

	High Reput.	Issue Focus	Contrib. Extent	Contrib. Persistence	Proj. Age	Comm. Size
High Reputation	1					
Issue Focus	-0.21***	1				
Contrib. Extent	-0.29***	0.29***	1			
Contrib. Persistence	-0.13***	0.16***	0.20***	1		
Project Age	-0.03	0.07	0.10**	0.26***	1	
Community Size	0.09*	0.00	-0.17***	0.10**	0.08*	1
Note:	*p<0.1; **p<0.05; ***p<0.01					

Correlations of variables–shown in Table 2–are relatively small with the maximum value being .29 in absolute terms. The direction of correlations is, however, worth mentioning: the share of members with high reputation is negatively correlated with all other measures, whereas all other correlations are positive. Table 3 details the regression models. The first model only includes the subgroup measures as independent variables, whereas the second and third one add the control variables project age and whether there have been releases in the project. The control variables do not change the direction of correlations but influence levels of significance. While we expected the attribution of members to subgroups to be meaningful for community size, the information content of the model is rather low judging from the pseudo R^2 values.

H1 regarding the effect of a large share of members with high reputation is partly supported: We observe a positive albeit insignificant and small relation.

H2 regarding the effects of a large share of members with a focus on issue activity is likewise partly supported with a small positive, albeit insignificant relation.

H3 regarding the effect of a large share of extensively contributing members is not supported with a highly significant and strong negative relation.

H4 regarding the effect of a large share of persistently contributing members is supported with a significant and strong positive relation.

Table 3 Results of Regression Models

Model	Community Size (Number of Non-Core Members) 1	2	3
Relative Size of Subgroup of Members with			
High Reputation	.621*	.411	.413
Issue Focus	.377	.307	.317
Contribution Extent	**-2.176*** **	**-1.926*** **	**-1.959*** **
Contrib. Persistence	**1.283*** **	**1.304*** **	**1.201*** **
Releases		**.491*** **	**.484*** **
Project Age			.001
Constant	**4.797*** **	**4.482*** **	**4.171*** **
Pearson Dispersion	1.257	1.228	1.26
Pseudo R^2 (McFadden)	0.007	0.011	0.011
Pseudo R^2 (Nagelkerke)	0.076	0.117	0.121
Observations	482	482	482
Log Likelihood	-2,762.340	-2,751.393	-2,750.319
theta	.804*** (.046)	.834*** (.048)	.837*** (.048)
Akaike Inf. Criterion	5,534.680	5,514.786	5,514.639
Note:	*p<0.1;	**p<0.05;	***p<0.01

6 Discussion

Based on the characterization of work in OSS projects and theory on faultlines and subgrouping, we investigated the relation of contribution-based subgroups and community size as a measure of success. While the applied regressions explain only a small share of variance, large sets of core members with high reputation, a focus on issues, and especially persistent contributions positively relate to community size. A large share of extensively contributing members is significantly negatively related.

As expected, a large share of high-reputation core members has a positive but small and after including controls insignificant relation with community size. With reputation being a key aspect of OSS culture [5], we expected the resulting differences in power, resource access and status to be attenuated by the culture of OSS work and thus to lead to a positive relation. Results suggest, however, that reputation may also in OSS projects lead to negative repercussions–possibly due to an identity- or resource-based subgroup. This relation may interact with the hypothesized positive effect. Operationalized as a social proximity measure, the positive finding is in line with previous work on the positive effect of internal cohesion for OSS success [37]. Structurally speaking, a larger share of developers with more direct access to other core members positively relate to community size. Drawing on previous research describing a positive effect of loosely coupled, decentralized developers for design as opposed to technical work [2], the expected signaling effect of high-reputation projects may draw in peripheral contributors–whereas the technical work of closely related core contributors may trigger feelings of inaptitude and thus present barriers to onboarding [6, 41]. Previous findings thus help interpret the only partly expected findings. In addition, reputation based on the distance of the social network may not be perceivable to outsiders and thus reduce the expected signaling effect. The current operationalization of reputation may overestimate values of members being in constant exchange with others without adding value to the project. Investigating other metrics, e.g. formal collaborator status, thus seems worthwhile.

The positive relation between a larger share of members focusing on issue activity and community size is relatively small and insignificant. With a grain of salt, this result may be interpreted as slight proof of the proposition that issue-focused core members foster community size as defacto mentors helping to overcome onboarding issues [34]. Moreover, supporting others as a core value in OSS [5] could propel membership. This line of reasoning has, however, to be questioned since the correlation between the share of high-reputation and issue-focused individuals is slightly negative. The small effect size may be due to our specific threshold values for considering members part of the project core as it could have included too many contributors and thus left no room for outside community. In addition, as stated before, the operationalization of issue focus suffers from the inability to classify some comments. Effects may be more reliably tested if the content of contributions was to be analyzed in more detail: In particular, the community building effect may be identifiable if responses to activity by non-core members were studied in particular.

The relations of contribution extent and persistence are somewhat surprising: Persistence is–as expected–significantly positively related, while extent is significantly negatively related. The correlation between the two measures is weak, which implies they capture distinct contribution types. Persistence might not only be the sum of contributions over time but may signal activity, future maintenance, and thus value in contributions to outsiders. It might also imply technical proficiency and learning forming part of the OSS culture [5]. Seeing sense in one's contributions can be related to the intrinsic motivational factors as key drivers of OSS membership [1, 4]. Persistence might thus signal a project is worthy of contributions. Extensive contributions on the other hand are operationalized by the overall activity of individuals. A large share of extensively contributing core members might create the impression of a closed circle and thus deter contributions–relating to the finding that newcomers face barriers in where to start contributing [6]. In addition, the negative correlation of contribution measures and high reputation is noteworthy since it may imply that contribution quality by high-reputation individuals is distinct from quantity.

This research provides initial evidence that the relative size of subgroups in OSS projects may have differential effects based on underlying faultlines. Findings on positive relations add to existing research on the onboarding of new members [6, 34] by outlining potential levers for action. It seems plausible that persistence and issue-related work can act as mentoring and thus as means to help newcomers get started [34]. For OSS practitioners, analyzing and possibly steering the observed relations may be helpful for increasing community size and thus potential human capital in their projects. Results also add to the discussion on the effects of balanced versus imbalanced configurations of subgroups [10, 11]. Our findings indicate that a larger share of members as an imbalanced configuration may have positive outcomes. Results further add to research on the differential effects of subgroups depending on their reason for formation and typology [11, 21].

7 Limitations and Future Research

This research is only a first step towards understanding the configurational properties of OSS members based on faultline and subgroup theory. There are several limitations, which in part may also explain the low pseudo R^2 values. A significant set of limitations arises from the choice of sampling and model specification. First of, the filtering criteria for including projects may have skewed results. In addition, the choice and operationalization of variables affect results. As faultline and subgroup measures, the entire breadth of characteristics studied in group research and psychology are conceivable. While carefully developed, operationalizations may not capture the phenomenon under study as expected. As an example, the operationalization of success as community size is just one option considering propositions to operationalize OSS success in multiple dimensions [29]. Furthermore, the inability to classify some comments may have skewed results. We strongly encourage further research using additional variables and testing the applicability of other operationalizations. Data has been collected during a limited timeframe using a lagged structure, which may have reduced explanatory power, especially if the timeframe studied was not representative for longer running projects. To inch closer to causal inferences, other methodologies such as experiments or mixed method approaches may be beneficial.

The distinction between core members and community poses two issues. Firstly, the threshold of attribution of members to either group may skew results. The operationalization may conflict with the observed fluid nature of OSS teams [23]. Secondly, we have studied relations of the share of members in the core team on the size and the extended community. This implies that all effects are indirect across the boundary of the core team, which may have caused some unexpected results.

Addressing these limitations and investigating additional aspects are promising avenues for future research. The effects of faultlines and subgrouping in virtual, loosely coupled groups warrants further exploration. In addition, investigating the effects of subgroups on outside individuals seems promising. Moreover, it may be worthwhile to investigate interaction effects between the proposed subgroups. As an example, the share of members with a combination of high reputation and issue focus would further the investigation of the proposed onboarding mechanism provided by these factors.

8 Conclusion

Open Source development has become an established organizational way of building software. Performance effects of faultlines and subgroups are commonly discussed in team research. While most subgrouping is described to be detrimental for team outcomes, more recent works have proposed to consider different basis for subgrouping and their configuration. We have investigated the faultline-based subgroup concept in OSS projects by first identifying characteristics that may trigger faultlines and subgroups. This assertion is the basis for the empirical investigation of the relations of community size and the relative share of core members belonging to subgroups characterized by high levels of reputation, focus on issues, and extent as well as persistence of activity. We find significant relations with the size of the extended project community by contribution persistence and extent and positive albeit insignificant relations of a large share of members with high reputation and issue focus. Our results add to extant research on subgrouping and their configurational properties. In addition, they provide an additional step towards understanding how success as community size of OSS projects can be fostered.

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[redacted] P3: A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking

Table AX3: P3: A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking

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A Human-Centric Approach to Digital Innovation Projects in Health Care: Learnings from Applying Design Thinking

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Abstract

Digital innovation is described to harbor great potential to improve health care. Yet, much of this potential has not been realized. A number of context-specific factors are described to limit implementation of innovative digital solutions. To attenuate these limits in development, we propose a human-centric approach using elements of Design Thinking. We follow a design science research approach using two cases of digital innovation in health care. Based on qualitative and quantitative evaluations performed with care givers we used an iterative prototyping approach to create digital artifacts aimed at improving the underlying health care processes. We detail the research processes of an augmented reality smart glass application for documenting chronic wounds and a smartphone application to support dispensing medication. Based on the exemplary cases, we derive process learnings on applying Design Thinking methods to digital innovation projects in health care.

Keywords: digital innovation, design thinking, health care, human-centered innovation, information systems, design science, augmented reality

Introduction

Adoption of information systems as a class of digital innovation has been praised to enable a plethora of positive developments in the provision of health care. Multibillion dollar savings, improved quality of care, and a reduction in fatalities have been touted as potential benefits (RAND 2005). Nonetheless, as of 2017, health care expenditure is on the rise in many countries and equality in access to care is an open issue (OECD 2017). Given this assertion, the question of why there has been no adoption of systems leading to these effects arises. Already with the initial proposition of these benefits, obstacles to adoption that may make these gains unattainable have been voiced (RAND 2005).

As a specific aspect of digital solutions in health care, electronic health records have been in the research limelight. While a federal push in the US for adoption with the aim of widespread use by 2014 could be expected to aid adoption, the opposite became true: Compared to before the federal initiative, outright resistance of physicians to adopt electronic health records has increased (Ford et al. 2009). In addition to fledgling political incentives, the specific setting of health care delivery as the point of use also contributes to difficulties in adoption. As an example, organizational characteristics have been found to play an important role in adoption and implementation of ICT in health care (Cresswell and Sheikh 2013).

In addition to the described organizational and political aspects, health care processes differ from business processes such as inventory management in that they are all centered on caring for a human being. Put differently, health care is inherently human-centered. This implies that potential changes cannot only be evaluated regarding efficiency gains, but implications for personnel and patients also have to be taken into consideration. This view foots on research describing use of technology in health care as very much a social process (Holden 2013). Consequently, research has called for sociotechnical approaches to adequately balance technical requirements with the specific work necessary in health care by putting the user first (Berg 1999). This assertion raises the issue what shape such user involvement should take: While developers may be convinced they act on users' interests and wishes, users may think differently and feel not adequately heard (Martikainen et al. 2014). This observation is attributed to the lack of iterative feedback on what developers have made of user suggestions.

Taken together, the described hindrances lead to the question how the specifics of health care services, especially their human-centered nature, can be adequately considered in digital innovation projects. We suggest to use Design Thinking to provide a more human-centric approach to digital innovation projects in health care. Design Thinking focuses on human-centered innovation (Brown 2008) and seeks to balance requirements regarding human needs, technological feasibility, and business viability. In this paper, we describe how methods described in Design Thinking can help spur innovation in health care. Embracing Design Thinking methods in the process has important repercussions on the resulting output. We illustrate our approach based on two innovation projects in health care and suggest guidelines how to exploit Design Thinking to improve digital innovation projects in health care.

Theoretical Background

Digital Innovation in Health Care

Being an integral part of people's lives, the provision of health care is continuously challenging and susceptible to a wide variety of effects. Shifts in the population, e.g. longer life expectancy or levels of obesity, pose challenges for health care (OECD 2017). A related yet separate issue are costs associated with health care, which have increased substantially in many industrialized countries (OECD 2017). Process deficiencies, for example in the quality of electronic patient records, have been found to also affect employee satisfaction (Maillet et al. 2015).

Non-care-related processes make up for a significant part of working time. A nurse can only allocate about 19% of work time to patient care activities, while care coordination and documentation take up 56% of the work time. These issues do not only pertain to nursing staff, physicians are affected as well (Füchtbauer et al. 2013; Hendrich et al. 2008). Based on these figures, improving process efficiency seems to be a promising endeavor to enable physicians and nurses to spend more time on the core activity of patient care. Moreover, the call for increased equality in access to health care (OECD 2017) can be supported by freeing up valuable time of health care professionals and reducing the personnel costs incurred-effectively reducing overall cost of treatment.

The very existence of these challenges in health care and the call for more efficient practices lead to the question how innovative remedies may be developed and implemented and what obstacles inhibit progress. Information systems have been described to have great potential to improve health care (RAND 2005), but this potential has not yet been leveraged for e.g. ergonomics reasons (Holden et al. 2012).

An impediment is the highly regulated yet flexible nature of health care. Given its literal life-or-death importance, adherence to processes is sought while at the same time, flexibility in care is needed to accommodate each patient's specific needs (Fichman et al. 2011). These bipolar requirements may require much effort to adequately deal with in development. In addition, while developers are convinced to act on health care professionals' needs in information systems, the user group may feel left out

(Martikainen et al. 2014). Even if new systems are procured, adoption in terms of use may be problematic. Health care provision is a multidisciplinary endeavor and personnel may show resistance to new systems, which due to hierarchical structures can proliferate (Fichman et al. 2011). Organizational characteristics have been named as important aspects of implementation and adoption of information systems (Cresswell and Sheikh 2013). In addition, organizations may exhibit a perception of imbalance regarding opportunity and risk (Fries et al. 2016). Conversely, information technology has been found to enable and shape control within organizations (Wiesche, Bodner, et al. 2013). Moreover, interaction between patients, caregivers, and ICT are described to influence each other (Grisot et al. 2014) and use of information systems is seen as a social process (Holden 2013), which implies potential solutions need to consider and work in the context of these social interactions. These interactions may result in unintended use in e.g. workarounds , which can bolster performance (Röder et al. 2014) and could be considered explicitly in designing the processes (Röder et al. 2015). Critical support of all stakeholders has been found to be a greater risk than technical issues (Schreieck et al. 2017).

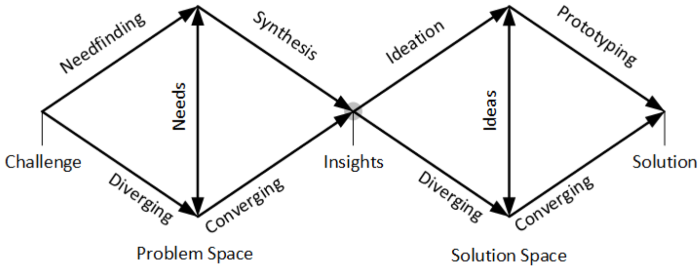

Figure 1 Double-diamond shape of a Design Thinking Project, based on Design Council (2015)

Design Thinking

Design Thinking is a methodology to achieve human-centered innovation while ensuring technical feasibility and economic viability (Brown 2008). Innovation is human-centered when the needs and wishes of users are the main determinants of its development. Design Thinking is a collection of several methods originally used by designers, which are now applied to management problems (Brown 2008; Johansson-Sköldberg et al. 2013; Martin 2009). A Design Thinking project can be represented by the double diamond consisting of the problem and solution spaces (Design Council 2015)–see Figure 1. Within each space, a diverging, i.e. explorative, phase that widens the space is followed by a converging, i.e. defining, phase that narrows the space. A challenge, i.e. a statement on the problem to be tackled, is the starting point into the problem space. Needfinding is used to get in touch with users and to discover needs related to the challenge. In order to synthesize the information gathered throughout the Needfinding phase, insights are formulated during the following converging phase. Insights provide the starting point for ideation and open up the solution space. The collection of feedback from user testing of prototypes allows to converge towards a final solution. Closely monitoring user needs has been found to be helpful in a plethora of instances, e.g. for educating health care workers (Klinker et al. 2017).

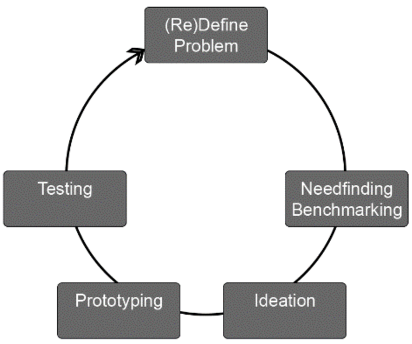

Figure 2 Microcycle of activities in Design Thinking, based on Hehn et al. (2018)

Within these broad phases, an iterative cycle of five steps is completed several times (Stanford d.school 2010). As can be discerned from figure 2, the (current) definition of the problem is followed by the discovery of unarticulated user needs, which then inform ideation to develop new ideas. Prototyping and testing of these ideas allows for learning to what degree the needs to be targeted have been fulfilled– which allows for a new, more concise problem definition that restarts the cycle. In each step, sets of different methods can be harnessed, but should be tailored to the specific situation to prevent e.g. dysfunctional behavior (Wiesche, Schermann, et al. 2013). Examples that can be applied in needfinding include ethnographic observations, i.e. surveying behavior of people in the field (Emerson et al. 2011), interviews (Kvale and Brinkmann 2009), and personas, i.e. abstract representations of idealized user groups (Pruitt and Grundin 2003), for synthesis. In ideation for example traditional brainstorming (Rossiter and Lilien 1994) or derivatives such as brainwriting (VanGundy 1984) can be used. In the prototyping phase, projects start with low-fidelity prototypes, e.g. paper prototypes, which already provide a suitable medium for discussion (Vetterli et al. 2016), are iteratively tested and refined to reach high levels of fidelity at the end (Hehn et al. 2018; Stanford d.school 2010). User testing is supported by methods such as observation frameworks (Hanington and Martin 2012). Synthesized test results from the field allow for restarting the cycle.

Method

We studied the adoption of Design Thinking for digital innovation projects in health care following a design science research approach using empirical data from two cases in health care–the documentation of chronic wounds and dispensing prescription medication. In each case we used Design Thinking methods throughout the innovation projects to foster human-centricity and develop innovative ideas, which were picked up in the following development phases.

Design Science Research

We followed the methodology of Design Science Research to implement and evaluate two digital prototypes in our case settings (Gregor and Jones 2007; Peffers et al. 2007; Sonnenberg and vom Brocke 2012). Focusing on human-centric innovation, we applied Design Thinking methods, which in their aim for artifacts and meeting user needs contrast the prescriptive approach of Design Science, throughout the process. Design Science Research commonly follows a two-step build-evaluate process, i.e. to build an artifact and test whether it adds value in practice (Gregor and Jones 2007; Peffers et al. 2007). Recently, continuous evaluations of the artifact and its evolution have been proposed (Sonnenberg and vom Brocke 2012). To this end, a step-wise cyclical procedure of four evaluation stages, in which knowledge on the artifact and the process co-evolve, has been proposed (Sonnenberg and vom Brocke 2012). The first two phases focus on the definition of a concise problem statement and design objective, whereas the latter focus on evaluating the artifact's practical relevance (Sonnenberg and vom Brocke 2012). Especially within the rigid-yet-flexible health care context, the need to learn about the use case and to adapt the technology to be implemented has been highlighted (Fichman et al. 2011). While proposing a general model of such a process, Sonnenberg and vom Brocke (2012) do so devoid of information on which methods may be suited to obtain which type of information. Following the propositions made by Sonnenberg and vom Brocke (2012) to generate knowledge on both the artifact and design decisions and process results, we detail the exploratory use of Design Thinking methods regarding both artifact outcomes as well as procedural learnings.

Case Selection

Within health care settings, the processes wound documentation and dispensing prescription drugs were identified in the research process. Following the case study design proposed by Yin (2011) for general structure, we engaged in ethnography-type studies during several weeks in hospitals and elderly care facilities. Condensing and analyzing our minutes, these two processes stood out as bearing much potential for improvement for two reasons: Both are currently mostly manual tasks without significant support by information systems. Improvements are of practical relevance since both processes are carried out frequently, which makes even small improvements relevant. Moreover, both exhibit the bipolar nature of being tightly defined while showing the need to act on context-specific information.

The two processes differ, however, on the need for mobility and aseptic use: wound documentation is mobile and aseptic, whereas dispensing drugs is non-critical on either dimension.

Results

Table 1: Overview of Research Phases in Innovative Health Care Project Cases

Research Phase	**Documentation of Chronic Wounds**	**Dispensing Prescription Drugs**
User Observations	2 weeks in hospital 2 weeks in elderly care home	1 week in hospital 1 week in elderly care home
Initial Ideation	High-resolution tablet app akin to current paper documentation	Google Glass displaying information on patient medication
First user feedback	Workshop for hands-on evaluation	Trial in hospital setting
Requirements specification	Solution needs to be usable hands-free during wound treatment	Digital replication of analog process not sufficient
Prototype I	Smart glass (Vuzix) with voice commands for hands-free use	Smart glass and smartphone paper prototypes
Evaluation I	Workshop with wound management experts to evaluate fulfillment of requirements	Workshop with nurses to identify appropriate device
Prototype II	Smart glass (HoloLens) with functionality of Prototype I	Smartphone application with parallel dispensing per medication
Evaluation II	Workshop with wound management experts to test ergonomics	Test with non-professionals and students concerning usability
Final prototype	HoloLens application with 3 interaction designs and semi-automatic wound measurement	Smartphone application for dispensing per medication, ex-post matching with patients
Evaluation	Experiment (n=45) on interaction design	Experiment (n=14) on efficiency and error reduction.

In the following, we report on the two digital innovation projects that applied Design Thinking methods. While the resulting artifacts provide a contribution to digital health care innovation research, we take main interest in learning about the process that produced the artifacts and co-evolved with them. Thus, the following results focus on how the Design Thinking method was applied.

As can be discerned from Table 1, we followed an iterative approach consisting of alternations of prototyping and evaluation phases. While we instantiated a Design Science approach, our intention to augment it with methods from Design Thinking led us to label each phase neutrally based on content. Initial ideation in both cases followed a pure Design Science approach and comprised high-resolution prototypes. Negative feedback on both prototypes showed they were over-engineered for capturing early feedback and strengthened the case for iteratively advancing prototypes instead of presenting a finished artifact. Starting with prototype one, rough prototypes continuously evolved with changes becoming smaller and more targeted with each iteration. A main learning has been to achieve a balance of the lowest possible resolution while still achieving insightful feedback. While the first user feedback on initial ideation aims at the later stages of the model proposed by Sonnenberg and vom Brocke (2012), the lessons learned in these tests and the subsequent early prototypes were used to obtain a concise problem statement and design objective-which roughly matches the earlier phases of the model (Sonnenberg and vom Brocke 2012).

In line with Design Thinking methodology, we employed several different methods. To achieve broad and in-depth insights into the processes in the observations phase, we conducted ethnography-style user observations, interviewed representatives of several stakeholder groups, and conducted workshops to capture discussions among professionals. Practitioners' feedback in evaluation phases was used to refine the problem definition for the next phase. In addition to showing our prototypes to practitioners and walking them through core ideas, we also handed prototypes to practitioners without explanation and asked them to "think aloud" and tell us about their perceptions. To capture feedback on specific aspects of our prototypes in a structured way, we conducted experimental studies. Note should be taken that the final prototype in this case does not imply a shippable product, but merely represents the end of the scientific project. The chosen methods primarily support achieving user-centeredness in innovation. The aspects technical feasibility and business viability naturally have been considered but are not the focus of this research. Below, we will describe each phase in detail concerning both the artifacts and procedural implications.

Documentation of Chronic Wounds

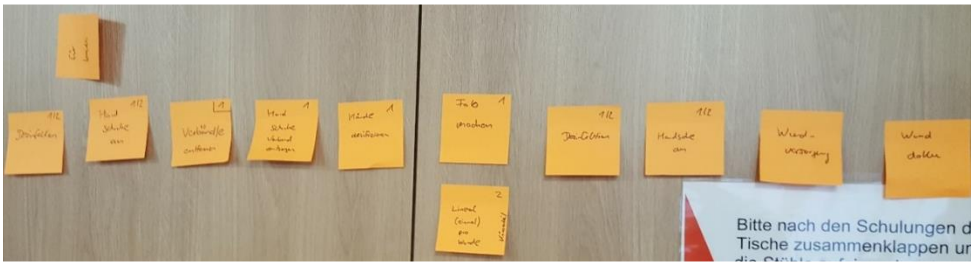

Figure 3 Current wound documentation process

Observations

While time-intensive, the deep immersion using several methods of documentation allowed us to gain a thorough understanding of the processes as they are currently enacted, which is our main methodical learning. Spending 120 hours in elderly care homes and 40 hours in a hospital, we followed health care personnel throughout their routine, observed their actions, took notes, and made photos. In a subsequent step, we assembled all data and analyzed it for key themes. This allowed us to model the current process of wound documentation, which is shown in figure 3. The current wound documentation process is complicated and time-intensive: Health care professionals have to disinfect their hands and put on new gloves several times. In addition, a second person is needed if documentation is to include the length of the wound, which constitutes a key characteristic for assessment. Due to hygienic reasons, wounds are inspected and treated at the patient's bedside while documentation is only done when staff returns to the station room. This implies a considerable amount of time passes between the apprehension of information and its documentation, which carries the risk of a lack of quality in documentation.

Initial Ideation

Based on these learnings, we built a fully functional tablet application that was supposed to address the observed issue of the temporal gap between wound treatment and documentation. This prototype has the main goal of improved documentation quality by providing the ability to document at the patient's bedside without performing any intermediate tasks or having to go to other rooms. In line with previous descriptions of resistance to information systems (Fichman et al. 2011), health care professionals seemed to some extent set in their ways, which led us to make the application resemble the current paper-based documentation. Figure 4 shows screenshots of the tablet prototype.

Figure 4 Tablet prototype

First User Feedback

In a workshop, we had wound management experts test the prototype application and share their thoughts. While they liked the overall idea of documenting in the patient's room, they found a tablet to be impractical. They were concerned to have to change gloves and sanitize hands even more often, if they are to interact with the application at the bedside. Moreover, participants wished for even more immediate documentation during actual treatment. While this initial user feedback was very negative for the fully developed high-resolution prototype, it allowed us to identify additional important user needs. We added the requirement that both hands need to be available for treating the patient. Documentation should thus be possible using a hands-free interface–at best during treatment. Moreover, this profound criticism of a prototype we had expected to improve the process led us to strictly embrace the notion put forth by Design Thinking to evaluate only key aspects of artifacts with low-resolution prototypes instead of presenting a high-resolution prototype right after initial Needfinding.

Prototype I

Focusing on the single requirement of hands-free documentation, we developed a first low-resolution prototype on the smart glass Vuzix M100. It can display information in front of one of the user's eyes using a small frame-mounted display. Hands-free interaction was implemented using voice commands (Klinker et al. 2018). In addition, it features a built-in camera that can be used for visual documentation.

We tested the prototype with several wound documentation professionals. The idea of a hands-free documentation system to be used during treatment triggered very positive reactions. There was, however, criticism regarding the technical implementation. Speech recognition was deemed difficult to use in loud environments. In addition, the camera resolution was found to be inadequate for documentation. Ergonomics were also a point of criticism. Participants deemed the prism too small to look at and reported the one-sided design to be unbalanced–triggering the fear of losing the smart glass. From a process perspective, the positive evaluation of the core functionality we intended to implement is perceived as supportive of our use of low-resolution prototypes for targeted testing of single features.

Prototype II

Prototype II focused on alleviating the negative feedback concerning the hardware design of prototype I. Since we could not change the Vuzix, we switched to the Microsoft HoloLens. It features a balanced hardware design, has a high-resolution camera and covers both eyes for larger, binocular augmentation. These features are expected to remedy many problems reported with Prototype I. The same set of features that had been available in Prototype I were implemented. As an alternative to speech commands, Microsoft HoloLens allows for using hand gestures to interact with the application.

We evaluated the prototype in a workshop with wound management experts. All participants gave very positive feedback on the feature set and the hardware. Contradicting previous evidence that voice commands are favored (Huck-Fries et al. 2017), there were, however, different opinions on which interaction method is better suited. As a remaining issue, participants noted the necessity to handle a ruler to be able to document the length of the wound.

Taken together, switching to Microsoft HoloLens had the intended effect, which gives credibility to our assumption of hardware limitations. As in the evaluation of Prototype I, the evaluation of incremental changes worked well. Note should be taken that while the feature set was basically unchanged, the evaluation led to the identification of the previously unknown need to be able to measure the wound without additional hardware.

Prototype III

To address the specific issue of having to handle a ruler during wound documentation, we used the HoloLens's spatial mapping abilities to implement a digital measurement function. Setting two measurement points allows the HoloLens to calculate wound length. As shown in figure 5, this functionality was first tested using paper prototypes with colleagues before writing software code. Based on the insight that one interaction design may not be universally optimal, Prototype III can be controlled via voice commands, gestures, or blinking. Blinking is implemented as a wizard-of-oz prototype, i.e. facilitators survey a participant's eyes and trigger clicks remotely. To further improve usability, feedback obtained in the preceding workshop was used to optimize interface elements.

Figure 5 Measurement of wound length using spatial mapping

For evaluating usability of the three interaction modes, we conducted a one-factorial within-subjects experiment with 45 wound experts. Each participant was given the task of documenting different wounds using the random choice of either a HoloLens interaction mode or a paper-based assessment sheet. After each treatment, participants were asked to complete a survey to capture their evaluations. A statistical analysis of the questionnaire data with ANOVA established that all interaction modes on the HoloLens performed significantly better (alpha=.05) than the paper-based treatment resembling current practices. Within the HoloLens-based treatments, blinking is found to be significantly faster than either gestures or voice commands.

In addition to the quantitative analysis, we observed use and collected comments during testing. All data indicates that using the smart glass-based solution for wound documentation is feasible. The correct mode of interaction is, however, an open issue. Blinking received much positive feedback. While some participants strongly favored voice-based interaction, some raised concerns that speaking commands during wound treatment would be unsettling for patients, especially when they are mentally incapacitated, e.g. after surgery. Given technical feasibility, it thus seems optimal to offer a choice of different interaction modes so that users can utilize their favorite mode.

In this last evaluation phase the choice of a tightly controlled experiment coupled with ethnographic observations allowed us to gather rich data and ensure reliability of results, which is of relevance not only to research but also to practice since evaluations can inform adoption decisions.

Drug Dispensing

Observations

Analogously to wound documentation, we conducted ethnography-style user observations using multiple methods to understand which aspects of current processes are non-optimal. We spent one week each in a hospital setting and in an elderly care facility. During this time, we observed personnel in their daily routine, took photos, conducted interviews, and collated these different data sources to achieve a thorough description. The process of drug dispensing exhibits the following characteristics: It is carried out routinely and needs to be performed for most patients, which means even small efficiency gains imply relevant time savings. Moreover, the current process is completely manual.

Initial Ideation

Based on our observations, we assumed the correct matching of patient and drug type to be the most critical issue in the process. To address this issue, we used a Google Glass with an application mimicking the manual drug dispensing process. It uses a sequence of QR codes identifying the patient and the drug to be dispensed. The application then displays the necessary daily doses. In order to continue, a screen summarizing the dispensed amount has to be acknowledged, which should reduce the error rate. While being an exact replica content-wise, we expected the application to help with maintaining focus on the correct matching of drugs to patients.

First User Feedback

The prototype was tested with nine nurses in a hospital setting. The mere replication of the analog process did not perform well. Five of the participants could not complete the process of dispensing drugs. In addition, participants had problems using the interface and expected the device to operate in ways that are beyond its technical capabilities, e.g. to recognize barcodes from a long distance. Process-wise, as in the wound documentation project, the negative feedback on a fully developed solution underlines the call for more frequent testing and evaluations.

Prototype I

Given the very negative results, we rethought the smart glass application from scratch. While the initial prototype built on the premise that finding the appropriate column and lines in a spreadsheet is time-consuming and error-prone, Prototype I redesigns the process by providing step-by-step statements what to do for each patient. In addition, we conceived a smartphone application with a similar feature set. In the smartphone application, medication data is displayed at the top and the middle area shows a live-picture of the drug dispensing aid (DAA) augmented with the number of pills of the current drug to be put in each tray.

The two concepts were tested with nurses in a hospital setting using very low-resolution paper prototypes. The facilitator manipulated the paper mock-ups as instructed by the participant to simulate use of the application. The potential to aid with daily drug dispensing was rated as promising. Regarding technological implementation, a preference for the smartphone application was expressed. The ability to augment the live picture of the DAA to be completed was stated to be especially helpful.

Successful use of very low-fidelity paper prototypes to demonstrate innovative software applications is interpreted to support applicability of Design Thinking methods in software innovation for health care. Moreover, the insight that a smartphone application is more positively received by potential users pre-empted significant amounts of effort that would have been spent on a less than optimal smart glass application.

Figure 6 Example of augmented DAA

Prototype II

Following the user evaluation, we focused solely on the development of a smartphone application. We implemented the functionality described in the paper prototype. Following user feedback, the augmentation of the DAA was changed to include patient and medication information displayed next to the DAA–see figure 6. In addition, the ability to track dosing into up to ten DAAs at a time was added by dispensing by drug type instead of per-patient dosing. To evaluate correct functioning of the prototype, we did trial runs with students. While the overall application concept worked well, there were, however, technical shortcomings. Due to the limited number of visual features on the DAA, object recognition and tracking did not perform satisfactorily. Insufficient lighting or brief obstructions by e.g. hands greatly affected performance. While a reduction in error rates would still be possible, no efficiency gains were to be expected with this implementation.

With this step's trial run with users not being part of the intended target group, we further strayed from common user testing practices but kept with Design Thinking's notion to evaluate a clearly defined function. A sufficient number of students was perfectly apt to uncover technical glitches, which in a final artifact could lead to dismissal of an otherwise advantageous prototype.

Figure 7 Overview of flow in prototype III

Prototype III

In order to address the image recognition and tracking issue, the flow of the application was redesigned. Keeping a per-drug dosing paradigm, medication is now to be placed into non-descript "anonymous" trays that are tracked by position–see figure 7. After dispensing all drugs, the application assigns the corresponding patient labels. The prototype was evaluated in an experiment (n=14) to test for efficiency and error reduction. Participants were asked to dispense drugs using both the prototype and the standard paper-based method. We found a reduction in time of 41% and a 79% decrease in errors. These quantitative results and the positive comments by the testers are seen to be a very positive evaluation.

Table 2: Overview of Characteristics to be Considered in Design Thinking in Health Care

Criteria Class	**Operationalization in Health Care**
Social factors	Little experience in using Information Systems
	IT not used if not aligned with the process
	A lot of repetitive work increases process runs
Domain-specific restrictions	Aseptic use of documentation tool
	Patient safety
	Patient privacy
	Tests with live data difficult
Separation of needfinding and ideation	Need for prepared ideation sessions with examples of tangible domain-specific prototypes
	IT Developers should not guess needs of health professionals
	Users know their pains but not the solution
Innovation Process Agility	Provide opportunities to test prototypes, especially specific aspects
Business perspective	User is not the customer
	Insurance provider
	Health care provider

Learnings on Context Criteria to Consider

Characteristics of health care provision that at first sight can inhibit innovation were identified in ex-ante literature research and in both development projects. Characteristics taken from literature research are included if they have been observed in the two projects, which implies universally applicable factors are included as well. Table 2 provides an overview of these criteria and their abstraction into classes, which were derived by the authors through several iterations of coding.

A key set of criteria to consider relates to social factors. As an example, the fit of information systems with health care workers' workflow has been described as critical (Berg 1999). Solutions thus have to be tested for their acceptance by staff. In addition, some tasks are repeated continuously, which presents an opportunity since even small gains in efficiency can lead to a meaningful reduction in workload. Such optimization potential may, however, be overlooked.

Another important set of criteria to consider are domain-specific restrictions that must be observed. In health care, very detailed regulations and the need to adhere to strictly defined processes limit opportunities to test prototypes in live settings. The next set of characteristics pertains to the process of a health care innovation project. We have learned the hard way that providing full-fledged solutions is not a good starting point for evaluation in initial phases of a project. We spent a total of three months on the tablet application for wound documentation without having realized the key issue of having to disinfect hands. Drawing on Design Thinking, facilitated testing sessions of low-resolution prototypes have in our case performed much better. As observed in the double diamond (Design Council 2015), Design Thinking practices a de-facto division of labor regarding needfinding and ideation in innovation projects. Users hold information on the problem to be solved but do not know about solutions. Developers on the other hand hold knowledge on potential solutions but should not assume needs of their own since they are usually not users. This assertion implies that users and developers have to interact frequently, especially during early project phases. In these interactions it is advisable for developers to bring experienceable artifacts since users cannot articulate their needs but state whether a proposed solution addresses their needs (Stanford d.school 2010).

Discussion

In this research, we have applied Design Thinking methods in two digital innovation projects concerning health care. Both cases have shown advantages of embracing Design Thinking propositions regarding evolving the resolution of prototypes and continuous testing. After several iterations, both prototypes have been evaluated to potentially improve current processes. Using Design Thinking methods in the process has helped in attaining highly promising prototypes. Since health care is an inherently human-centered field, and Design Thinking is intended for human-centered innovation, it has helped us to address issues of actual relevance to the user instead of pushing the most sophisticated technological aspect. The observations we synthesized from the two case studies can help advance innovation in health care by highlighting aspects that may be of critical relevance.

Repeated testing with users in their context of application is seen to have been decisive for the projects' successes. It revealed key points to consider that before had not been seen as relevant or had been unknown. Our results also reiterate the value of testing with low-resolution prototypes at first and then gradually increasing fidelity. Changes have become smaller and more targeted at individual aspects within each iteration. This in turn raises the question of when to stop iterating and consider a solution "final"–an issue which in our prototypical development has not had to be considered. As implied by the Design Thinking double-diamond attributing equal space to problem and solution, we spent nearly 50% of time on precisely identifying underlying needs in early phases. While an undeniable drawback to this approach is the overall time needed before having a detailed concept of a solution, we argue that at least as much time is spent on building high-resolution artifacts that fail to deliver practical relevance. We thus strongly reiterate previous calls for paying much attention to knowledge generated in early phases of development and to have several build-evaluate cycles (Sonnenberg and vom Brocke 2012). Moreover, fulfilling psychological needs of users has been proposed to explain aspects of technology acceptance (Rocznik et al. 2017), which may further help in overcoming stated resistance in health care settings (Fichman et al. 2011).

For work in the problem space, loosely structured methods described in the context of Design Thinking that allow for a holistic representation using rich data have been very helpful. As examples, ethnography-style studies and open try-out experiments with think-aloud feedback allow for assessing much more than just evaluations of aspects of the artifact. Such rich data allowed us to identify some of the criteria presented in table 2. While all of them provide guidance as requirements to be satisfied that go beyond technical considerations, caution should be taken. Considering only some of the sets may result in unusable prototypes–as with the first tablet prototype that was tailored to fulfill all social aspects but missed the context characteristics. The domain characteristics are thus akin to the Iron Triangle of project management in that aspects should be balanced in tradeoff relationships.

Our exploration of how Design Thinking methods can help innovation in health care has several limitations. We have studied only two cases, both of which have been in the domain of in-patient settings. While we expect some generalizability to other settings, context-specific factors such as those described in table 2 could have influenced results. In addition, while having applied some methods and having them found to be appropriate, we do not know whether there would have been better alternatives. We thus call for more research towards assessing usefulness of a diverse set of methods. Since testing prototypes during actual care is hardly possible due to regulations and privacy concerns, most of our tests have been in laboratory settings. While we tried to ensure realistic conditions, simulations inherently cannot encompass all real-world details. All of our testing has taken place in German facilities and thus describe processes in German health care. While we expect key findings to hold in other countries, replicating our simulations and field work in other countries is a worthwhile endeavor.

Our findings contribute to both research and practice. From a research perspective, we have exemplified how Design Thinking approaches such as repeated, iterative testing can help in identifying important boundary conditions for development. Our results shed light on potential weaknesses in standard Design Science research. Especially for human-centered design tasks, extant propositions regarding testing and requirements elicitation may be insufficient and benefit from additions. As an example, testing only at late stages may lead to a waste in development effort and in missing key requirements to ensure human-centered usability. In addition, our collection of characteristics to consider in innovation projects is helpful for subsequent research that can consciously embrace these challenges. On a more abstract level, the presented results can be helpful in developing theoretical extensions to Design Science. Practical contributions are made to both health care IS providers and health care providers. For information systems providers, we have shown what may be promising new systems that can improve existing processes in health care without needing major process redesign. For health care providers, we have shown how information systems can be used to overcome issues in current processes.

Conclusion

Despite their promise of improved processes, adoption of information systems in health care is held back by context characteristics. To overcome this effect, we applied Design Thinking as a methodology for human-centered innovation to two digital innovation projects on chronic wounds and dispensing drugs. In both cases, iterative development of prototypes and testing with users led to the identification of previously missing key requirements. The final prototypes received positive feedback in user experiments and were judged to be apt to improve current processes. We contribute to research by describing characteristics that may be relevant to consider when conducting innovation projects in health care. In addition, we provide practical contributions to information systems and health care by exemplarily showing how user testing helps to develop innovative solutions that address core issues.

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[redacted] P4: Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility

Table AX4: P4: Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility

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Design Thinking in Digital Innovation Projects—Exploring the Effects of Intangibility

Leonard Przybilla, Kai Klinker, Michael Lang, Maximilian Schreieck, Manuel Wiesche, and Helmut Krcmar

***Abstract*—The locus of innovation has shifted from mechanical advances to digital solutions. By emphasizing the importance of user needs, Design Thinking is apt to develop human-centered innovation, including digital solutions. Using two representative examples from 21 Design Thinking projects spanning the gamut of mechatronic to fully digital solutions, we report on critical incidents as opportunities and challenges of applying Design Thinking in a digital context. In the case of mechatronic solutions, we identified opportunities related to improved collaboration and higher quality prototyping as well as in innovative business models, which in turn created challenges in managing stakeholders. In the fully digital context, we observed opportunities in improved needfinding and the ability to offer individualized products. Conversely, we uncover difficulties in imagining digital features, estimating their feasibility, and correctly setting the fidelity of prototypes. Based on these observations, we discuss the intangibility of digital artifacts as enabler and inhibitor of Design Thinking in a digital context.**

***Index Terms*—Creativity, design engineering, design tools, innovation management, project management, research and development management, technological innovation.**

I. Introduction

INNOVATION, that is, changing the status quo and developing new or improved products, services, or processes, is the lifeblood of competitive advantage and thus a key consideration for organizations [1]. In recent times, the locus of innovation has shifted from mechanical advances to digital features [2]–[4]—either as standalone products or as part of hardware- and software-based, mechatronic, solutions. Digital innovation, that is, innovation enabled by software products and services, has specific traits. Unlike physical goods, software is intangible as it integrates knowledge and thought as its main constituents [5].

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Since the increasing shift to value creation in digital features forces "traditional" industries to change their strategy and embrace digital technologies [3], [4], many innovation projects, ranging from optimized internal processes to novel offerings designed to draw in new customers, may naturally lead to digital outcomes. As a consequence, the rapid introduction of digital technologies touches upon nearly every aspect of life [6], which puts it at the heart of several megatrends of our time [7].

Although the gold rush sentiment that digitalization can make anything faster, more efficient, or more user friendly implies infinite possibilities, digital innovation projects still face the issues commonly encountered in innovation. Given the high rate of new products failing in the market [8], [9] and given that innovation is inherently a risky and uncertain process [10], [11], the recent push to start innovation projects based on user needs, instead of technical feasibility, is not surprising. A focus on user needs and the requirement of an elaborate toolset for innovation made approaches such as Design Thinking widely popular [6], [12]. As a methodology for achieving human-centered innovation by addressing actual human needs [13], Design Thinking is applicable to the type of ill-defined or "wicked" problems [14] presented by innovation initiatives. Through its strong emphasis on repeated interaction with users [12], it can tease out what issues should be addressed within a broader problem area. By providing guidance throughout the course of the innovation process and by integrating specific tools, Design Thinking improves innovation outcomes by acting as a social technology [15].

Despite its recent growth in popularity, Design Thinking is not new, but builds on a rich foundation of theories and applications [12], [16]. Rooted in how designers work, Design Thinking encompasses a variety of different processes and tools [12] and is not bound to any specific application area [1], but is meant to address "wicked," that is, ill-defined and hard-to-grasp, problems in a variety of areas [12], [14]. While digital innovation provides new means to tackle wicked problems, making sure solutions address *actual* needs calls precisely for approaches such as Design Thinking [6]. At the same time, the development of digital solutions *is* a wicked problem requiring Design Thinking approaches [17]. Considering the shift of innovation to the digital realm [2]–[4] and given the general lack of research on Design Thinking in innovation [6], we raise the research question: "What are the opportunities and challenges of applying Design Thinking in digital contexts?" In this article, we help to fill this void by reporting on our experiences with opportunities

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and challenges of using Design Thinking in real-world projects set in a digital context.

The remainder of this article is structured as follows: first, we provide background information on Design Thinking and describe our methodological approach. Drawing on critical incidents in two projects representing mechatronic and fully digital projects, we illustrate the key opportunities and challenges of Design Thinking we observed in a digital context. We discuss our findings, especially those concerning the intangible nature of digital artifacts, before ending with concluding remarks.

II. Background on Design Thinking

While the term "Design Thinking" enjoys wide popularity in management [18], there is no commonly accepted definition [12]. Overall, Design Thinking can refer to a discipline, an approach to attain specific aims, or a mindset [12]. Considering the area of application, Design Thinking can either pertain to different, parallel, schools of thought concerned with *designerly thinking* or to separate streams of discussions in management [16]. In our projects, we utilize Design Thinking in the managerial tradition of transferring approaches usually adopted by designers to other domains [13], [16]. The key objective of the most widely referenced managerial application of Design Thinking is to accomplish human-centered innovation, while also maintaining technical feasibility and economic viability [12], [13]. Human-centricity means the needs and wishes of users are the guiding considerations in development [13].

While constituting a distinct practice for problem-solving, Design Thinking does not comprise a clearly defined set of ingredients, but constitutes a "'basket' of tools and processes" [18, p. 925]. Based on insights from industrial practice, Design Thinking exhibits the key traits *user focus, problem framing, visualization, experimentation*, and *diversity* [12]. *User focus* implies adopting an empathic approach, based on rich interaction with users [12]. *Problem framing* refers to practices for working with, for example, restating or further expanding, the problem instead of seeking a solution from the outset [12]. *Visualization* means concepts and results should be made tangible, and *experimentation* calls for teams to iteratively implement, test, and refine ideas [12]. *Diversity* implies that both the team and outside contacts to stakeholders should be varied [12]. A common theme of working in Design Thinking is to embrace abductive reasoning, that is, creating new solutions, in conjunction with the "traditional" inductive/deductive ways of working [12], [18].

Comparing state-of-the-art processes of Design Thinking, such as the ones used by Ideo and the Stanford Design School, yields a common set of core phases [18]. To understand user needs and to delineate the problem to be solved, all surveyed processes start out with an *exploratory phase*, which provides input for the second phase of *idea generation* [18]. The third and last phase aims at creating prototypes and testing them with users, in order to gather feedback for further development [18]. Each of these phases is supported by numerous tools such as ethnographic observation or brainstorming [18]. Notwithstanding a common set of activities, all of the surveyed processes use slightly different terms and structures. For example, Stanford Design School splits the third phase in "prototype" and "test," whereas Ideo uses the terms "experimentation and evolution" [18], [19].

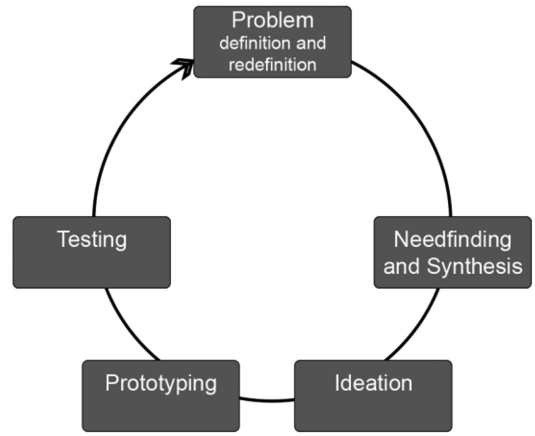

Fig. 1. Design thinking microcycle, based on [22].

In addition to a common structure, all of the processes surveyed emphasize iterating between these steps, harnessing diversity in teams, and involving users [18]. Since these key traits, which were uncovered by comparing process models of Design Thinking, closely align with the criteria found in organizational use [12], we will apply them as hypothetical defining criteria of a Design Thinking process in this article.

As one specific example of a Design Thinking process, we introduce the Design Thinking Micro-Cycle. This process originally developed in the ME310 Design Innovation course at Stanford, where it is called Stanford Design Innovation Process [20]–[22]. The iterative process, depicted in Fig. 1, which we used in all projects underlying this research, covers the steps *problem definition and redefinition, needfinding and synthesis, ideation, prototyping,* and *testing*.

Problem definition and redefinition initiates the cycle by putting forth a goal-oriented, yet solution-neutral, question [22]. *Needfinding and synthesis* harnesses a variety of tools for inquiry and analysis, such as interviews, observations, and frameworks, in order to unveil user needs and to derive precise insights [22]. These insights provide a starting point for *ideation* to generate ideas for potential solutions that address user needs, for example, through brainstorming [22]. *Prototyping* aims to make these ideas tangible by creating a first implementation [22]. Prototypes help to create shared understanding within the project team and to test assumptions, raise new questions, and thus to refine concepts [22]. Early in a project, prototypes should be of low fidelity to allow for testing core ideas [19], [22]. Over time, fidelity should increase to allow for more detailed representations and gathering feedback on details of concepts [22]. As the last step, *testing* calls for handing prototypes to potential users and other stakeholders to establish the validity of assumptions and whether solutions address actual user needs [22]. Testing results, in turn, help to reformulate the problem [22] and thus restart the cycle.

In iteratively applying this Design Thinking process, the relative focus on each step may shift: Early iterations emphasize

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needfinding and gathering detailed stakeholder information to broaden the problem space, whereas later iterations focus on idea generation and testing to establish a final concept [20]. By actively involving stakeholders and testing prototypes to iteratively refine the problem definition, this process exhibits the defining traits of Design Thinking processes described in literature [12], [18].

III. Method

To investigate how a digital context affects Design Thinking projects, we drew on the Critical Incident Technique (CIT), a well-established qualitative research method meant to be flexibly adapted to the context [23], [24]. Since the CIT was first introduced in organizational and industrial psychology, with the goal to make observations of behavior usable for practical purposes such as job assessment [23], it has been applied in diverse areas [24]. Critical incidents are defined as events that constitute extreme behavior or make a significant contribution [23], [24]. We thus deem the CIT to fit well with our intention of providing an explorative account of how a digital context affects Design Thinking projects.

As outlined in the seminal account by Flanagan [23], a CIT study comprises five steps:

1) General Aims.
2) Plans and Specifications.
3) Collecting the Data.
4) Analyzing the Data.
5) Interpreting and Reporting.

In the following, we describe how we instantiated each of the five steps.

The first phase *General Aims* sets out to clarify the scope of the research project [23], [25]. Following our aim to investigate Design Thinking in the digital context, we defined the scope as the opportunities and challenges a digital context evokes in conducting Design Thinking projects.

Based on the *General Aims*, *Plans and Specifications* cover the detailed design of the study such as who is to be observed and how data is gathered [23], [25]. We included 21 Design Thinking projects of three types: research projects as well as long and short classroom projects. All projects incorporated Design Thinking using the previously introduced Design Thinking Micro-Cycle. As detailed in Table I, the projects covered a variety of subjects from a regulated health care context to emergent possibilities in B2C mobility services, and lasted between five months and four years. This variety helped us to establish a comprehensive view of Design Thinking in the digital context. While several projects comprise hardware-based aspects, each project worked on software-based or -supported artifacts, which positions them in a digital context. Depending on the project type, at least two of the six authors either took part as team members or acted as coaches. Our experience with Design Thinking and active involvement enabled us to act as knowledgeable experts called for in CIT [23] and to report critical incidents from the unique vantage point of researchers directly involved in the projects.

Research projects encompass interdisciplinary teams from both research institutions and industry. Researchers, such as the participating authors of this article, typically led the projects, developed and evaluated concepts. Industry partners provided relevant domain knowledge, engaged in testing, or helped with implementation. While Design Thinking was only introduced to Projects 1 and 2 while they were already underway, all research projects harnessed the Design Thinking Micro-Cycle. Each project especially used tools for needfinding, such as ethnographic observations, in combination with iterative prototyping.

Long Industry Class Projects comprise graduate student projects on topics given by industry partners. Student teams, which typically encompassed diverse disciplines such as information systems, informatics, business, design, or mechanical engineering, worked on these real-world challenges for nine months as part of a two-semester course. Several of the authors, who had been trained on conducting and teaching Design Thinking projects based on a detailed curriculum derived from Stanford university's ME310 course, see [26], provided methodical input in a weekly two-hour lecture as well as coaching to individual projects in a weekly one-hour session. Students learned basic principles of Design Thinking as well as how and when to use tools, such as interviewing, observation, user journeys, or rapid prototyping. While putting special emphasis on detailed needfinding and exploration of the problem space in the beginning, the projects covered multiple iterations of the Design Thinking cycle. The teams usually collaborated with international partner teams and interacted frequently with external entities such as industry partners and users for testing.

Short Industry Class Projects also comprise student projects on topics given by industry partners. Compared to the Long Industry Class Projects, the projects had a shorter duration of five months with several student teams working on the same challenge in parallel. The methodical input was more condensed and teams ran through fewer iterations.

In *Collecting the Data*, we retrospectively self-reported observations of critical incidents [23], which is apt to collect recent or noteworthy incidents [23], [25]. To resolve inconsistencies in the critical incidents reported, we also used the project documentation summarized in Table II as a neutral instance. We integrated several approaches to identify and collect incidents for this article: we individually wrote down critical incidents across projects, held interactive group discussions, and exchanged documents such as category definitions and assignments as a critical incident log across projects. Iteratively drawing on emergent analysis results, we collected incidents that were 1) due to the digital context, for example, related to the digital nature of a prototype, and 2) inhibited or enhanced conducting Design Thinking by, for example, stalling ideation in the project.

Analyzing the Data as inductive, subjective reasoning [23], [25] aims at summarizing data in a practical format [23]. We coded all projects, based on where on a continuum stretching from fully digital to hardware-based the project outcome was. Within this general frame, we developed categories of challenges and opportunities in a digital context arising from the observed incidents, and validated them while also involving external expertise [23]. In the following, we report on five major categories of opportunities and four categories of challenges by detailing

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TABLE I
OVERVIEW OF DESIGN THINKING PROJECTS IN THE DIGITAL CONTEXT

ID	Project Name	Type	Project Goal: How might we…
1	Improved Handover in Nursing	R	… improve handover between shifts in patient care?
2	Accurate Wound Documentation	R	… improve accuracy and efficiency of documenting chronic wounds in nursing settings?
3	Accurate Dispensing of Medication	R	… improve the accuracy of dispensing medication in hospitals?
4	Flexible Maintenance	R	…help maintenance workers deal with process variety?
5	Craftsmen Scheduling and Routing	R	… improve scheduling and routing of craftsmen within cities considering the traffic situation?
6	Nursing Service Scheduling and Routing	R	… improve scheduling and routing of nursing service employees within cities considering the traffic situation?
7	Energize	LICP	… design new offerings for residential customers considering the digitisation of the industry?
8	Foilizer	LICP	… use retrofit film solutions to advance the well-being in buildings considering different living conditions?
9	EuroAssist	LICP	… design innovative truck assistance services for drivers and freight forwarders?
10	LightCorp. 1	LICP	… design innovative exterior automotive lighting solutions in the context of fully automated driving?
11	ConsumeLit.	LICP	… design human-centred lighting to support elderly in X to extend living within their own home?
12	LightCorp. 2	LICP	… design individualizability using light for automotive mobility users considering a sustainable business model?
13	Automotive Inc.	LICP	… design the ultimate connected experience for future Automotive Inc. mobility users considering seamless, device-independent customer connectivity?
14	Capacity Development	LICP	… present consulting and information services for X citizens to prevent emigration and to support re-immigration into X considering Capacity Development's existing infrastructure?
15	Fleet Manager	SICP	… design a mobility service that builds on car data to create additional value for the car manufacturer's customers?
16	Gamification for Eco-friendly driving	SICP	… design a mobility service that builds on car data to create additional value for the car manufacturer's customers?
17	Parental Control for Young Drivers	SICP	… design a mobility service that builds on car data to create additional value for the car manufacturer's customers?
18	Secure Parking	SICP	… design a mobility service that builds on car data to create additional value for the car manufacturer's customers?
19	Crowd feedback service	SICP	… design the essential mobile service for smart urban transportation?
20	Location-dependent mobile advertising	SICP	… design the essential mobile service for smart urban transportation?
21	Matching service for transport and travel	SICP	… design the essential mobile service for smart urban transportation?
Legend: R: Research, LICP: Long Industry Class Project, SICP: Short Industry Class Project			

TABLE II
SUPPORTING DATA PER PROJECT TYPE

Research Project	Long Industry Class Project	Short Industry Class Project
- Scientific **articles** on outcomes - Formal **reports** to project sponsors - Working **documents**, e.g. results of experiments	- One-page **summaries** created ~ every 6 weeks - Large **presentations**, ~ every 3 months - Comprehensive **reports**, ~ every 3 months on o Needfinding o Prototypes o Final Prototype	- Intermediate **reports** on o Idea to answer challenge o User Flow o Final Prototype - Final **report** on entire project including final prototype

a total of 43 major incidents, which each include a single or multiple events. Assessing the prevalence of each major category across all projects, we identified 63 occurrences, see Table III in the results section. The involvement of each author in different project types and in different roles allowed us to compare across project types, and thus to retest own observations [24]. We iteratively conducted interactive discussions in which at least two co-authors checked, discussed, and refined the categories and critical incidents. To improve reliability, we cross-checked observations [23], [24], also involving at least one author who had not been part of the project and thus in a "neutral" position. If there was no agreement among authors, we consulted project documentation as an additional, neutral instance to achieve consensus.

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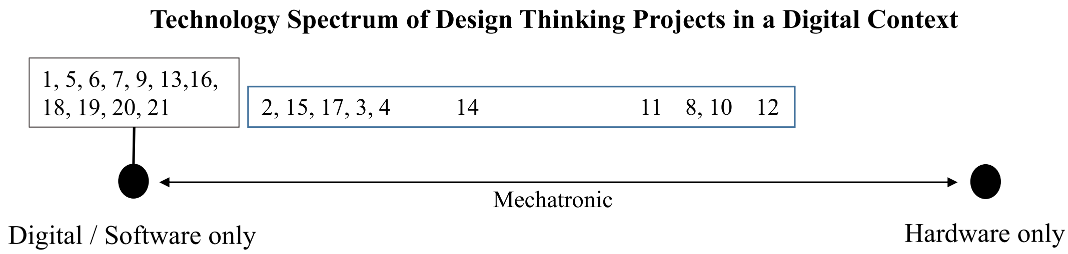

Fig. 2. Technology continuum of design thinking in a digital context.

In *Interpreting and Reporting* [23], we reflected on our use of the CIT and underlying themes of the resulting opportunities and challenges. Both intangibility as a key driver of observed critical incidents and potential limitations of our research approach are part of the discussion section.

IV. Results

To report on the effects of a digital context on conducting Design Thinking projects, we first describe the technology spectrum of projects—ranging from fully digital to hardware-based. Second, we report on opportunities and challenges observed in the opposing cases of fully digital and mechatronic projects. To conclude, we summarize our observations and assess their prevalence across project types.

While digital solutions become more and more important [2]–[4], innovation in hardware is not going away. We observed the outcomes of projects to lie on a continuum, which ranged from fully digital, software-based solutions at one end to hardware products at the other. Fig. 2 illustrates the relative position of the projects in our sample in the mechanical or digital space.

Hardware-only products constitute one extreme of the technology continuum. In these projects, a physical, hardware-based product made of tangible materials, such as metal, or flows of medium, such as electrical current, is the main outcome. Hardware-only projects are not part of the digital context this article focuses on.

Software-only or *fully digital* solutions, such as apps or technical backend solutions, are characterized as the outcome of pure knowledge work [5] and are thus intangible: that is, the underlying code is not physically perceivable. Naturally, all software has to run on hardware, which in these cases is, however, taken as a boundary condition and not elaborated as part of the outcome. While prototypes created throughout the project may include hardware elements, e.g., to explore the given boundary conditions or to hypothetically break assumptions, all projects attaining this position converged on a fully digital solution. In our sample, Projects 9 and 13 attained this position, for example. While Project 9 on roadside assistance dealt with services in the physical environment, these aspects did not form part of the final solution. Already from the outset, work in Project 13 on a "connected experience" was meant to run on a predefined hardware setup.

Many projects led to a mechatronic solution as a mix of hardware and software working together. The relative share of hardware and software determines the position on the continuum: At one end of the continuum, a software solution may be supported by specific hardware. At the other end, only minor digital features, such as a programmable digital timer, are part of the solution. Even though the software content may be small, by enabling the innovative function, it forms part of digital innovation. Between these extremes, innovative outcomes rely on a more even mix of hardware and software. For example, in Projects 8, 10, and 12, the key innovative outcome is embedded in software elements. This software is, however, tied to a hardware design specified in the project, which, if missing, would make implementing the solution impossible.

In the following, we elaborate on opportunities and challenges due to the digital context based on two projects at the opposing ends of the range we observed: Project 10 as a digitally enabled mechatronic project and Project 13 as a fully digital one. This choice enables us to summarize our key observations in critical incidents while considering the relative role of hardware in the project outcome. As applicable, we will draw on instances from other projects to explain the prevalence of the observed characteristics.

A. Digitally Enabled Innovation in a Mechatronic Solution (Project 10, LightCorp)

As a rich case of a mechatronic solution consisting of hardware and software, we chose Long Industry Class Project 10 to detail opportunities and challenges. LightCorp, a leading international innovator of lighting solutions, posed the project challenge "How might we design innovative exterior automotive lighting solutions in the context of fully automated driving?" Following LightCorp's focus on automotive OEMs, the challenge was set in a B2B context. As shown in Fig. 3, the project led to a mechatronic solution: Lights and their placement as hardware features were a key part, while software controlling these lights enabled innovative features.

In the setting of a Long Industry Class Project of nine months, a newly formed team, consisting of five graduate students with backgrounds in computer science, design, and management, collaborated with an international partner team of three students, who were located about three hours away by car. This distance enabled the two parts of the team to meet in person several times but still posed too much of a barrier to meet regularly. Interaction thus mainly took place via Skype and by exchanging documents. As neither the challenge nor the feature description referenced digital technology, the team embarked on broad needfinding, spearheaded by the exploration of the design space on lighting and fully automated driving. The first iterations of roughly built prototypes incorporated basic aspects of ideas, without any

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Fig. 3. Final prototype in Project 10 (edited for anonymity).

consideration of implementation. As the level of detail increased, the digital control of lights to communicate with road users became salient. While the team first explicitly discussed digital features in prototyping, they subsequently also ideated on how to best address user needs via the digital control of lights.

Since work in Project 10 gained a focus on digital aspects only gradually, effects of the digital context stand out in comparison to work on hardware. We observed positive effects of the digital context on both the process of prototyping and the prototypes themselves. Moreover, the digital context allowed for the development of an innovative business model, which made addressing a larger number of human needs viable. However, we observed the management of stakeholders in the business model to be challenging.

1) Opportunity: Improved Collaboration in Prototyping and Testing: To implement light patterns for communication with road users in a mechatronic prototype, hardware modules provided light as a basic function, which was controlled by software to enable the innovative features. The local and the international collaboration team both had access to a hardware setup capable of showing the software features. This setting allowed us to observe the positive effects the ease of adjustments and the easy transfer of digital artifacts had on collaboration in prototyping and testing.

While changing digital aspects may not always be easier than adjusting hardware, already the local team in Project 10 benefitted from the relative ease of rapidly altering and updating software. The team very quickly created several variations of the software controls for testing, which they in turn adjusted based on testing results. Had the key feature been a hardware component, developing the same number of alternatives would likely have been prohibitively costly in terms of time and material. Thus, the digital context facilitated continued adherence to the key notion of Design Thinking to “fail quickly and cheaply” [19, p. 4].

The easy transfer of digital artifacts, moreover, played a very positive role in collaboration with the international team. Since digital artifacts are intangible, they can be moved and replicated electronically without hauling physical goods. The (marginal) cost of replicating and transferring a digital innovation is thus nearly zero [3]. In Project 10, this characteristic impacted profoundly, and compared to work on hardware components, improved collaboration. The international partner team, who were a three-hour drive away, had better testing conditions but were not as knowledgeable in software implementation. Since the main innovative feature used an Arduino program, bugfixes and new functions could be developed by the technical experts and shared as a file. If the team had needed to exchange physical items, leveraging these comparative advantages in testing would not have been feasible. This juxtaposition is exemplified by a critical incident in which the collaborating team called a local team member to fix issues with the hardware, which turned out to be a daunting task over the phone. The ability to easily share artifacts afforded high-quality testing while minimizing effort, which in turn enhanced the ability to iteratively learn about user needs.

In other projects: This effect may be more pronounced, the more a solution relies on software, that is, the further to the left on the technology continuum a project is situated. For example, Project 2, on wound documentation, involved only a minimal share of hardware. In such projects, fully software-based prototypes using standardized hardware can be nearly freely shared. We observed similar effects, for example, with a database prototype in Project 9 on roadside assistance and in Project 13 on a connected experience for mobility users.

2) Opportunity: High-Quality Prototypes With Low Effort: Project 10 also exemplifies the opportunity to harness high-quality predefined building blocks in digital innovation. As digital innovation is self-referential due to its reliance on existing digital technologies [27], there is an abundance of software packages, templates, and Application Programming Interfaces ready for use in prototyping features. There are marked differences compared to the use of prefabricated parts in mechanical prototypes: whereas mechanical parts need to be delivered first and may need major rework to function together as intended, digital building blocks are in many cases available for download and are meant to be integrated, which can lead to much faster results. In Project 10, the team identified a hardware and software extension to the open Arduino platform as promising. After the hardware had been delivered, the team swiftly created a working software prototype.

Compared to the mechanical part of the prototype, the software containing the innovative function attained a higher level of fidelity much more quickly. Notwithstanding the value of low-fidelity prototypes for testing [28], the higher fidelity of the digital artifact allowed for showing the intended feature in detail while still being easily adjustable. Combined with the ease of changes previously mentioned, this enabled the team to iterate very quickly in testing and prototyping by swiftly gathering and incorporating user feedback on the exact specifications of the light pattern contained in the solution.

In other projects: We made similar observations in Projects 12 and 13, for example. While Project 13 on a “connected experience” was inherently digital, Project 12 also resulted in a mechatronic solution. Project 12 had nearly perfected the software in user testing before work on sophisticated physical

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prototypes had even started, which illustrates the relative difference in fidelity between hardware and software.

Achieving higher fidelity within the same timeframe also changes the role of the final prototype. The value and the status of a final prototype as an artifact embodying the information gained through development [10], [29], [30] may vary between digital and hardware prototypes. A mechanical final prototype demonstrates core functionality and foreshadows what a production version may look like. Such prototypes are, however, frequently made using materials or processes that differ from those used in production. For example, a small quantity of prototypes may not allow for tooling such as diecasts. In comparison, digital final prototypes may afford more comprehensive reuse. By controlling the lights and thus showing the logic of the innovative feature, the software code was the most significant outcome of Project 10. The hardware elements of the prototype had the sole purpose of supporting the innovative software features, without detailed consideration of actual operational requirements or manufacturing. Relatively speaking, the software was much more mature and could be reused in further development by LightCorp.

In other projects: This observation also applies to several other projects. For example, Project 12 implemented the key function of improving well-being using context-sensitive light in the software of the mechatronic prototype. Compared to Project 10, the hardware, however, played a more prominent role: Hardware design was a key priority for the team, who, for example, developed different hardware types for children and adult users. In fully software-based prototypes, such as in Projects 9 or 13, the key software functionality may not be ready for use in a production version, but higher level aspects, such as the logic and user flow, may be directly carried over into implementation.

3) Opportunity: Innovative Business Model as Enabler of Human-Centered Innovation: While human-centricity is the cornerstone of Design Thinking, it has to be in balance with business viability [13]. In Project 10, we observed digital solutions to facilitate new business models, which in turn enabled the team to better address user needs.

The team had collected positive user feedback on the proposed functionality of personalized light displays, but deemed hardware costs unviable. Hardware-based products are commonly sold to a customer or, in a more contemporary approach, form part of a product-service-system [31]. In both cases, a constant core functionality is provided in exchange for either a one-time payment or a continuous revenue stream. In this traditional logic, covering the high hardware cost via the purchase price or leasing fee seemed unviable.

Reckoning that digital control enabled the key feature of personalization, the team turned to exploring options in the business model, which led to an innovative approach alleviating the limitations of purchasing and leasing. The final business model incorporated three traits common in the digital realm: pay-per-use-servitization, ad-based monetization, and a platform mechanism. In pay-per-use servitization, which digital technologies can enable, customers do not pay for the product but its use [32]. The team changed the business model from quoting a feature price to quoting a price for *using* the feature in, for example, car rides. While servitization may stretch the time for payments, customers still have to bear the feature cost. To alleviate the issue of high overall cost, the team adopted an ad-based strategy. In ad-based business models, such as implemented in Google search, customers benefit from functionality by accepting the display of ads or gathering of their data instead of paying money. Hence, the team made the display feature of the prototype usable for displaying ads, which, if users chose this option, would subsidize overall cost. To match customers looking for subsidized feature price with those seeking to display ads, the team adopted a platform approach, that is a multisided market in which the platform owner acts as a facilitator to match diverse parties [33], [34].

In this platform- and ad-based business model, the high hardware cost could be, at least in part, passed on to ad sponsors, while users got to keep most of the benefits of personalization. Digital features enabled an innovative business model, which in turn made addressing the observed need for personalization viable. It has to be noted, though, that the effort required to develop and test the business model partly shifted the focus of work from elaborating and testing a high-resolution prototype to detailing the business model.

In other projects: We mostly observed this opportunity in projects set in the fully digital realm. Project 9, on roadside assistance, worked on more direct interaction between stakeholders within a quasi-platform, whereas Project 13 on connected services was inherently set to work with multiple providers.

4) Challenge: Networked Stakeholders in the Business Model: To tackle "wicked" issues involving high levels of ambiguity and a complex interaction of effects [14], [35], Design Thinking puts much emphasis on identifying and managing stakeholders [12], [13]. While design always acts within a network of stakeholders [36], we observed the digital context to lead to complex, networked stakeholder relationships related to the business model, which require adequate management.

Even hardware-based business models may exhibit multitiered value chains, which make addressing user needs complex. For example, Project 10 was set in a B2B context: While investigating user needs, the business model did not plan for a direct relationship between LightCorp and users. Hence, the approach to addressing user needs became more complex: Instead of directly addressing user needs, they had to be integrated with the interests of intermediaries along the value chain, especially those of automotive OEMs.

By embedding organizations in an increased number of dependencies [37], which results in a networked ecosystem [33] as opposed to a value chain, digital innovation further increases the complexity of stakeholder management related to the business model. Since digital artifacts commonly interact with each other and draw on existing technologies [27], procurement dependencies mount beyond ordering mechanical parts. Similarly, digital solutions frequently act as building blocks for customers to develop their own solutions [27] and thus propagate dependencies. Moreover, digital technologies change frequently [38], which renders all technological interactions and relationships inherently *dynamic* and thus further adds to complexity.

By including the stakeholder category of complementors, platform business models, such as the one developed in Project

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10, add yet another layer of complexity. A platform business model is not only embedded in an ecosystem of dependencies but constitutes a multisided market bringing together diverse entities co-creating value with the platform owner [33], [34]. Providing adequate resources for complementors and defining their role is a complex issue in what has been called platform governance [39]. Hence, addressing user needs becomes more complex by requiring their integration in the co-creation network. The personalization prototype of Project 10 illustrates this challenge: In addition to managing intermediaries in a multitiered value chain and managing dependencies of (digital) building blocks, the platform business model required orchestrating ad- and content-providers as complementors. Without their contribution, the business model would not have been feasible. Work on the business model thus was much more complex and effortful compared to projects without a digital platform business model.

Overcoming this challenge: The team in Project 10 coped with this challenge by expending a lot of effort on stakeholder management throughout the project. The team interacted frequently with selected intermediaries and other stakeholders to gather their motivations and interests, which they integrated into prototype development and assessment. As evaluation criteria, the team emphasized actual user needs. In our observation, it was especially beneficial the team considered the needs of OEMs early in exploring the multitiered value chain: it made the transition to orchestrating complementors in the platform business model an extension to instead of an onslaught of complexity.

In other projects: We observed similar, if lesser, challenges, for example, in Project 13, which aimed at the development of solutions for mobility users in collaboration with internal and external stakeholders. Especially since the parties involved differed by country, the team was at points unsure to what extent they could take required building blocks and relationships with partners for granted. In Project 13, however, the corporate partner was able to provide guidance on how to deal with these open questions, which enabled the team to either readily address these challenges or to go on with working hypotheses while focusing on user needs.

B. Fully Digital Innovation (Project 13, Automotive Inc.)

Showcasing a number of opportunities and challenges to applying Design Thinking in a digital context, we chose Project 13 as an exemplar of fully digital innovation. Automotive Inc., a leading international producer of passenger vehicles, posed the challenge "How might we design the ultimate connected experience for future Automotive Inc. mobility users considering seamless, device-independent customer connectivity?" The challenge was set in a B2C context and aimed for direct use by Automotive Inc.'s customers. Fig. 4 depicts an overview screen of the final prototype app.

Project 13 was a Long Industry Class Project lasting nine months. The newly formed team, consisting of five graduate students with backgrounds in computer science, information systems, robotics, and management, collaborated with an international partner team of four students. The partner team was located on another continent—requiring a flight of more than ten hours to meet. While the teams met for an initial kickoff and

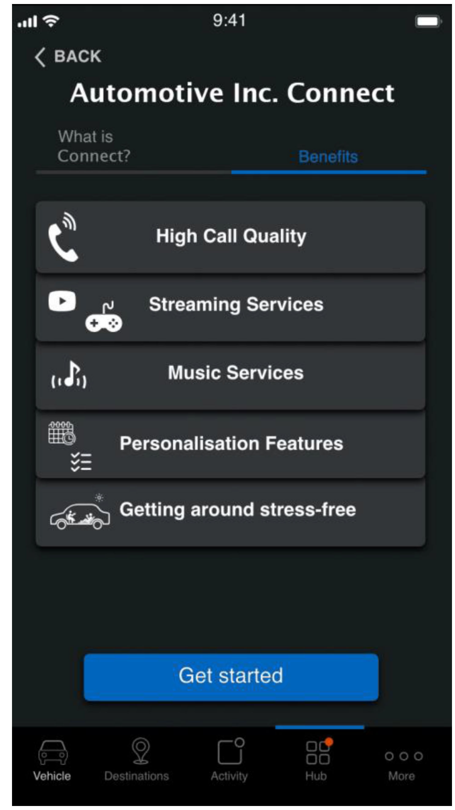

Fig. 4. Screenshot of final prototype app from Project 13 (edited for anonymity).

two intermediate meetings, collaboration centered on Skype and exchanges of documents.

By calling for a "connected experience" considering "device-independent […] connectivity," Project 13 implies a fully digital solution, that is, all innovative features are software-based without specifically considering hardware details, from the outset. Hence, while sometimes including hardware elements as necessary enablers, ideation and prototyping throughout the project focused on software features. Since the project converged on a fully digital solution and resulted in an app as the final prototype, it lies on the fully digital end of the technology spectrum. This context allowed us to observe opportunities and challenges to Design Thinking traceable to fully digital innovation. We observed opportunities in needfinding through engagement at a distance and in greater potential for individualization. At the same time, we observed challenges related to imagining intangible features, estimating feasibility, and the choice of medium and resolution for prototypes.

1) Opportunity: Immersive Engagement at a Distance: In Project 13, the boundaryless availability of digital artifacts facilitated immersive needfinding through engagement. Digital artifacts, such as services or apps, can be used virtually irrespective of physical location, which improved the understanding of stakeholder needs while working at a distance.

In any project, online sources, such as discussion forums, blogs, or product reviews, can provide rich information in the voice of the customer [22]. This ability comes in especially handy whenever direct access to the target group or the context of use proves difficult due to, for example, physical distance. The

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data may, however, provide only limited insights—especially when compared to experiencing a situation first-hand by taking the place of stakeholders, as is recommended for needfinding [22]. For example, if one were to gain insights on the actual use of turn indicators in China, harnessing online sources may prove difficult since they do not allow for unfiltered observation, let alone immersion in the context of use.

Compared to only consuming information about the experiences of others, a digital context can, however, enable immersive needfinding through engagement in the actual activity, which is recommended for Design Thinking [22]. Given their intangible nature, digital artifacts, such as apps or services, are easily transferable [3] using electronic means. It is thus possible to use and explore a digital artifact nearly irrespective of location. For example, while it may not be possible to engage in Chinese traffic to investigate the use of turn indicators, it is well possible to access a Chinese e-commerce site and try out the user flow. In this sense, the focus on a "connected experience" enabled the team in Project 13 to engage in the target group's actual behavior. To understand the use of social networks in Asia, for example, the team explored social media aimed at Asian users. Without having to travel to Asian countries, the team was able to experience the actual digital artifacts and their features for themselves. This ability allowed the team to quickly gain insights into how the target group likes to be seen and interact, which in turn helped in ideation on connected solutions in the mobility context. Insights gained in this manner complemented on-site research by the team, which was inherently limited by physical distance.

In other projects: We observed similar opportunities in, for example, Projects 2 and 7. The team in Project 2 on documenting wounds tested a number of existing apps for that purpose in benchmarking, which enabled them to gain an in-depth understanding of the shortcomings of existing solutions. In particular, the team was able to trace complaints of current users and to evaluate the degree to which needs have been fulfilled. Engaging with physical artifacts in the same manner would not have been possible considering the effort needed for traveling to facilities or shipping devices. Similarly, Project 7 engaged with a number of existing smart services without having to bear the effort of engaging with physical artifacts.

2) Opportunity: Potential for Individualization: Compared to hardware products, digital solutions make offering individualized products easier. For example, although the exterior of cars can be individualized with different colors, offering such customization based on producing different *physical parts* is effortful and can incur high cost [40]. By providing a common basis for content, features, or behaviors, digital solutions afford scalable individualization without changes in hardware at near-zero marginal cost. Hence, a digital solution can address highly individualized needs of different user groups or even serve as a canvas for self-expression of individual users.

In its initial exploratory needfinding, the team in Project 13 identified several needs applicable to larger user groups. These needs, such as "personalization," were, however, very generic and not concrete enough for creating prototypes. At the same time, they identified niche needs for specific target groups, which in turn limited general appeal. Considering the cost and effort involved in offering individualized versions [40], it would only have been viable to work on a few promising hardware features. The digital context, however, enabled the team to consider the entire "long tail," that is, highly individualized needs [41]. Thus, they built a prototype addressing the generic need, which, serving as a canvas for personalization, offered different options to fulfill individual niche needs according to, for example, context or user profile.

This prototype journey, which integrates user needs at different levels of abstraction, exemplifies the dichotomy of diverging and converging activities in Design Thinking [12]: While the team diverged to observe and accommodate many needs, they had to converge on appropriate generic features at the same time. Creating generic groups made concise introductions in testing and complexity in prototyping manageable. To differentiate generic and individualized aspects, the team focused on finding universally well-received elements, e.g. personal entertainment, and personalized individual features such as the music played.

In other projects: We made similar observations in several other projects. While revolving around a common online platform, Project 7 devised very different value propositions and features for users based on their technical proficiency concerning smart home products. Project 9 developed a common digital platform for roadside assistance, which offered different information and features to different stakeholder groups such as truck drivers and repair workshops. The team in Project 10 developed a prototype centered on individualization, which offered a platform for different designs based on user preferences. In all of these projects, the digital core was implemented as a canvas for users to fulfill their individual needs.

3) Challenge: Imagining Intangible Digital Features: The team in Project 13 experienced difficulties in imagining and creating tangible prototypes of digital features, which were additionally set in a future context. While the team sought to adhere to the key Design Thinking principle to make ideas tangible [12], [13], the fact that digital innovation is either not perceivable at all or, in many cases, only as screens on existing devices, proved challenging. The team in Project 13 had to imagine and prototype digital features in the context of future mobility, which added a layer of complexity by having to anticipate future developments in mobility. While this situation provided a blank canvas for ideating features, we observed that the team was overwhelmed by the breadth of the potential solution space that contained only few or even no physical elements as boundary conditions.

This challenge was exacerbated by having to consider multiple levels of abstraction: The user experience as a key outcome, user interaction, and prior set-up, for example, by installing apps. A prototype in Project 13 integrating several needs such as in-car entertainment and relaxation exemplifies this challenge: After initial set-up, the critical user experience relied not only on interaction via voice but also on automatically registering underlying user needs, which does not relate to a discernable interface. To enable user testing, the team had to expend much effort to come up with an experienceable, perceivable embodiment of the intangible digital solution. This was especially difficult, since testing aimed at gaining feedback on the automated, unperceivable part of the prototype.

Overcoming this challenge: To overcome or at least ameliorate this challenge, the team constantly renewed its focus on

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user needs: What kind of experience would users appreciate? In particular, they tried to trigger the respective reactions without considering implementation. In hardware-based or mechatronic projects, this is possible by mimicking the intended shape and feature using materials such as cardboard, which makes the core feature experienceable and directly tangible. In the fully digital context, the ability to recreate the overall experience is more limited. To create rough prototypes, the team used paper prototypes showing wireframes of screen-based solutions. As the team reported, the prototypes were, however, not self-explanatory as testing required describing the context. While this approach worked well to start conversations, we consider it a deviation from the "show don't tell" principle [19, p. 35]. As an even greater deviation, a Design Thinking project in the context of autonomous driving prepared mock-ups as abstractions of both the feature and its use context, which worked well to make fully digital features experienceable, even if still not tangible. For example, a cardboard scenario featuring toy cars illustrated the experience of sensing and sharing data on parking spots. Team members would then present the envisioned scenario to testees and collect comments. These observations are in line with findings that rudimentary, low-fidelity prototypes are sufficient to conduct initial tests of digital innovation [42].

For increasing fidelity and to collect rich feedback, the team in Project 13 inched closer to recreating the actual experience by, for example, testing paper prototypes inside car cockpits or by developing a tangible wizard-of-oz prototype catering to entertainment and relaxation needs. Thus, we conclude that, after overcoming the initial challenge of imagining features on the blank canvas of digital innovation, the continuous evolution of prototypes in Design Thinking [19], [22] worked well to iteratively refine ideas.

In other projects: We made similar observations in other projects. In Project 3, for example, the team identified an Augmented Reality solution to display the number of pills to be distributed to medical dispensers as the most promising experience. Testing this proposition without developing a fully implemented solution was possible by using paper mockups. Placing these below actual dispensers emulated the experience of having necessary information right on the dispenser as a wizard-of-oz prototype, which allowed for rich feedback early on. By placing it in the use context, the team successfully translated the digital experience of virtual augmentation into a physical one. With the dispenser as a clear physical reference, the approach in Project 3 worked better than the one in Project 13 but still required explanation to users and thus violated the "show don't tell" principle [19, p. 35].

4) Challenge: Correctly Estimating Feasibility: We observed that adequately estimating technical feasibility was a challenge in Project 13. While the team struggled with ideation on intangible digital solutions, see above, they conversely showed a tendency to overestimate feasibility in implementation. Drawing on inspiration gained from digital assistants such as Amazon Alexa, they intended to not only show but actually implement personalized services using sensors and artificial intelligence. Despite warnings that even the general state of technology would not allow for such a solution, they pursued a full-fledged prototype, which contained a broad feature set. After failing in implementation, the team relied on a mostly wizard-of-oz prototype with far fewer features than initially planned, but which still allowed for gathering rich user feedback.

While estimating feasibility is also a concern in hardware implementation, the specifics of digital artifacts make it more challenging. Software is made up of interdependent modules, which all have to work together to achieve the overall outcome [43]. As a consequence, whereas a failed hardware implementation may be considered "quite close," inadequate performance of one of the software modules can more easily obliterate all functionality—making the implementation of a feature a binary outcome. Overestimating feasibility had several negative effects. Trying to force implementation took much time, which the team could have used instead to build several prototypes to gather feedback and "fail quickly and cheaply" [19, p. 4]. In addition, the team focused a lot on this idea and considered it as the only solution for some time, which inhibited creative ideation.

Overcoming this challenge: To overcome this challenge, the team had to take a step back and reevaluate their goal in building the prototype. Declaring the user experience the most important aspect, they were able to reduce the feature set. They then assessed the feasibility of different system designs ranging from safe bets to moonshots. Based on such a more conservative estimate of feasibility, they were able to implement features in prototypes. They did, however, leave features needing much effort in implementation as wizard-of-oz experiences by adjusting controls themselves. This approach allowed the team to return to iteratively refining prototypes to address user needs instead of obsessing with technical feasibility.

In other projects: We observed related, if not entirely similar, issues in other projects. Unlike in Project 13 *over*estimating feasibility, Project 9 on improving roadside assistance suffered from *under*estimating feasibility. The technically skilled team member did not believe the envisioned solution of a shared online platform could be implemented. This engaged all team members in the search for a solution, in spite of the fact that implementation of the database backend of a web application was straightforward.

5) Challenge: Adequate Medium and Resolution for Prototyping: Iterative prototyping to make ideas tangible and thus readily understandable is a key aspect of Design Thinking [12], [13]. The fidelity of prototypes should evolve over the course of the project [19], [22]: To evaluate initial ideas, it is advantageous to demonstrate core features using only low-fidelity prototypes. In the fully digital context of Project 13, we repeatedly observed team members, especially those with a background in computer science, to be inclined to forego in-depth user testing and needfinding in favor of developing a fully coded solution right away. Showing these prototypes of a higher-than-necessary level of fidelity to stakeholders repeatedly led to the sobering insight that the solutions did not address user needs.

Even at a preproject stage, one of the members solved a warm-up challenge as an app without considering actual user needs. In developing a late-stage prototype app to introduce customers to the "connected experience," the team used an existing Automotive Inc. app as a template without considering whether the existing layout and user experience address user needs. Showing such full-fledged solutions in testing changes

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TABLE III
OVERVIEW OF OPPORTUNITIES AND CHALLENGES OF DESIGN THINKING IN A DIGITAL CONTEXT

Opportunity	Description	Observed in	Challenge	Description	Observed in
Immersive Engagement at a Distance	Ability to try existing digital solutions allows for immersive needfinding even at a distance.	Mechatronic: 2, 14 **Fully Digital: 13**, 5, 7	**Imagining Intangible Digital Features**	Intangibility of digital artifacts poses issues in ideation and prototyping.	Mechatronic: 2, 3 **Fully Digital**: **13**, 5, 9
Improved Collaboration in Prototyping and Testing	Digital features enable frequent changes and easy transfer of prototypes.	**Mechatronic: 10,** 12, 2 Fully Digital: 7, 9, 13	**Correctly Estimating Feasibility**	Nature of interdependent artifacts of knowledge work makes feasibility hard to assess and a discrete event.	Mechatronic: 2, 4, 8 **Fully Digital**: **13**, 9, 21
Potential for Individualization	Easy adaptability of digital solutions allows for fulfilling even niche needs.	Mechatronic: 8, 10, 17 **Fully Digital**: **13**, 5, 6, 7, 9	**Adequate Medium and Resolution for Prototyping**	Inclination of technical experts to leap into implementation without considering user needs.	Mechatronic: 2, 15 **Fully Digital**: **13**, 7, 9, 21
High-Quality Prototypes with Low Effort	Availability and easy integration of high-quality building blocks enable fast creation of prototypes, which can be reused in later implementation.	**Mechatronic**: **10**, 2, 3, 4, 8, 12 Fully Digital: 5, 6, 7, 9, 13	**Networked Stakeholders in the Business Model**	Digital solutions as enablers of innovative features and parts of platform business models increase complexity in stakeholder management.	**Mechatronic**: **10**, 2, 8 Fully Digital: 1, 5, 6, 9, 13, 16, 19
Innovative Business Models to Make Addressing Human Needs Viable	Digital features aid implementation of innovative business models based on pay-per-use servitization, ad sponsoring, and platforms.	**Mechatronic**: **10** Fully Digital: 9, 13, 16, 18, 20	Opportunities and challenges ordered by project phase. Projects used as representative examples put in **bold.**		

interaction [44] and risks evoking reactions from stakeholders on details rather than the core idea [13], [30]. Feedback on polished details may thus fail to answer the key questions [13], [30], for example, whether features are desirable for users.

Overcoming this challenge: To overcome these issues, the team was forced to adhere to Design Thinking principles, that is, to focus on desirability in early project phases using low-resolution prototypes without considering technical feasibility and details. During later stages, they separated testing for feasibility, the "how" in implementation, and desirability, the "what." After experiencing lackluster results from testing with the high-fidelity prototype, they reverted to testing desirability using a stripped down, less functional prototype. A next iteration may thus have included fewer features to focus on understanding user concerns in depth. This helped the team to at least lessen the issue of drawing user comments on technical aspects.

In other projects: We observed similar challenges in other projects. For example, in Project 2, team members developed a fully functional tablet app, only to find that the key issue was to devise a solution that could be used handsfree. In this case, the effort wasted was substantive and enough of a shock to lead the team to fully embrace a needs-driven approach.

C. *Summary of Results*

To investigate opportunities and challenges arising for Design Thinking in a digital context, we detailed critical incidents in two projects representative of the opposing cases mechatronic, that is hardware- and software-based, and fully digital, software-based, innovation. In the mechatronic Project 10 with LightCorp, we found that the digital context improved prototyping through efficient collaboration and the opportunity to quickly generate high-quality prototypes. In addition, we observed that the digital context enabled innovative business models making fulfillment of previously unsatisfiable needs viable. The fully digital Project 13 with Automotive Inc. highlighted new opportunities in needfinding through engagement in the use context–even remotely. Moreover, the digital context made offering highly individualized solutions easier. The digital context also gave, however, rise to several challenges. In the digitally enabled mechatronic project with LightCorp., devising a platform-based business model presented a challenge in terms of adequately managing stakeholders. The fully digital Project 13 exposed issues in imagining intangible, digital features and correctly estimating their feasibility. In addition, finding the right level of fidelity in prototyping proved difficult.

Ordered by project phase, Table III summarizes the prevalence of opportunities and challenges. We observed opportunities, which run the gamut from early needfinding to elaborating business models, in both mechatronic and digital-only projects. In our recollection of critical incidents, the contrast between digital elements and hardware features, however, made them much more salient in mechatronic projects making greater use of hardware. Except for the challenge of managing stakeholders in innovative business models, challenges are most pronounced in dealing with digital artifacts during ideation and prototyping. Although we observed each challenge in both project types, we found that critical incidents in mechatronic projects led

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to less severe effects. In these cases, working on hardware may have ameliorated some of the issues with imagining and assessing digital features. This line of thought is supported by our observations on the challenge of imagining intangible digital features: It was prevalent only in fully digital projects and mechatronic Projects 2 and 3, which contained a large share of digital features. While presenting different contexts, we did not note differences based on whether projects were Research or Class Challenges. As discernable from Table III, we observed nearly all opportunities and challenges in both settings.

V. Discussion

Design Thinking has become a popular approach to problem solving and innovation [13], [16]. With innovation shifting to digital features [2]–[4], the question arises which opportunities and challenges are unique to applying Design Thinking in a digital context. Drawing on 21 Design Thinking projects, we reported on critical incidents in one mechatronic, that is, software and hardware forming an integrated solution, and one fully digital, software-based, project. In the following, we discuss our observations on the intangibility of digital artifacts as an enabler or inhibitor of Design Thinking. These considerations lead us to propose implications for Design Thinking projects in a digital context before we position our results in extant research on Design Thinking.

A. Intangibility of Digital Artifacts: Enabler or Inhibitor?

Taken together, our observations lead to the insight that the intangibility of digital artifacts can either boost or inhibit Design Thinking projects. As an artifact of digital innovation, software is the result of pure knowledge work [5] and is thus intangible. This characteristic enabled key opportunities we observed. First, software features of prototypes could be easily adjusted, which allowed for creating broad variety in testing. Even core functions of software can be changed quickly without the need for any additional material. While this trait was taken as given in fully digital projects, the restrictions in adjusting hardware components in mechatronic solutions emphasized the difference: Adjusting major hardware components entailed considerable effort from procuring parts, through integration, to ensuring the long-term physical stability of the prototype. In comparison, in many cases, while software changes presented a headache for the coder, they did not exhibit as many external dependencies causing delays.

Second, intangibility makes software easily transferable [3]. This trait enabled immersive needfinding by engaging in the use context and effortlessly sharing artifacts among collaborators, no matter where they were located. In particular, this ability allowed for frequent iteration on prototypes, for example, by sharing unfinished states and subsequently addressing any bugs. Taken together, the ease of changes and the inherent transferability allowed for scalable, decentralized prototyping and testing: By creating a digital solution once and transferring it instantly, the team in Project 10 could test at two locations simultaneously. This advantage is again emphasized by the direct opposition to work on the hardware components in Project 10 on exterior lighting: Whereas the software could simply be transmitted online, hardware problems in the collaborating team were much more difficult to resolve remotely.

Opposing these positive traits, we can trace the root cause of several of the challenges we observed to the inherent intangibility of digital innovation. Located at the fully digital, software-based end of the continuum, the team in Project 13 had a hard time imagining intangible features. In fact, these difficulties may have set off a vicious circle: Our observations imply that only considering a use context, without hardware components as a reference, may have made the scope of the problem space too broad, which, in turn, prevented the team from coming up with concrete ideas of what the user experience ought to be. While the team was able to describe the prototype idea of an artificial intelligence solution in abstract terms, it struggled with creating a low-resolution prototype embodying what made their idea desirable. The absence of a universally clear picture of the "what" subsequently led to problems in defining the "how" of technical implementation due to underestimating the effort needed for implementation—our second observed challenge. This lack of insight into actual feasibility most likely contributed to the third observed challenge: Choosing an appropriate level of fidelity in prototypes. The team may implicitly have considered building a high-resolution prototype, which would also answer the "how" of technical feasibility, as the only way to get a grip on the intangible feature. As a violation of key Design Thinking principles, they would have used a fully implemented feature to test whether the feature was desirable. The drive to build high-resolution prototypes thus relates back to the root cause of the difficulties related to imagining intangible digital features.

B. Implications for Design Thinking Projects in a Digital Context

Our findings have implications for conducting Design Thinking projects in a digital context. Especially when compared to hardware, we observed that digital features presented opportunities related to, for example, prototyping and testing. If a project contains hardware elements, incorporating digital features may open up opportunities in design and new business models. This can involve either shifting an existing feature to the digital realm [3] or including additional features as a way of exploiting the opportunities we observed. Conversely, managing the observed challenges of digital features is a key consideration. While requiring increased effort, the challenge of managing stakeholders in digitally enabled business models could be adequately addressed by embracing the Design Thinking mindset to empathically investigate actual needs using tools, such as stakeholder maps.

Unfortunately, the challenges posed by the intangibility of digital features were more difficult to overcome. Since projects working on mechatronic solutions exhibited the challenges to a lesser extent, we suggest that hardware should be included at least as a boundary consideration in projects, which makes applying the Design Thinking principle to "make it tangible" [12], [13] easier. A fully digital context without elaborating any hardware elements may lead to difficulties in making ideas tangible: for example, if the relevant features are intended to run automatically based on sensors. In these instances, we suggest

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splitting up the task of prototyping: projects may for a relatively long time strictly focus on the question of which experience is desirable—the "what" in development. To accomplish this goal, we found that, in early stages, using a very basic prototype abstracting from a use scenario works well. Such a prototype, for example, a cardboard with toy cars, may not provide any functionality but may serve as a graphic description of the context. Even though these prototypes required explanation during testing and thus violated the "show don't tell" principle [19, p. 35], they functioned well to start conversations. In later stages, projects *also* have to estimate technical feasibility—"how" the feature is going to work, which requires a technical proof-of-concept of an artificial intelligence solution, for example.

The right medium and resolution for prototypes in later stages may lie in a dual approach: Continued use of low-resolution prototypes to ascertain desirability and the development of prototypes as technical proof-of-concepts to iteratively update estimations of feasibility. Technical proof-of-concept prototypes are especially meant for use within the team. Using proof-of-concept prototypes in user testing may lead to the issue of users commenting on aspects "under the hood" instead of providing feedback on the desirability of features [13], [30]. In user testing, projects can continue using relatively low-fidelity prototypes for corroborating "what" the features should do. While these prototypes aimed at "what" to develop also evolve—from a paper mock-up of a scenario to, for example, a full website layout showing the user interface, they may remain far less detailed in terms of functionality. Based on our observations and experiences, we see such a dual approach as a promising way to handle the intangibility of fully digital artifacts in prototyping and testing.

C. Contribution to Design Thinking Research and Limitations

Drawing on a rich and diverse history in design studies, Design Thinking now acts as a managerial approach to problem-solving [16]. With its ability to address "wicked," hard-to-grasp problems [14], it has drawn much interest as an approach to innovation in a range of different contexts [1], [13], [28]. Increasingly, innovation has, however, shifted to the digital realm [2]–[4], which implies specific changes in artifacts and working style—calling for adopting Design Thinking [6], [17].

Extant research into Design Thinking in the digital context has, for example, investigated the potential benefits of introducing Design Thinking into IT organizations [20] or those derived from its ability to improve requirements engineering [45]. As a specific example, combining Design Thinking with agile software development may lead to superior outcomes [46]. Embracing the notion that Design Thinking is a valuable approach to innovation in the digital context, we add to this stream of research by providing initial insights on *how* the digital context affects conducting Design Thinking projects. By reporting on our observations of opportunities and challenges, we hope to contribute to the evolution of tools in Design Thinking. Our results highlight areas that may benefit from additional methodical support. The observed dual nature of intangibility, which both drives opportunities and poses challenges, especially links to previous findings on how prototypes and their characteristics shape interactions in design [29], [44]. We moreover add to propositions to further develop the role of prototyping as a key activity of Design Thinking in treating wicked problems [47]. Such developments may also position Design Thinking as a go-to approach in areas of digital innovation that are currently lacking adequate support. For example, there have been calls for more methodical support in embracing digital solutions for providing services [48]. In our expectation, a digital-aware toolset in Design Thinking, that is sufficiently developed, may help to overcome such issues.

As with any research endeavor, this study is subject to limitations. To identify opportunities and challenges of a digital context for Design Thinking, we iteratively identified and analyzed critical incidents from 21 projects. While the projects exhibit thematic variance, the joint involvement of the authors and similarities between the cases limit generalizability. Our sample and methodological approach are exploratory and further research may help in achieving comprehensive coverage of the effects of a digital context. Our observations of specific traits of the digital context in part rely on comparisons with hardware features in our projects. Since all projects comprise at least some digital features, a comparison with hardware-only projects would be fruitful future research. To render as accurate an account of critical incidents as possible, we sought to provide detailed, rich descriptions [23] including information on antecedents and effects [24]. As stated in the method section, the involvement of several, but not all, authors in each of the projects improved reliability in iteratively identifying and categorizing critical incidents. Similarly, by taking several roles in multiple projects, each author was able to take multiple perspectives in judging incidents, which should improve reliability. Despite such efforts, personal biases may still have influenced our results.

VI. Conclusion

The locus of innovation has shifted from purely mechanical advances to hybrid hardware- and software-based or fully digital forms. Design Thinking is an established methodology for creating human-centered innovation, which is independent of the application context and therefore suitable for use in a digital context. Drawing on 21 Design Thinking projects, we identified opportunities and challenges related to applying Design Thinking in a digital context. We reported on critical incidents in two projects positioned at opposing ends of the technology spectrum ranging from digitally enabled mechatronic solutions to fully digital projects. In the mechatronic project, we observed opportunities in improved collaboration in prototyping, high-quality prototypes, and innovative business models. Complex relationships of stakeholders in the business model did, however, present challenges. In a fully digital context, we observed opportunities in improved needfinding and the ability to offer individualized solutions. However, the fully digital project showcased several challenges associated with imagining intangible digital features, correctly estimating feasibility, and finding the right medium and fidelity in prototyping. In discussing our observations, we identified the intangibility of digital innovation to drive both opportunities and challenges. We would like to initiate a discussion on how existing tools in Design Thinking can be best used or supplemented for innovation in a digital context.

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[redacted] P5: Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity

Table AX5: P5: Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity

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Machines as Teammates in Creative Teams: Digital Facilitation of the Dual Pathways to Creativity

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ABSTRACT

Considering recent advances in information systems, we pose the question how well a digital facilitator can support the complex task of creative idea generation in teams–especially compared to a human one. Drawing on the dual pathway to creativity model and extant research in group creativity and information systems, we develop a set of interventions for both human and digital facilitation. We test the hypothesized effects in a 2x2 study design with 24 participants and a human or digital voice assistant as facilitators. We find that objective outcomes of digital facilitation are not significantly different from those of human facilitation. Digital facilitation is, however, significantly worse in subjectively perceived helpfulness. These results add to the scant research on the effects of intelligent systems on team interactions and help inform future research on group effects of intelligent information systems.

CCS CONCEPTS

• *Information systems~Decision support systems* • *Human-centered computing~Collaborative and social computing*

KEYWORDS

group creativity support system; creativity; facilitation; laboratory study; voice assistant

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1. INTRODUCTION

The last centuries are marked by an increasing reliance on technology to take over more and more labor. During the last decades, this trend has markedly accelerated, especially in terms of information processing and intellectual work. (Personal) computing and information systems are a pervasive element of today's workplace, whether it be individual or groupwork. Consequently, a large research stream on information systems as a means of work has emerged (e.g. [59]). In addition to individual versus collaborative work, use of IS has sprawled from tasks directly related to data processing, e.g. accounting, to more general areas. Tasks involving innovation and creating new ideas are an example of such tasks. Creative and inventive tasks are a particularly important type of work since generating ideas and innovative propositions are key to competitive advantage [60]. Creative methodologies are used on a wide range of topics such as digital innovation in healthcare [44].

Creative efforts can be carried out using original creativity methods, methods from other areas such as agile development [45], and can be supported by a variety of information systems: Either by standard software, e.g. office applications, specific tools, e.g. computer aided design, or specialized systems aimed at fostering creative thinking termed creativity support systems [60]. While the use of information systems as a means for communication between group members has been a longstanding topic of investigation [59], the emergence of intelligent systems is, though, likely to shift the role of technological artifacts in groupwork. Intelligent systems do not merely carry out tasks at the discretion of human team members but become active participants in groupwork and discussions [54].

Implications of information systems becoming more equal team members in groupwork are likely to be exacerbated in creative tasks since the emergence of ideas is known to be dependent on context, e.g. the specific path taken [35]. Untimely participation or even disturbances by the digital system may thus cause negative effects. In addition, the mechanisms underlying improvements of creative performance, especially with support through current passive information systems, are described to be underresearched [1]. Since creative settings are known to be susceptible to interpersonal dynamics [30] and overall acceptance of artificial intelligence (AI) technology has been found to hinge on an appropriately human appearance and demeanor [50], investigating the effects of intelligent systems on group processes and outcomes such as creativity seems promising. We are concerned with the facilitating aspect of intelligent systems and do not focus on the intelligence or comprehension of the system as such.

Gaining a deeper understanding of creativity and its emergence has been featured in psychology research for decades [6]. Much previous research has focused on increasing the breadth and flexibility of idea search by e.g. providing stimuli on areas to explore (e.g. [56]). Current work in psychology, however, proposes that not only covering a wide basis for ideas but also persistent, in-depth exploration are important for creative outcomes [35]. In conjunction with research on group facilitation, this proposition makes a number of possible interventions appear suitable to increase creative outcomes. Moreover, while facilitation by humans has been found capable of affecting creative processes, the question in how far such interventions can be carried out by information systems emerges when considering advances in intelligent systems.

Against this backdrop, we pose the following research question:

> How do digital systems support flexibility, persistence, and thus creativity in innovation teams?

The current paper is a first step to answering this question. By drawing on extant literature in psychology and information systems, we develop hypotheses on the effects of facilitative interventions concerning the structure of and cognitive stimulation in an idea generation task. Interventions are targeted at either more breadth or more depth in exploration. In addition, drawing on extant knowledge in information systems, we hypothesize differences between facilitation conducted by a human versus a digital assistant. We test the hypotheses in an explorative lab experiment with 24 participants.

The remainder of the paper is structured as follows: First, we provide theoretical background information on creative teamwork and facilitation using information systems. Drawing on this basis, we develop the research model and hypotheses regarding facilitation of breadth and depth of idea generation. In the following, we present the method used before providing and discussing results. We end the paper in describing limitations and providing concluding remarks.

2. THEORETICAL BACKGROUND

We will briefly introduce extant knowledge on creative teamwork and facilitating group creativity using information systems.

2.1 Creative Teamwork

The organization of work in groups and especially teams is a widespread practice in today's companies and institutions [16], especially when the task to be accomplished is complex and requires creativity [30]. Creativity can be seen as a process, personal trait or product that brings previously unrelated aspects to form a novel outcome [4]. In a more operational sense, creativity has been judged based on criteria such as fluency, originality / novelty, flexibility, and persistence [47]. Seeking to understand how creative outcomes emerge, personality traits and cognitive abilities [5] have been assessed before environmental and social factors have been added to a componential model of creativity [4]. Research in cognitive psychology concerning this area has evolved in three stages [56]: Reasons for the comparatively lower performance of groups in brainstorming have been investigated before cognitive underpinnings of these effects became the focus, which were followed by a shift to measuring the quality in addition to the quantity of ideas.

As a representative of more nuanced evaluation of creativity, the dual pathway to creativity model proposes that both persistence and flexibility in the idea generation process can improve creative outcomes [23]. An overview of the model is shown in figure 1. Persistence describes the depth of exploration, i.e. to what extent a specific category is considered, whereas flexibility signifies the breadth of exploration, i.e. how many different categories are considered [35]. Context factors such as mood states or stimulation can influence whether individuals go down either path in creative tasks [1, 23, 35]. In group settings, it is to be expected that encouraging participants to be more persistent by taking more time for idea generation may compensate for the observed relatively lower performance of groups compared to individuals [38].

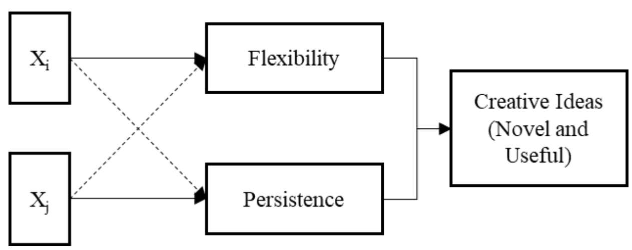

Figure 1 Dual Pathway to Creativity Model, based on [23]

Based on the findings of how groups work together, different approaches to facilitating group processes and outcomes such as creativity have been put forth. Providing structure regarding the process [57] or the task [9] is meant to encourage productive and inhibit unproductive behaviors [10]. Such interventions have been shown to increase the rate of idea generation [18] as well as their quantity and quality [1]. Whereas structural cues can be considered boundary conditions, cognitive stimulation is a content-related means enhancing creativity by leading individuals to consider a larger knowledgebase [49].

2.2 Facilitation Using IS Artifacts

Information systems specifically aimed at supporting creative work have been classified as creativity support systems [1] and group creativity support systems when applied to group settings [58]. While these systems are meant to foster creative performance, their use also can impose additional cognitive load, which needs to be ameliorated by e.g. structural facilitation [12]. Such tools can support the entire lifespan concerning idea generation from generating ideas to converging on promising candidates [19, 33]. Examples thus range from communication channels for electronic brainstorming [40], software to facilitate idea generation [34], to evaluation and decision support systems [19].

Interventions using digital artifacts rely on the previously identified concepts for facilitation such as structural support and cognitive stimulation. Structural interventions in the context of information systems can focus on both content, i.e. the process [57] and task [9, 19], or the use of technology as such [20]. Providing structure has been found to improve a number of outcomes such as the rate of idea generation [18] or uniqueness [55], whereas aiding in decision-making is reported to increase decision quality without changing the number of ideas [19]. Providing stimuli has been found to influence idea generation by e.g. sustaining or changing the category considered [52], leading to more in-depth exploration [1], or to boost creative output of less creative people [2]. Similar effects have been found for the subtler form of priming, in which stimulation may not be as salient, by e.g. using a video game setting to alter idea generation [8].

3. RESEARCH MODEL

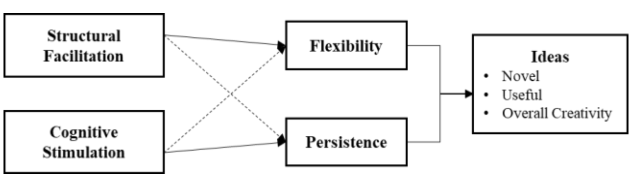

Figure 2 Overview of Research Model

Drawing on extant knowledge, we develop a general overview of the facilitative effects of structure and cognitive stimulation, which leads to hypotheses concerning the two pathways to creativity shown in figure 2. Additionally, we develop hypotheses on the differences between human and digital facilitation concerning performance, satisfaction, and perceived helpfulness.

As highlighted before, providing structure in creative processes has been found to positively influence outcomes. Concerning the observed inferior performance of groups in brainstorming [56], it has been put forth that the interference effects of within-team communication keep teams from working systematically [22], likely because structure determines the (mis)allocation of attention [42]. Moreover, how a group structures its work can lead to negative effects such as production blocking but also contribute to positive group performance [36]. Adequate structural facilitation has moreover been found to foster more in-depth exploration of categories [15] and increased rates of idea generation [18]. Examples of structural interventions include time-constraints [18], directed brainstorming [51], and guiding the process [1].

Another key means to facilitating group creativity lies in cognitive stimulation. Providing stimuli is described to lead individuals to explore larger parts of their knowledge [49]. In addition, the type of knowledge that is salient can be increased and adjusted to the situation at hand [37]. When the stimuli provided are in line with the category currently under consideration, ideation tends to stay within the bounds of this category. On the other hand, when stimuli refer to a different category, ideation follows suit [52]. Another difference in stimulation lies in its salience, which can range from the explicit introduction of stimuli to less salient priming, which can still increase individual cognition [7].

Considering the extant knowledge presented above, we expect a combination of interventions based on structure and cognitive stimulation to foster flexibility in group ideation. To this extent, structural interventions that push for more divergence seem promising. Examples include structures to keep group attention on the ideas of others [24]. In addition, cognitive stimulation with many diverse stimuli is expected to lead to e.g. more unique ideas [32, 37]. Combining these effects, we put forth:

> H1: Providing appropriate structure and cognitive stimulation triggers groups to ideate on the flexibility pathway.

Analogously to flexibility, it seems likely a combination of structural interventions and stimulation can enhance persistence in group idea generation. Providing structure can lead groups to more fully explore given categories [15], which links to the prescribed more systematic approach in the persistence pathway [35]. An example lies in curtailing the area of exploration to defined subcategories [48]. In addition, ideation outcomes can be improved for a given topic by activating knowledge closely related to the category under investigation through e.g. asking leading questions [49]. Combining these facilitation effects, we put forth:

> H2: Providing appropriate structure and cognitive stimulation triggers groups to ideate on the persistence pathway.

While the preceding arguments for positive facilitation have been independent of whether facilitation is provided by human or digital actors, a key interest of this research is digital facilitation. A digital facilitator capable of providing the interventions described previously is likely to take a special spot in the team based on the combination of roles as structural facilitator and cognitive stimulator with high or low salience. These combined roles arguably make the digital facilitator more like its human counterpart. Such an increase in humanness is expected to increase trust and thus acceptance [50]–eventually it may even make it appear to be a teammate [54]. This expectation coincides, however, with the assertion that the role of digital artifacts in group settings is hardly understood [28, 54]. The above argument can, however, be evaluated by drawing on research concerning chatbots. On the one hand, dialogs with chatbots tend to be of lower quality than with humans [25], which may reduce especially stimulation effects of facilitation. Digital facilitators may also draw attention away from the task and interrupt group interactions with bad timing, which may reduce team performance [43]. On the other hand, the facilitative features are limited to those deemed helpful, which may reduce nonproductive interruptions, and may make interruptions seem as purely informative breaks. Intelligent systems have been found to perform as well as human counterparts, especially in giving advice [50]. In addition, the digital facilitator may be seen as a neutral expert [29], which may make it more trustworthy. Balancing the expectation of humanness and explicitly helpful cues on the one hand and the less natural dialogs on the other, we posit:

> H3: There is no difference in the effects of facilitation between human and digital facilitators.

Beyond the more objective criterion of outcomes, it is worthwhile to consider perceptions of group members regarding the quality of facilitation. As a pars pro toto of perceptions, we consider the satisfaction of participants as an important basis for future adoption [11, 55]. Satisfaction is assessed concerning both the process and outcomes, i.e. ideas, to capture perceptions of net goal attainment [46]. Since we expect no differences in outcomes for digital facilitation, we put forth:

> H4a: There is no differences in satisfaction with ideas between digital and human facilitation.

Since interacting with a digital facilitator may be more cumbersome and not fully attain the same level of humanness, see H3, we expect differences in process satisfaction. Moreover, the lower quality interactions may cause irritations, annoy participants and thus reduce perceptions of helpfulness. We thus posit:

> H4b: Process satisfaction will be lower for digital versus human facilitation.

> H4c: Perceived helpfulness will be lower for digital versus human facilitation.

4. METHOD

4.1 Intervention Design

In order to test the effects of facilitation, we derived interventions for improved creativity in general as well as specifically for enabling flexibility and persistence. These interventions are equally meant for human and digital facilitation. Providing instructions is known to positively affect idea generation in brainstorming [41]. For example, the type of instructions provided affects output quantity [14]. In addition, rules such as giving time for individual brainstorming without group interaction can alleviate issues of production blocking [24]. Based on these findings, the following interventions were used for all sessions:

> *G1: The facilitator encourages teams to go for quantity.*

> *G2: The facilitator provides teams with general rules for brainstorming.*

> *G3: Teams get time for individual brainstorming to minimize effects of production blocking.*

Both structure and cognitive simulation are expected to help with achieving flexibility in ideation. To achieve attention to ideas of others, which leads to more useful ideas [31], a structural cue is implemented in F1. The procedural structure is supported by using a stakeholder map [13] providing an overview of categories and their relations. In addition, cognitive stimulation is used to achieve more creative outcomes. This leads to the following two interventions:

> *F1: The facilitator gives instructions to brainstorm for categories first, in order to cover more categories than in conventional brainstorming, which should inspire the next brainstorming on the task itself as more categories are salient.*

> *F2: The facilitator provides external stimuli in the form of new (and not yet mentioned) categories and analogies.*

Analogously, to induce persistence, structural facilitation aims at limiting the search scope to a small segment, which should be explored in-depth. Brainwriting increases exposure to the ideas of others further by having participants write down ideas and passing them on to others for continued elaboration, which has been found to increase unique ideas [24]. As cognitive stimulation priming participants with leading questions has been proposed to increase productivity within the category [49]. We thus use the following strategies for facilitation:

> *P1: The facilitator asks questions to activate knowledge prior to brainstorming (priming).*

> *P2: The facilitator suggests groups to perform brainwriting to motivate group members to pay close attention to and build upon others' ideas.*

4.2 Implementation

Drawing on the dual pathway to creativity model [35], we operationalize the outcomes of facilitation concerning the two dimensions process and characteristics of ideas generated. Ideas are evaluated based on novelty, usefulness, and overall creativity [1, 3]. The process is assessed based on fluency, i.e. number of ideas generated [47], breadth (flexibility) and depth (persistence) [23, 35]. To allow for assessing process variables, ideas are categorized based on goals and means [22], which allows for counting the number of categories as breadth of exploration. Depth of exploration is taken as fluency divided by breadth. Satisfaction is assessed using a slightly adapted version of the scale by Reinig [46], whereas for perceived helpfulness three items have been developed covering ease of use, helpfulness, and distraction. As controls, familiarity of group members, diversity based on experience and characteristics related to the technology and task, as well as averages of openness to experience [27], creative thinking capability [53], and intrinsic motivation [17] have been included. All items were implemented with 7-point Likert scales.

We conducted eight sessions in laboratory settings with three participants each, mostly with a university background. Each session lasted for about 60 minutes and covered the two previously covered topics "how to retain health" [39] and "how to improve university" [31]. Before and after each of the two brainstorming tasks, forms were administered to collect survey responses.

The lab study was set-up as a 2x2 design. Digital versus human facilitation was altered between subjects, whereas flexibility and persistence were surveyed within subjects. All sessions were divided into four segments: An introduction to the task and use of the general facilitation strategies G1 and G2 are followed by F1 or P1, depending on the treatment. For all treatments, participants get time for silent brainstorming before being exposed to strategy F2 or P2, which leads to the final documentation phase. Digital facilitation was implemented as a prototype of a digital voice assistant built on the Google DialogFlow programming system. Whereas the human facilitator intervened between the respective sections, the digital facilitator had to be woken up by the team to provide its input. Analogously to a menu selection it would ask for the current stage of the group to provide the appropriate instructions. More information on the digital assistant can be obtained from the authors.

Using the process by Diehl [22], one of the authors coded the ideas generated by the groups regarding goals and means. The results were rated on novelty, usefulness, and overall creativity by three Design Thinking coaches, including another author. The scale midpoint was taken to classify ideas as high or low [49]. This data was analyzed in conjunction with the survey data. Correlations and hierarchical regressions concerning control variables, facilitation treatment, and facilitation medium were conducted using R and additional libraries.

5. RESULTS AND DISCUSSION

Most of the hypotheses concerning (digital) facilitation were supported. While the standard threshold of agreement between

Table 1 Correlations of Process and Outcomes Variables

	M	(SD)	1	2	3	4	5	6	7	8	9	10
Outcome variables (# of ideas)												
1) Novel	10.88	7.97	-									
2) Useful	15.88	4.65	0.76*** (.0007)	-								
3) Creative	12.63	7.89	0.97*** (.0000)	0.78*** (.0004)	-							
Process variables												
4) Fluency	30.06	8.05	0.83*** (.0001)	0.74** (.0010)	0.78*** (.0004)	-						
5) Flexibility	18.88	5.46	0.75*** (.0009)	0.63** (.0093)	0.74** (.0011)	0.79*** (.0003)	-					
6) Persistence	1.63	0.34	0.10 (.7211)	0.16 (.5638)	0.02 (.9311)	0.27 (.3077)	-0.36 (.1719)	-				
Group differences (controls)												
7) Familliarity	2.81	1.11	-0.52* (.0410)	-0.45† (.0781)	-0.44† (.0852)	-0.51* (.0427)	-0.35 (.1786)	-0.30 (.2547)	-			
8) Avg openness to experience	4.92	0.62	0.60* (.0149)	0.69** (.0029)	0.61* (.0129)	0.56* (.0239)	0.39 (.1323)	0.24 (.3789)	-0.31 (.2390)	-		
9) Avg creative thinking capability	6.13	1.83	0.51* (.0441)	0.61* (.0114)	0.49† (.0540)	0.68** (.0040)	0.50† (.0511)	0.29 (.2813)	-0.56* (.0251)	0.81*** (.0001)	-	
10) Diversity	8.72	5.06	-0.24 (.3627)	0.01 (.9750)	-0.20 (.4464)	-0.07 (.8054)	-0.06 (.8281)	0.05 (.8510)	-0.06 (.8326)	0.41 (.1161)	0.56* (.0245)	-
Treatments												
11) Flexibility/persistence			0.24 (.3643)	-0.06 (.8380)	0.26 (.3273)	-0.02 (.9296)	0.47† (.0645)	-0.74** (.0011)	0 (1)	0 (1)	0 (1)	0 (1)
12) Digital/physical			-0.24 (.3643)	-0.14 (.6078)	-0.08 (.7633)	-0.06 (.8365)	0.07 (.7942)	-0.30 (.2660)	0.41 (.1177)	-0.02 (.9392)	-0.02 (.9311)	0.21 (.4243)
13) University vs. health topic			-0.05 (.8581)	-0.03 (.9186)	0.10 (.7176)	-0.07 (.7906)	-0.14 (.6004)	0.10 (.7128)	0 (1)	0 (1)	0 (1)	0 (1)

N = 16. †p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001; two-tailed p-values; dummies: flexibility = 1, digital = 1.

Table 2 Correlations of Treatment and Subjective Perceptions

	M	(SD)	1	2	3	4
Idea and process satisfaction (Avg)						
1) Intrinsic motivation	5.94	0.65	-			
2) Perceived helpfulness of assistant	4.75	0.97	0.28 (.2904)	-		
3) Satisfaction with ideas	5.38	0.55	0.80*** (.0002)	0.09 (.7310)	-	
4) Satisfaction with process	5.67	0.73	0.93*** (.0000)	0.40 (.1261)	0.85*** (.0000)	-
Treatment						
5) Digital vs. physical facilitation			-0.17 (.5398)	-0.82*** (.0001)	0.08 (.7714)	-0.30 (.2511)

N = 16. †p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001; dummy: digital = 1.

raters has not been attained [21] and all ratings are relatively high, this can be explained by the open ideation task that per se should foster creative outcomes.

As hypothesized, the facilitation strategies show the expected positive relations with the respective process measures. The flexibility treatment is positively correlated with the flexibility process variable, which is mirrored in the regression models. Analogous results are discernable for the persistence treatment. This supports H1 and H2. Concerning the differences between digital and human facilitation, we obtained mixed results. In terms of objective performance differences, correlations show a negative, albeit insignificant, tendency of digital facilitation, whereas regressions show mixed yet insignificant results. This leads us to tentatively support H3. Concerning the subjectively perceived differences, we observe a highly significant negative correlation with perceived helpfulness, supporting H4c, and insignificant effects on idea and process satisfaction, which tentatively supports H4a. H4b is rejected since the negative relation with process satisfaction is quite insignificant.

Beyond descriptive analyses, we discuss implications of results for information systems design and analysis in group contexts and related potentials for future research.

Our results indicate that interventions to invoke the specific pathways to creativity also work when administered by a digital facilitator. This result is all the more noteworthy considering the prototype status of the assistant, which required for example manual activation after each segment. These results could, however, be due to a lack of overall helpfulness of facilitation. While we do not deem this option likely, it could have been that groups perform just as well without any facilitation. To rule out this option, it may be worthwhile to add a control group with no facilitation at all.

Results add to extant findings on the facilitative capabilities of information systems for creativity [60] and the effects of using intelligent systems in group settings [54]. In this context, the marked difference between objective and subjective results is worth considering. The more objective results of only insignificant differences between human and digital facilitation in terms of process and outcome variables may imply that even in the challenging context of creative tasks, digital facilitation is nearly on par with human counterparts, mirroring findings of good task-based outcomes of intelligent systems [50]. This could be due to the relatively stark emphasis on structural facilitation, which has been shown to work well in settings with digital interaction [18]. Given the similarity of the voice assistant to a chatbot, this result is also in line with findings that human language use can be transferred to intelligent systems [25]. It should, however, be noted that the assessment criteria and procedure may have failed to capture existing differences in outcomes.

Considering more subjective outcomes related to participant perceptions, the highly significant difference in perceived helpfulness stands out. This difference in perceptions is curious when interpreted in light of the proposed relations between intelligent system characteristics and the work setting. It has been proposed that these attributes interact to change team outcomes and process variables such as affective and cognitive concepts [61]. Given the relatively short duration of the sessions, it may be the case that time was not sufficient for adverse effects on objective outcomes. An interesting interpretation arises from the joint consideration of the relations of digital facilitation with persistence and perceived helpfulness: Both are negative compared to the human counterpart, albeit significantly only for the subjectively perceived helpfulness. This perception may, however, have caused participants to be less persistent in exploration, which would constitute an indirect negative objective effect of digital facilitation. It thus seems worthwhile to investigate digital facilitation over extended periods of time and to seek out why perceived helpfulness is markedly lower. A possible explanation lies in the interaction with the digital system. The assistant had to be woken up for each interaction and told which phase users were in. Given this arguably low quality in interaction [25], it may be the case that the digital facilitator missed a markedly human touch, which has been found to be a main determinant of adopting intelligent systems [50]. It thus seems we are not (yet) on the brink of humans being readily replaced by voice assistants.

Table 3 Results of Hierarchical Regression

Explanatory variables	Process variables			Outcome variables (# of ideas)		
	Flexibility	Persistence	Fluency	novel	useful	creative
Intercept	11.51 (12.97)	1.42 (1.0)	12.68 (12.64)	-17.96 (12.54)	-4.91 (8.88)	-20.86 (14.01)
1 - Group differences						
Familliarity	0.56 (1.61)	-0.06 (.12)	0.52 (1.57)	-1.45 (1.56)	-0.54 (1.10)	-1.03 (1.74)
Avg openness to experience	-1.28 (3.82)	0.04 (.29)	-1.12 (3.71)	6.79 (3.69)†	4.25 (2.61)	7.47 (4.12)†
Divergent thinking cap.	2.92 (1.75)	0.03 (.13)	**5.13* (1.71)**	1.45 (1.69)	0.77 (1.20)	1.16 (1.89)
Diversity	-0.58 (.34)	-0.01 (.03)	**-1.08 (.33)****	**-1.04 (.01)***	-0.37 (.23)	**-0.94 (.03)***
Topic	-1.50 (2.51)	0.065 (.19)	-1.13 (2.44)	-0.75 (2.42)	-0.25 (1.71)	1.50 (.59)
R2	0.44	0.13	0.75	0.75	0.64	0.69
F(5.10)	1.57	0.3	**6.15****	**6.10****	**3.51***	**4.37***
2 - Pathway						
Flexibility / persistence treatment	**5.0 (2.05)***	**-0.48 (.12)****	-0.38 (2.57)	3.75 (2.23)	-0.5 (1.80)	4.0 (2.52)
R2	0.66	0.67	0.76	0.81	0.64	0.75
F(6.9)	2.94†	3.06†	4.63†	**6.49****	2.66†	4.62*
ΔF	**5.89***	**15.56****	0.02	2.52	0.07	2.45
3 - Facilitation						
Digital / physical facilitation	2.27 (2.38)	-0.17 (.14)	1.80 (3.09)	-0.01 (1.0)	0.23 (2.21)	2.56 (2.96)
R2	0.70	0.72	0.77	0.81	0.64	0.78
F(7.8)	2.63†	2.96†	3.73†	**4.95***	2.03	**3.96***
ΔF	0.91	1.45	0.34	0.00	0.01	0.75

N = 16. †p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001; two-tailed p-values; dummies: flexibility = 1. digital = 1.

Notes: Values represent unstandardized regression coefficients. with standard errors in parentheses

These observations also relate to the question how future collaboration between humans and intelligent systems will be designed. With intelligent systems effectively becoming team members, the interesting question how work will be divided arises: Who will be in a position of authority? How are group processes and outcomes affected? Drawing on known effects of authority distribution on cooperation between humans and intelligent systems [26], it is an interesting note that the digital system in this study was a facilitator giving instructions, attributing it relatively high authority. Since the digital facilitator was meant to have a natural, human-like appearance, participants may have let it gain control of their work [26]. This explanation is to some extent backed by the insignificant effects regarding satisfaction with ideas and the process. Participants may have perceived the interaction as not helpful, yet considering the annoyance in communication, were relatively satisfied with the process and their outcomes. To test this proposition, it would be necessary to test the effects of digital and human facilitation in a within-subjects design. Moreover, our results based on the dual pathway model imply that future designs of information systems should consider known nuances in group processes. Since facilitating the respective pathway is likely feasible, systems that aim at improving creativity may achieve superior performance if more targeted approaches are used.

Intertwined with decisions concerning the design of collaboration is the issue of a lack of knowledge on how technology artifacts and their design influence group interactions [1]. Changes in the design and characteristics of intelligent systems have been proposed to interact with task and human characteristics to influence both objective and subjective group processes and lastly outputs [61]. Additionally, more far-reaching issues may arise such as boundaries to developing relations with intelligent systems or possible political implications [54].

Judging from these issues, the already challenging task of determining antecedents and drivers of group performance is set to become markedly more complex by the involvement of intelligent systems. While these systems become more intelligent, their reactions still are not equal to humans and thus may make approaches of human groupwork not directly applicable to human/system workgroups. Research on the effects of information systems in groupwork may benefit from evolving from treating technology artifacts as objects with set purposes to a more sociological perspective. Considering the gravity of these issues and their intertwined nature, a co-evolution of designing systems and learning about their effects on teamwork seems promising.

6. LIMITATIONS

Also given our intention of initial exploration of digital facilitation, the current study has several limitations. We have only included a relatively small number of participants with a relatively homogeneous university background. In addition, the brainstorming task and chosen topics may have skewed results since the need for facilitation may have been perceived as too low. As a methodical observation, the agreement between raters on the characteristics of ideas was not as recommended in literature, which may limit the interpretation of results concerning the ideas themselves. Moreover, validation of the scales used to measure the underlying constructs would help draw more substantiated conclusions. In addition, our analysis of the effects of facilitation on process variables and outcomes is limited. A more comprehensive analysis of mediation effects may generate additional and more reliable insights. Moreover, the digital facilitator was only a prototype built on the Google DialogFlow system, which imposed constraints in terms of direct usability.

7. CONCLUSION

Information systems have proliferated in the workplace to support now virtually any activity, including creative groupwork. Given the nascence of intelligent systems, which go beyond "passive" information systems and may be perceived closer to humans, we investigated the question how well a digital facilitator is able to help in conducting a group idea generation task. We drew on the dual pathway to creativity model and extant knowledge on (digital) facilitation to derive a set of facilitative interventions, which have been implemented in a digital voice assistant. Hypotheses state that facilitative action concerning structure and cognitive stimulation is able to foster persistence or flexibility, respectively, in idea generation. Moreover, we expected the digital facilitator to perform equally to its human counterpart on objective measures but to show deficiencies in subjective evaluations. The performance of the digital facilitator has been tested in a 2x2 lab experiment with 24 participants. Results mostly support hypotheses with facilitation successfully influencing idea generation processes. The digital facilitator did not perform significantly differently compared to the human one considering objective criteria and satisfaction. It did, however, significantly fall behind in terms of perceived helpfulness. Our results add to the currently vibrant discussion on researching collaboration between humans and intelligent systems.

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[redacted] P6: Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance

Table AX6: P6: Stray Off-topic to Stay On-topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance

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Stray Off Topic to Stay On Topic: Preserving Interaction and Team Morale in a Highly Collaborative Course while at a Distance

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Abstract:

The coronavirus disease of 2019 (COVID-19) pandemic has prompted schools and universities to shift their teaching to virtual classrooms from one day to the other. As a unique example, we had to virtualize the second half of a two-semester course on human-centered innovation, which heavily relies on direct interaction with and among students in small groups. In going virtual, we found adapting assignments to be only the tip of the iceberg. Despite being familiar with the students, we faced challenges in preserving high levels of creative interaction and in surveying team morale and status. Reflecting on our experiences, we detail solutions related to the lack of creative interaction by fostering off-topic chit-chat and surveying team morale by introducing more explicit communication and seeking team consent. To help teachers adapt to virtual teaching, we discuss how our mitigation approaches, which we developed in an extreme setting that required close, creative collaboration, may apply to virtual teaching in general.

Keywords: Design Thinking, Practical Course, Virtual Teaching, Interaction, Team Morale.

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1 Initial Situation

As the coronavirus disease of 2019 (COVID-19) pandemic unfolded, we faced the challenge of virtualizing a unique university course on human-centered innovation, which we run as part of the SUGAR network for design innovation (see Wiesche et al. (2018) for an overview of the curriculum). Compared to conventional seminars, the course requires many resources and close, creative collaboration with and among student teams. Over nine months, nine students from diverse backgrounds intensively collaborate in two design thinking teams to solve real-world challenges that company partners pose. As is typical for design thinking, students solve “wicked” problems without definitive answers (Buchanan, 1992) and, thus, need to embrace ambiguity (Leifer & Steinert, 2011). Students perform an entire design thinking cycle: in understanding stakeholders’ needs in depth, they gain a foundation for ideating potential solutions, which they iteratively test with users and refine (Hasso Plattner Institute of Design at Stanford, n.d.; Uebernickel et al., 2020). Thus, teams complete diverse tasks from developing software to devising business models and have to integrate different perspectives, which their diverse backgrounds aid. Students need to create physical prototypes and collaborate with teachers, other students, and external parties for, for example, observations and prototype testing.

Before the COVID-19 pandemic, the course heavily relied on direct interaction. Each week, we conducted a two-hour lecture for both teams and one-hour team sessions. Since embracing seemingly crazy ideas can foster innovation in design thinking (Bushnell, Steber, Matta, Cutkosky, & Leifer, 2013), the course promotes associative thinking, which includes socializing and straying off topic. While heavily encouraging face-to-face meetings, teamwork had been partly virtual from the outset. Throughout the course, the teams shared online documents and cloud storage. Further, the teams and teachers communicated through collaborative messaging software between meetings. Following the assessment of virtuality based on the shares of members working virtually, the share of time spent working virtually, and the physical distance between members (Schweitzer & Duxbury, 2010), the course had a partially virtual set-up. About 20 percent of meetings that involved teachers took place at least partially virtually. In these meetings, up to 50 percent of participants would join virtually. Physical distance between members can, however, be neglected since members would mostly only join virtually on single occasions due to, for example, conflicting appointments.

2 From Highly Interactive Face-to-face Meetings to a Virtual Course

Before the pandemic fully hit, the course had operated for close to six months. With an estimated workload of 20 hours for every student per week, the teams had already gone through teambuilding, developed routines, and had become familiar with one another—a factor that improves performance (Harrison, Mohammed, McGrath, Florey, & Vanderstoep, 2003).

In early March, 2020, both teams presented their latest prototypes at a large event, which included socializing and a joint dinner. Drawing on the collected feedback, the teams were supposed to iteratively refine their prototypes based on tests with users. However, two days after the event, we received instructions to shift all teaching to online courses. Rather than the established hybrid format, two virtuality dimensions (Schweitzer & Duxbury, 2010) suddenly changed to an extreme: students had to complete all work online, and students and teachers could no longer meet at the same location.

Going virtual constrained the many resources that the teams previously had at their disposal. Without unfettered access to physical prototyping tools, testees, or even teachers and teammates, exercises and deliverables had to change. We compensated for the lack of direct interaction by either shifting to online tools (e.g., a collaborative, virtual whiteboard and breakout sessions in video conferences) or adjusting content. For example, prototyping activities now focused on concepts and software prototypes rather than hardware elements. While these changes represented an abrupt departure from established ways in which we had taught before, we could keep much of the content and especially its logical flow. Despite being familiar with the students, we found coping with virtualization’s negative effects as they relate to team processes much more challenging.

3 Preserving High Levels of Creative Interaction

In going virtual, maintaining high levels of creative interaction constituted the primary challenge that we faced. In this section, we draw on the notion of social translucence to interpret our experiences and their practical significance. Social translucence can help one explore challenges in virtual collaboration (Bjørn &

Ngwenyama, 2009; Erickson & Kellogg, 2000) and can enable coherent discussions (Erickson & Kellogg, 2000), which makes it a potential approach to design collaboration systems (Erickson & Kellogg, 2000). Social translucence incorporates three elements: visibility, awareness, and accountability (Erickson & Kellogg, 2000). Visibility allows one to perceive relevant social information; awareness means that one knows about others' actions, context, and needs; and accountability implies that one can monitor and, if necessary, sanction actions (Erickson & Kellogg, 2000).

In going virtual, we noticed a drop in student participation and interaction both on and off topic. During lectures that involved both teams, most would keep their camera turned off, which, in our impression, greatly reduced interactivity and the visibility of reactions for both teachers and students. When asking questions or seeking input on, for example, prototype ideas, few students would engage in discussions. Moreover, students and teachers found it hard to discern who would like to speak next. This lack of visibility and awareness (Erickson & Kellogg, 2000) mirrors long-standing research on how reducing media richness (i.e., a medium's traits that relate to speed and the ability to pick up cues) may present issues due to reduced social presence (Kayworth & Leidner, 2002; Yoo & Alavi, 2001). We were, however, not concerned about changes in accountability: intrinsic motivation to work on the projects and pronounced social bonds in the teams may have created a sense of responsibility. Moreover, graded course deliverables created a need for action.

Sessions with individual teams, which focused on the progress on their specific projects, involved more extensive and open interaction and discussion. We noticed, however, a palpable reduction in interaction speed. Reduced visibility and awareness likely caused this decrease: even with video turned on, the virtual setting restricted interaction by nonverbal cues such as grinning excitedly, pointing at objects, or leaning forward to indicate the intention to speak. Consequently, exchanging and ultimately integrating thoughts took longer and was more tedious. In addition, we recounted fewer creative ideas than in face-to-face interaction.

Beyond the decrease in media richness and social presence, we noticed how virtual sessions with more off-topic chit-chat and general socializing tended to work much better than virtual sessions that focused solely on project-related topics. Design thinking should include open ideation (Hasso Plattner Institute of Design at Stanford, n.d.; Uebernickel et al. 2020), which extends to pursuing wild and seemingly high-risk ideas to obtain relevant results (Bushnell et al., 2013). Following these propositions, we had experienced before how an off-topic comment can be a catalyst for associative thinking and, thus, facilitate ideation. Whereas students naturally strayed off topic in face-to-face interaction, in the virtual setting, we noticed a tendency for students to strictly focus on content, which meant we had to encourage creative detours.

3.1 Leading by (Fun) Example

Compared to face-to-face meetings in the laboratory, we felt students perceived having to act more professionally in the virtual setting—possibly due to their restricted ability to have private conversations with teammates before, during, and after class. To create a fun, open atmosphere, we found it vital to lead by example; sometimes, we even established a "no shame" approach, such as joking at our own expense. In a basic effort to improve meeting ambiance and to encourage students to share video, we ensured teachers turned on their own camera first. In addition, we conducted a Zoom background contest that we also participated in: the student with the coolest virtual background would win a muffin from the teaching team. While diverting time from elaborating content, we found this truly joint team activity to create a sense of connection and an opportunity for chit-chat, which, in turn, aided creative elaboration in the team.

3.2 Drawing on Shared Experiences

To create an open, creative atmosphere, we also drew on shared experiences. Since we had worked with the teams for several months, we knew about some. By occasionally bringing up tales of what we had experienced together, we helped to get everyone's attention and boost creative work. For example, we brought up funny incidents from prototype testing months ago, which, in our impression, created a shared sense of purpose in the team.

3.3 Embrace and Plan for Going Off Topic

In fostering a creative atmosphere, we embraced opportunities and included elements that would help students stray off topic. When beginning team sessions, we conducted mini stand-up meetings and asked team members to summarize what they had been working on. To strengthen personal relations in this content-related exercise, we started sharing funny anecdotes from our personal lives. While we already included this practice in our routine for structuring physical meetings, we found that, in the virtual setting, it worked well to create a relaxed atmosphere. The stand-up meetings also acted as springboards for spontaneous off-topic discussions, which set the stage for creative associations. For example, one student recommended a whiteboard sticker to work from home. He explained how he used the whiteboard sticker—a large piece of adhesive plastic foil—to have a whiteboard on the door of his dorm room. Immediately, this simple product recommendation turned into an improvised enactment of a home shopping show. While not directly resulting in a project idea, the upbeat atmosphere helped everyone to associate elements in the subsequent discussion on deliverables.

In addition to such emerging opportunities, we also purposefully introduced elements for generating off-topic discussions. While we included humor, which can propel team performance (Lehmann-Willenbrock & Allen, 2014), when teaching in face-to-face mode, we found humorous elements helpful in attenuating the lack of visibility and awareness in the virtual setting. For example, to explain COVID-19 restrictions, we played a hilarious interview with a local politician who failed spectacularly at describing the new rules. The brief diversion created many laughs and helped to get past the solemn topic of restrictions.

4 Surveying Team Morale and Status

Not least due to fewer opportunities for serendipitous interaction, we found surveying team and member morale to be another vital challenge. Before the COVID-19 pandemic, teams worked in one laboratory during and between lectures. As such, we could walk by and spontaneously talk with students, which meant we gained visibility and awareness of the work they performed, the teams' ambiance, and whether they required support. Additionally, we had kept an open-door policy, which meant we sometimes serendipitously encountered students who came by our office for assistance or feedback.

We could not feasibly observe or serendipitously encounter students in the fully virtual setting, which reduced communication to two video conferences per week and collaborative messaging. Since teams had experience in virtual collaboration, the reduced communication did not seem like a challenge at first. Over time, however, we noticed teams exhibited less alignment on responsibilities and their projects' direction. Moreover, we found it harder to assess team morale since we lacked visibility and awareness of each member's status.

We tried to address this challenge via more explicit communication. In addition to offering help when deeming points critical, we now always encouraged teams to seek assistance by reiterating that they could contact us either as a team or individually. Moreover, we frequently asked teams about their workflow, deliverable status, any potential issues, or whether they needed support. Knowing that students sometimes hesitate to communicate potential problems, we tried to gain as much visibility as possible. For example, we followed up on even slight irritations (e.g., dissatisfaction with the time we allocated to certain content, which, in a co-located setting, we would not have addressed). As a more efficient way to get knowledge of potential issues, we sometimes approached individual team members for their impressions on their deliverables' status and teamwork. Using this approach, we gleaned helpful insights on, for example, task distribution.

While one needs to observe students for visibility and awareness, intruding on autonomous teamwork puts team morale at risk. Thus, we learned to explicitly seek teams' consent. Before the COVID-19 pandemic, we could naturally approach teams in the laboratory since they expected and saw us coming. In the virtual equivalent (i.e., breakout video sessions), we asked whether they approved our listening in. In several instances, teams expressed they wanted to stay private. Thus, we occasionally lost visibility and awareness but strengthened a trusting relationship, which likely proved more positive in the long run.

5 Lessons Learned and Conclusion

Adapting exercises and deliverables constituted an important aspect in our effort to virtualize our course on human-centered innovation. Despite our familiarity with students, which one could expect to boost productivity above and beyond rich media (Yoo & Alavi, 2001), continuing creative work required supportive measures to safeguard interaction and survey team morale. Nonetheless, we benefitted from our familiarity with students in implementing the outlined mitigation approaches, such as by being able to anticipate reactions to going off topic. Off-topic discussions and general socializing constitute a common thread among our approaches (which we summarize in Table 1) as opposed to structured exercises. To alleviate the observed lack of visibility and awareness (Erickson & Kellogg, 2000) in the virtual setting, we drew on more explicit communication and earlier interventions in several approaches. Relying on close, sustained collaboration and creativity among a familiar group, we acknowledge our setting represents an extreme case. In this section, we discuss how the concept of social translucence (Erickson & Kellogg, 2000) can help one identify issues in virtual teaching and how our approaches, which focus on improving visibility and awareness, may generalize to other settings with less familiarity or need for interaction.

Table 1. Overview of Mitigation Approaches

Mitigation approach	Example	Effect	Applicable to
Leading by (fun) example	Having teachers turn on camera	Relaxed, personal atmosphere	All settings
	Zoom background contest	Off-topic diversion, sense of connection, creative interaction	Collaborative creativity
Drawing on shared experiences	Bringing up funny incidents from previous meetings	Relaxed atmosphere, shared sense of purpose	All settings
Embrace and plan for going off topic	Stand-up meetings	Increased visibility, awareness, relaxed atmosphere	Close collaboration
	Building on off-topic comments and encouraging creative deviation	Creative elaboration, associative thinking	Collaborative creativity
	Adding humorous off-topic elements	Visibility and awareness, relaxed atmosphere	All settings
More explicit communication	Encouraging feedback seeking	Visibility and awareness	All settings
	Inquiring on status and impediments	Visibility, awareness, and accountability	All settings, especially close collaboration
Seeking team consent	Asking for permission to listen in on team meetings	Good personal relations, trust	Close collaboration

Our strong focus on team interaction seems to have also resonated with students. In an anonymous course evaluation focusing on virtual teaching that our department sent out, students reported a lack of direct interaction and pointed to overly lengthy discussions on content. Nobody, however, mentioned too much joking or too many off-topic discussions. While we adopted quite subtle approaches and students may not have explicitly noticed them, we found it reassuring that nobody took issue with them. Fostering off-topic chit-chat helped not only with creative elaboration but, in our impression, also established the course sessions as predictable and much-needed diversions from the hardships of the COVID-19 pandemic.

By providing criteria for classification, the concept of social translucence (Erickson & Kellogg, 2000) may help one identify issues in virtual teaching. The relative importance of the dimensions may, however, differ based on the context. One may see having visibility of others' actions or circumstances as a basic enabler to gain awareness of their needs and concerns (Bjørn & Ngwenyama, 2009; Erickson & Kellogg, 2000). In courses that require less creativity and close collaboration, such as lectures or large-group seminars, visibility and awareness become relevant for short-term, operational considerations such as whether students are at ease and can follow along. Courses that involve prolonged, intense collaboration may additionally require visibility and awareness of how teams function and social processes to ensure productive collaboration. Concerning accountability, we expect an inverse pattern. Long-term, intense collaboration can lead to deep social bonds; in our case, such collaboration made teams self-reliant. Thus, accountability did not pose an issue. Conversely, in courses that do not require close collaboration, accountability may constitute a central concern. If teams have shallow or lack social bonds, one may have to assure accountability using formal measures, such as strict rules and reports, which relates back to gaining visibility and awareness of operational considerations. We hope this short elaboration can help teachers to 1) reflect on their course requirements and 2) gauge whether they can trace issues to mismatched levels of visibility, awareness, or accountability.

Leading by (fun) example may apply to all settings albeit to a different extent. Actions that do not take extra time and that are not likely to spark discussions, such as teachers turning on their cameras to encourage video sharing, may make for a more relaxed and personal experience in any setting. One may reserve our more extensive approaches, such as the "no shame approach" (e.g., joking at our own expense) or background contests for when one needs to ensure high levels of creativity and interaction more than convey course content. In courses with shallower social bonds and short-term collaboration, it may especially be inappropriate to reduce the perceived need to act professionally.

Drawing on shared experiences may be appropriate for all settings. If there are no joint experiences from the course, mentioning collectively known places, events, or rituals such as campus life or sporting events will likely work well as an icebreaker. Such icebreakers can help students and teachers build rapport in face-to-face interaction, but we found them really decisive in a virtual setting. They ameliorate the limited ability to get to know others and their habits through, for example, body language. We found that reports on shared experiences made teachers more relatable and, thus, possibly increased student participation and satisfaction.

Embracing and planning for going off topic may apply to different extents. Analogously to drawing on shared experiences, we see integrating humorous elements, such as personal anecdotes, as universally applicable to create a relaxed atmosphere. What constitutes an appropriate diversion likely depends on the course setting, student group characteristics, and teacher preferences. If a course does not require significant interaction or associative creativity, we would suggest limiting discussions by curtailing student comments on funny elements. Similarly, if individual performance takes precedence over collaboration, stand-up meetings may require strict time limits or may not be worthwhile at all.

Encouraging students to seek feedback may be vital in all virtual teaching to increase visibility and awareness of students' needs. Inquiring about status, which additionally can increase accountability, may be most relevant for prolonged, intense collaboration. While increasing the need for team status visibility, long-term collaboration allows teachers to better judge potential biases in student reports. Seeking team consent to join meetings may only be relevant for close collaboration. In most settings, students working in breakout video sessions set up by teachers would likely expect them to join eventually.

In our course, which required much creativity and close collaboration, our measures increased student engagement. However, we acknowledge straying off topic has its perils. In a more conventional setting or with less intrinsically motivated students, some approaches may be inappropriate. Adding to the rich body of research on the role that media plays in virtual teams, our propositions foremost practically exemplify how one has to consider how one uses different media versus such media's characteristics (e.g., Bartelt & Dennis, 2014; Espinosa, Nan, & Carmel, 2015). We encourage teachers to not only adapt content but to also emphasize atmosphere and team dynamics in going virtual. Hopefully, our proposed measures stimulate educators to experiment with how they can foster performance in virtual classes, especially when seeking creativity.

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[redacted] P7: The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective

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The Influence of Agile Practices on Performance in Software Engineering Teams: A Subgroup Perspective

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ABSTRACT

This research explores the influence of the agile practices daily stand-ups and retrospectives on negative effects of subgroups, i.e. of having several smaller groups within a team, on group conflict, satisfaction, and performance. Based on extant literature in agile software development (ASD) and group research, a model of effects of ASD practices and the constructs elaboration, i.e. direct sharing, of information and team reflexivity, i.e. how much teams reflect on processes and outcomes, is developed and assessed using a survey of agile teams. Previous findings on negative effects of subgroups on conflict and satisfaction are corroborated in an agile setting. Retrospectives enhance team reflexivity and elaboration of information. As expected, elaboration of information significantly attenuates effects on conflict. Surprisingly, reflexivity is seen to further exacerbate the negative effects of perceived subgroups on conflict and satisfaction.

Keywords

agile software development; subgroups; daily stand-up; retrospective; team dynamics.

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1. INTRODUCTION[i]

The agile manifesto is arguably the very basis on which most agile software development (ASD) methods are built. It prominently calls for putting people first in development activities–as opposed to processes or documentation [3]. As an operationalization of this proposition, ASD has been described to promote diversity in work teams [29]. This is to say team members differ regarding for example gender, age, or functional background [28]. Diverse team members can contribute diverse viewpoints, which fosters creativity, problem-solving, and ultimately achieves "agile," efficient response to change [28, 32]. As an example, a team comprised of both women and men, young and old members, who are trained in different areas such as business and computer science, can draw on a rich repository of different viewpoints and experiences. Even members having suffered project failures can bring positive effects [34].

The preceding description suggests increased diversity as a sure bet to increase performance. There is, however, research describing negative consequences of diversity, which may hinder progress in ASD projects. For example, the above-mentioned diverse viewpoints can clash and thus increase team conflict [33]. In turn, conflict has been found to reduce performance of agile practices [13]. How do such negative effects come about? Members of diverse groups may bond with people they perceive as similar to them. Such behaviour can lead to the emergence of subgroups in a team that act in opposition to one another and thus lead to increased conflict [28]. Emergence of perceived subgroups is described to be dependent on contextual factors, e.g. how much a group is kept together by a shared goal [28].

With its foundation in the agile manifesto and the resulting propositions how development projects should be executed, ASD has been described several times to shape a unique working environment. ASD has been characterized by several terms: it has been said to be about change and feedback [52], to be a cooperative game [6], and to be a culture of its own [49]. Given the consistent description of far-reaching effects and benefits of ASD, it stands to reason that using ASD practices may constitute a contextual factor that moderates the negative effects of subgrouping.

We are, however, not aware of any research that has empirically tested the effects of using ASD practices on subgrouping effects, which is a critical void since effects may have far-reaching implications for team dynamics and thus project success. Drawing on subgroup theory and extant literature in ASD, we therefore pose the following research question:

What are the effects of the ASD practices daily stand-ups and retrospectives on the effects of perceived subgroups?

In order to answer this question, a model of the effects of subgroups on team outcomes and the moderating effect of daily stand-ups and retrospectives is analysed and validated using a survey among ASD teams.

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2. THEORETICAL BACKGROUND

We provide a brief overview of extant works on teams in agile software development, subgrouping and its effects, as well as proposed moderators of subgrouping effects.

2.1 Teams in Agile Software Development

ASD has been described as very impactful in computer science during the past years [10] and found to significantly improve success of projects [42]. A common thread in ASD methods is harnessing heterogeneous project teams [29] and promoting people aspects, as prominently put forth in the agile manifesto [3]. For the purpose of this research, we see ASD practices, e.g. daily stand-up meetings [46], as constituents of ASD methods or frameworks, e.g. Scrum or eXtreme Programming.

While ASD has been described to be mostly based on practitioners' experiences and to be underresearched in academia [10], research has made strides to understand how exactly ASD works and its effect on final outcomes. In this quest, different levels of abstraction have been considered.

At the team level, the picture of a special type of work environment is corroborated on several dimensions. At a general level, ASD projects are characterized as complex adaptive systems, which means team dynamics cannot be explained by investigating team constituents since they are constantly changed by inputs and outputs–leading to a need for constant communication [1]. For insights into this complex adaptive system, social aspects have been studied extensively in ASD research [10] on a wide range of topics such as recruitment and training, social skills, or conflict [7, 13]. Naturally, characteristics of members are also of relevance [50]. Considering work principles in ASD teams to incorporate a culture of change and feedback [52], and to heavily emphasize direct interaction via face-to-face communication [3]. From a structural perspective, decentralized work, which is typical of ASD, has been found well-suited for coordinating expertise in design tasks, but less beneficial for completing technical tasks [26]. Adding the influence of context factors, a complex trade-off interaction with the effects of ASD has been described: Autonomy and diversity impact ASD work differently, which in turn has differential effects on project success [29].

Agile practices have been found to improve project success, e.g. through helping teams to achieve shared cognition [41]. As an example of an individual practice, pair programming has been described to have several positive effects, e.g. increased satisfaction in programmers [2]. These effects are, however, also found to be contingent on contextual factors, e.g. task complexity [15], and therefore do not come to fruition in every case. As with other methodologies and tools, use thus should be considered carefully [51].

To put it briefly, current evidence points to generally positive effects of ASD but investigations at more detailed levels expose these effects to be contingent on specific situational factors. It is thus hardly possible to anticipate the effects of ASD in a given situation.

2.2 Subgroups and their effects

Subgroups can be defined as entities comprised of members sharing a distinctive common relation based on their characteristics. These entities form part of a larger, overarching team [5]. Emergence and dynamics of subgroups can be predicted by so-called faultlines, which are based on e.g. demographic attributes [28]. Faultlines that go unnoticed have been said to be "dormant" and can become "active," i.e. as perceivable subgroups [21]. Figure 1 provides an exemplary case, in which job title, sex, group size, and geography align to form highly distinct subgroups.

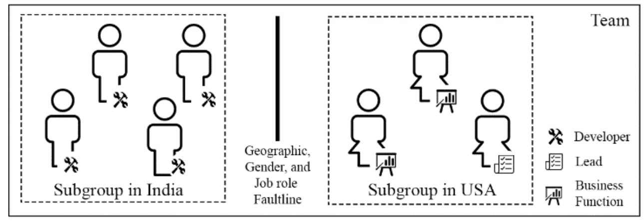

Figure 1 Exemplary illustration of subgroups based on several characteristics, adapted from [27]

According to meta-analytic review, both dormant and active faultlines have been found to negatively affect team outcomes with active faultlines showing stronger effects. Specifically, performance, satisfaction, and conflict have been studied [45]. If conflict arises, each subgroup may act as one cohesive entity in opposition to all other groups, which in turn reinforces subgrouping behavior [28]. The choice of development methodology has been found to influence the basis for subgroup formation with agile teams showing groups based on previous ties [35].

Albeit most research emphasizes the negative effects of faultlines and subgrouping, previous meta-analysis also cites instances in which faultlines are seen to be positive [45]. Since most research focuses on the negative implications of faultlines and subgroups, we constrain our investigation to negative effects.

2.3 Moderators of subgroup effects

The emergence and impact of subgroups are described to be contingent on situational factors [28]. Several known moderators have been proposed to fit conceptionally with ASD practices [27]. *Elaboration of information* and *team reflexivity* will be described in the following as examples of such moderators.

Elaboration of information is described to be a key mechanism through which diversity can benefit team performance: "Elaboration is defined as the exchange of information and perspectives [... and] the process of feeding back the results of [...] individual-level processing into the group" [25]. Means of directly sharing knowledge are described to enable easy communication, which reduces task conflict and thus is proposed to deactivate faultlines [23]. Such direct communication facilitates constructive discussions, which can prevent misunderstandings and thus ensure smooth teamwork.

Team reflexivity has been found to moderate the negative effects of perceived subgroups on performance [47]. It encompasses discussions of processes, task-related issues and members' reflections on group goals and strategies [40]. The aspects of team reflexivity enable team members to render themselves a more detailed picture of their current context, to identify and mitigate information-sampling biases, and lastly to consider information beyond the perceived subgroups they may belong to [8, 47]. As another consequence, members may develop a shared understanding of the task at hand and its requirements [12], which enables members to reframe cognitive representations, and lastly helps transcending intergroup bias, and thus to mitigate conflicts [23].

3. RESEARCH MODEL

Subgroups are described to negatively affect team dynamics and outcomes. These effects are, however, dependent on context [28] and multiple moderators have been proposed in literature. Several of these seem conceptionally very close to core principles operationalized in ASD practices [27]. This leads us to propose that using for example daily stand-ups or retrospectives may attenuate the effects of subgroups. We chose these two practices since they are widely applied [48] and share common characteristics, see below. Figure 2 offers an overview of the research model. In the following, we will motivate each hypothesized interaction.

Effect of subgroups on conflict and satisfaction

Subgroups have been found to increase task and relationship conflict as well as reduce satisfaction, cohesion, and performance [21, 44]. At a more detailed level, negative categorization is summarized to lead to frustration, anxiety, and discomfort in teams [21], which in turn decrease satisfaction and increase conflicts. While these observations and propositions have been made in the domain of general group research, we expect them to hold in the context of ASD and thus posit:

H1a: Perceived subgroups negatively influence satisfaction in agile software development teams.

H1b: Perceived subgroups positively influence the prevalence of conflicts in agile software development teams.

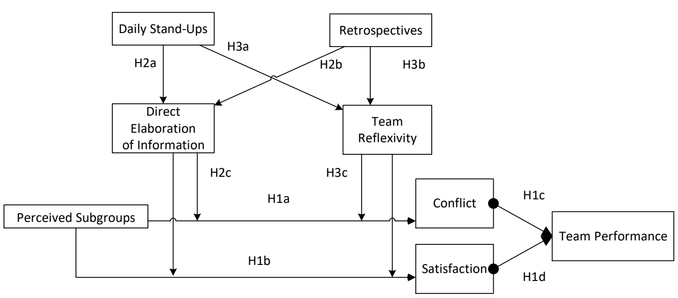

Figure 2 Overview of research model

Relation between conflict, satisfaction and performance

Moreover, the relation between conflict, satisfaction, and performance is to be validated. Previous research has described both task- and relationship-conflict to be detrimental to performance [9]. In addition, conflict has been linked to reduced cohesion, cooperation, and support [21]. While satisfaction has been found to positively correlate with performance, meta-analytic research discusses the possibility this result may be spurious [4]. Since this relation is not the focus of this research, we limit our model to the expectation of a positive relation. Combining extant research, we posit:

H1c: Satisfaction positively influences the performance of agile software development teams.

H1d: Conflict negatively influences the performance of agile software development teams.

Elaboration of information, i.e. especially face-to-face communication, has been described to be beneficial in attenuating negative effects of subgroups and to reduce task conflict [23]. These positive effects have also been reported in the realm of software development: direct forms of communication are seen to foster knowledge on members' capabilities and a common understanding of tasks [16].

At a theoretical level, ASD supports elaboration of information by prescribing direct, face-to-face communication [3]. Moreover, ASD oftentimes is conducted in collaborative workspaces, which support communication [30]. In addition, ASD extends the requirement of frequent and informal communication to business people [20], which arguably can help in bridging professional divides.

At the operational level, practices such as daily standups provide a venue in which communication helps achieve work outcomes [24]. Arguably, this assertion extends to retrospectives, in which members are expected to communicate on past issues and experiences–thus integrating personal information with collective group memory.

Empirical results support the preceding argumentation since ASD practices have been found to improve team communication [36]. Given theoretical and empirical descriptions of how ASD fosters communication in teams and evidence of such communication being a moderator of subgroup effects, we posit:

H2a: Daily stand-ups positively influence the elaboration of information and knowledge in agile software development teams.

H2b: Retrospectives positively influence the elaboration of information and knowledge in agile software development teams.

H2c: ASD practices moderate the negative relationship between perceived subgroups and performance/satisfaction and the positive relationship between perceived subgroups and team conflict through the elaboration of information.

Team reflexivity–defined as discussing task-related issues, processes, and reflecting on group goals and strategies [40]–has been found to create a shared understanding in groups [12], which in turn is described to attenuate subgroup effects [23].

The construct of team reflexivity can be readily related to ASD: Reflexivity forms part of the core principles put forth in the agile manifesto [3] and ASD practices, e.g. stand-ups require team members to reflect on their behavior and performance [53]. Retrospectives for reflecting on how things have been done and what has happened during a project increment have been described as a critical success factor in agile work and been recommended to be done habitually [6].

Theory on shared mental models as outcomes of team reflexivity has been used to theoretically describe the effects of three agile practices [53]. Empirical evidence points to the creation of shared mental models through using ASD, which in turn improve performance [41]. Moreover, the presence of shared mental models has been related to effective work in ASD [22].

Extant evidence describes team reflexivity as a moderator of subgroup effects. ASD methods and practices put a strong focus on reflexivity and have been linked to contribute to and profit from shared mental models. Drawing on this extant research, we posit:

H3a: Daily stand-ups positively influence team reflexivity in agile software development teams.

H3b: Retrospectives positively influence team reflexivity in agile software development teams.

H3c: ASD practices moderate the negative relationship between perceived subgroups and performance/satisfaction and the positive relationship between perceived subgroups and conflict through team reflexivity.

4. METHOD

In order to test the theoretical model of the effects of ASD practices on the effects of subgroups in ASD, we have distributed an online survey to agile development teams. For the survey, we have identified tested scales from extant research and where necessary slightly adapted them to the context of this research. All items are measured on Likert scales, with items concerning ASD practices using 7-point scales, whereas all other items use 5-point scales. Table 1 provides an overview of the measures used.

Table 1 Measures used to assess constructs in online survey

Construct	Scale Source	Construct	Scale Source
Information elaboration	[18]	Perceived subgroups	[38]
Team reflexivity	[40, 43]	Performance	[17]
ASD practices	[46]	Conflict	[31]
		Satisfaction	[21]

For assessing *perceived subgroups* the 4-item scale developed by Rico et al. [38], which measures whether there are salient subgroups, task-based cohesiveness, and the existence of "us vs. them" feelings, has been employed. Three items each from the scale by Tripp et al. [46] have been used for the agile practices *daily stand-ups* and *retrospectives. Satisfaction* is assessed using a 3-item scale asking participants about their happiness, satisfaction, and intention to continue working in this team [21]. For conflict, the 4-item scale by Li & Hambrick [31] gauging both task and relationship conflict on two items each is used. *Performance* is assessed relatively by asking participants to gauge efficiency, quality, innovativeness, work excellence, and schedule and budget adherence, relative to the best team they have worked in [17]. For gauging *team reflexivity,* evaluation and learning dimensions of the scale by Shin [43] have been chosen, which encompass six items and are adapted from Schippers et al. [39]. *Elaboration of information* is operationalized using an instrument built on the original description that asks participants to assess the use of information in their team [18].

In addition to the constructs of main interest, single items for colocation, i.e. how spread out teammates are ranging from the same room to off-shore, and agile experience are included as control variables as well as demographic data on age and team size for characterizing the sample. Previous research on ASD effects has proposed to control for programming experience when assessing performance [2]. Given our interest in effects of ASD practices, this aspect is slightly adapted to reflect experience with ASD. Colocation is deemed relevant given previous research on the negative effects of geographical distance on teamwork in software development [11].

5. RESULTS AND DISCUSSION

We find the hypotheses regarding effects of subgroups mostly supported with subgroups reducing satisfaction and increasing conflict. Conflict and satisfaction show the anticipated effects on performance. The moderating effects of agile practices are found to be a double-edged sword: As expected, elaboration of information ameliorates the effects of subgroups on conflict and satisfaction, whereas reflexivity is found to further add to conflict and reduce satisfaction. While we can thus partly confirm findings on elaboration of information, results on team reflexivity are in opposition to extant research–implying a special relation in ASD.

Since the perception of subgroups can differ within teams, analysis is aimed at the individual level. The survey was distributed to members and project managers of a convenience sample of agile teams in several domains. Of the 102 survey participants we removed three for not filling in any items for satisfaction, which we deemed inappropriate for inclusion since it is a key latent construct. Table 2 gives an overview of demographic characteristics of the remaining participants regarding team size, age, and agile experience. Answers on these dimensions imply the sample to be quite homogeneous.

Table 2 Overview of demographic data

Age (in years)		Agile Experience (in years)		Team Size	
21 - 25	7.07%	None	3.03%	0 - 3	18.18%
26 - 30	30.30%	<1	18.18%	4 - 5	18.18%
31 - 35	28.28%	1 - 2	28.28%	6 - 8	38.38%
36 - 40	13.13%	3 - 4	28.28%	9 - 11	11.11%
41 - 45	3.03%	5 - 10	14.14%	12 - 14	5.05%
46 - 50	1.01%	>10	4.04%	15 - 17	2.02%
>50	5.05%	NA	4.04%	>17	2.02%
NA	12.12%			NA	5.05%

All constructs are interpreted to be reflective. To estimate validity, we have surveyed factor loadings and the reliability criteria of Cronbach's alpha, composite reliability, and average variance extracted. Items not attaining the threshold loading of .70 have been eliminated iteratively: two items on performance innovation and schedule, the fourth item on perceived subgroups, and three items of the reflexivity scale. For both retrospectives and daily stand-ups one item has been removed due to a high variance inflation factor. Despite eliminating several indicators, all but the agile practices constructs are operationalized using at least three indicators.

With the exception of elaboration of information and team reflexivity at .69, all latent constructs have Cronbach's alpha values in excess of .70. Following advice not to primarily consider Cronbach's alpha we surveyed composite reliability and average variance extracted [14], which have been found to be satisfactory for all constructs. Table 3 provides an overview of the reliability measures.

Considering crossloadings, the criterion that all items should load most on the expected underlying factor is satisfied. There are, however, some items with relatively high loadings on other factors, e.g. items for daily stand-ups and retrospectives have loadings of >.50 on the respective other factor. This is an expected finding and in line with our theoretical model, where we hypothesize both daily stand-ups and retrospectives to be linked to a common methodological core.

Table 3 Reliability of Constructs

Construct	R^2	Alpha	Comp. Reliability	AVE
Perceived Subgroups		.73	.84	.63
Daily Stand-ups		.81	.91	.84
Retrospectives		.80	.91	.83
Elaboration of Information	.13	.70	.83	.62
Reflexivity	.32	.70	.83	.62
Conflict	.34	.87	.91	.71
Satisfaction	.47	.88	.93	.81
Performance	.39	.76	.86	.68

PLS was chosen for analysis as it has been found to outperform traditional methods concerning violations of some assumptions [19], which given our sample size and the number of variables cannot be ruled out. Following the approach by Hair et al. [14], a maximum of 1000 iterations and Simple Bootstrapping without sign changes using the bias-corrected and accelerated method on 10,000 subsamples have been used to calculate the structural model. Figure 3 illustrates the results. Moderating effects are operationalized as interactions of perceived subgroups and the respective moderator, i.e. elaboration of information or team reflexivity. For latent constructs, R^2 values are shown, for paths the weight and in parentheses the p-value are given.

Considering the fuzziness of some constructs, the resulting R^2 values seem satisfactory. While only 13% of the variance in elaboration of information is explained by daily stand-ups and retrospectives, medium-levels of R^2 are attained for conflict, performance, and reflexivity. The R^2 of .47 for satisfaction is considered to be quite strong given it is not feasible to assume reflexivity and direct elaboration of information to be the only determinants of satisfaction.

Effects of perceived subgroups on team outcomes

Regarding the influence of perceived subgroups on team outcomes, hypotheses 1a and 1b are mostly supported. Perceived subgroups exert a highly significant negative effect on satisfaction, which mirrors previous findings. This result is promising since it implies effects found in general group settings translate to ASD teams. The relationship between perceived subgroups and conflict is positive–as expected, albeit not significant at the 5% level (p=.057). Both task and relationship conflict are operationalized with two items each. Keeping only the items on relationship conflict results in a significant weight of .24 (p=.038), which implies the relation may be more pronounced. We therefore confirm hypothesis 1b and tentatively reject hypothesis 1a for a slight lack of significance.

In line with prior research, conflict and satisfaction both relate to performance: conflict is significantly negatively related, whereas satisfaction exhibits a highly significant positive relation. We can thus confirm hypotheses 1c and 1d. Taken together, the results of the current model support most of the propositions regarding the effects of subgroups on performance in ASD teams.

Considering its effect on satisfaction, conflict, and performance, the control variable agile experience is not significantly related to any of the outcomes with all p-values >.20. Colocation, however, exhibits a highly significant effect on performance with more distance leading to inferior performance (-.27, p=.003).

Relation between ASD practices and psychological constructs

In line with expectations, retrospectives are highly significantly related to the construct *team reflexivity* and to a lesser extent positively related to *elaboration of information*–confirming hypotheses 2b and 3b. Based on this finding, we expect ASD practices to not map directly to constructs proposed in psychology, no matter how closely related they may appear. Engaging in a retrospective seems to also contribute to elaboration of information. This is readily understandable given the definition of elaboration of information as group-based information exchange [25], which arguably is part of what happens in a retrospective.

Contrasting with retrospectives, the relationships of daily stand-ups are more surprising. While given their operational nature, daily stand-ups are expected to contribute to *elaboration of information*, this relationship is very weak and highly insignificant. Following theory stating daily stand-ups to be helpful in creating shared mental models [53], the relationship with *team reflexivity* is positive, albeit also considerably smaller than either of the effects of retrospectives. This may be due to the dataset, in which daily stand-ups were apparently widely used with median values for daily stand-ups at 6 and mean values > 5.7 on a 7-point Likert scale. In addition to use-driven explanations, it is conceivable that the focus of daily stand-ups on operational updates does not qualify them for elaboration of information. In addition, it may be the case that items on elaboration of information were attributed to a specific task without any involvement of daily stand-ups. While the expected effects of daily stand-ups on psychological constructs could not be corroborated, a general direction of effects can still be inferred. Investigating the effective mechanism through which daily stand-ups affect outcomes is thus an issue for future research.

We therefore tentatively reject hypotheses 2a and 3a for a lack of statistical power, noting that the direction of the effect is as expected. Agile practices are found to relate to several psychological constructs, which means results from general group research cannot be transferred directly.

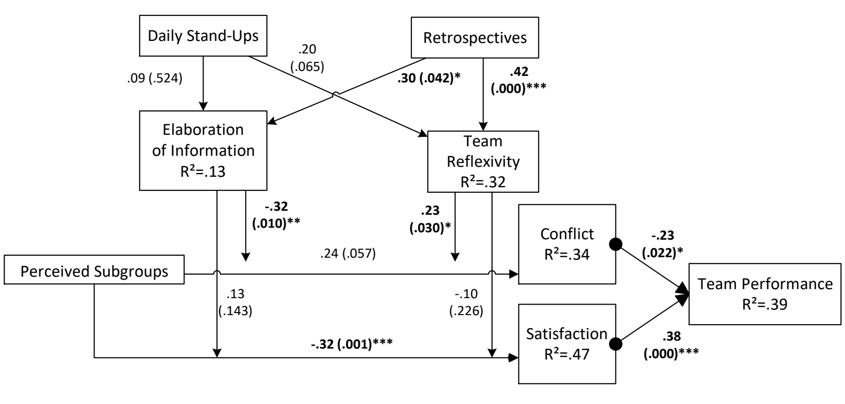

Figure 3 Overview of Results

Table 4 Total effects of Daily Stand-Ups and Retrospectives

Path	Original Sample (O)	Sample Mean (M)	P Values
DSU -> Conflict	-.05	-.05	.334
DSU -> Performance	.03	.04	.366
DSU -> Satisfaction	.06	.06	.370
Retrosp. -> Conflict	-.14	-.15	.095
Retrosp. -> Performance	.09	.10	.072
Retrosp. -> Satisfaction	.16	.17	.054

Moderating effect of agile practices: conflict

Both *team reflexivity* and *elaboration of information*, as explained by using ASD practices, are expected to negatively moderate the relation between subgroups and conflict. *Elaboration of information* indeed highly significantly attenuates the relationship with conflict, which supports our proposition that the conflict-reducing effect of direct communication [23] is achieved by ASD practices. While the moderating effect of *team reflexivity* on conflict is only significant at the 5% level (p=.030), the sign of the effect is worth noting: Reflexivity seems to further add to conflict in presence of perceived subgroups, contradicting predictions based on extant research that reflexivity reduces negative effects of faultlines [47].

This result can, however, be related to extant research describing limits to the positive effects of *team reflexivity*. In the setting of software development, reflexivity has been found to benefit effectiveness but not efficiency [22], where many arguments for the positive effects of reflexivity seem conceptually closer to *elaboration of information*. Moreover, content of communication has been theorized to be decisive for the effect [40]. Following this line of thought, it may be the case that for task-focused work in ASD, the dimensions captured by *team reflexivity* pale in terms of informational value compared to e.g. *elaboration of information*. In addition, the effects of differences between members are found to be strengthened through increased interactions when teams have a large span of control [37]. We suspect the planned and intense communication in daily stand-ups and retrospectives to frequently show team members potential divides and dissent with their colleagues and thus leading to increased conflict.

Moderating effect of agile practices: satisfaction

Neither *elaboration of information* nor *team reflexivity* have been found to significantly moderate the relationship between perceived subgroups and satisfaction, leading us to reject parts of hypotheses 2c and 3c because of lack of statistical power. Analogously to the effects on conflict, *elaboration of information* is positively related as expected, whereas *team reflexivity* further exacerbates negative tendencies.

Following the conflict-enhancing effect of *team reflexivity*, this result may be explained by seeing *team reflexivity* performed in retrospectives and daily stand-ups as instances in which negative experiences may be triggered, come to mind, and thus reduce satisfaction. Positive effects of ASD practices on satisfaction by influencing *elaboration of information*, but missing the contingencies that explain when this result holds is in line with previous research. An overall positive effect of ASD practices on satisfaction has been found but some ASD practices have been described to be excluded from this assertion [46]. By shedding light on a pathway and interaction of psychological constructs through which this effect may come about, the current research adds to this finding.

Lastly, the total effects of daily stand-ups and retrospectives are to be considered and are shown in table 4. The direction of all effects is as expected: Reducing levels of conflict and increasing performance and satisfaction. While none of the effects is significant at the 5% level, the effect sizes for retrospectives are consistently stronger than for daily stand-ups, which is in line with individual analysis.

6. CONTRIBUTION AND LIMITATIONS

The present study makes both academic and practical contributions. From an academic perspective, it provides insights into how a much researched group topic affects and is affected by ASD. It thus contributes to an increased insight into the contingencies of ASD. Especially, it adds further details to the existing knowledge on contingencies regarding diversity [29], effects of conflict in ASD [13], and the effects of practices on satisfaction [46]. For practitioners, knowledge on possible (side) effects of ASD practices helps in estimating their potential and effects to influence group dynamics.

The current research does, however, present only a first step in understanding the role of ASD practices in light of subgroups and has several limitations. First, the sample could be improved. Given the number of constructs and their complex interaction, the 99 members of ASD teams in the current study may not be sufficient for fully reliable results. In addition, as outlined previously, the sample is quite homogenous regarding demographics, which may limit generalizability. A second potential issue lies in the operationalization of constructs. While scales have been taken from validated sources, some–especially *elaboration of information* and *team reflexivity*–have not shown the anticipated statistical power. While they are close to the .70 threshold on Cronbach's alpha, results are contrasting the original ones: *Team reflexivity* has attained a value of .91 [43] and *elaboration of information* of .85 [18]. This stark deviation is peculiar. On the one hand, the result could be an artifact associated with our specific sample or, on the other hand, being part of an ASD team and its context may have affected validity of these items.

7. CONCLUSION

Working in an agile manner prominently emphasizes diversity in teams. A possible consequence of diversity is the emergence of subgroups, which can negatively affect team outcomes. We argue that daily stand-ups and retrospectives moderate these effects since they can be related to the proposed moderators elaboration of information and team reflexivity.

To test the proposed relationship, we have surveyed members of ASD teams. Results of the partial least squares model mostly confirm the expected relations between perceived subgroups and group processes. The practice of retrospectives exhibits a significant positive relation with elaboration of information and team reflexivity. Contrary to expectations, daily stand-ups have relatively weak relations to both dimensions.

Elaboration of information is found to significantly moderate the relation between perceived subgroups and conflict. Surprisingly, results imply a negative effect of reflexivity on the effects of subgroups: a significant increase in conflict and a further decrease in satisfaction are found. The results provide first insights into subgroup effects in ASD and add to previous works on contingencies of ASD work.

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[redacted] P8: Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects

Table AX8: P8: Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects

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Combining Design Thinking and Agile Development to Master Highly Innovative IT Projects

Leonard Przybilla[1], Maximilian Schreieck[1], Kai Klinker[1], Christoph Pflügler[1], Manuel Wiesche[1] and Helmut Krcmar[1]

Abstract: Agile development methods have become mainstream. Notwithstanding the improvements they bring about in implementation, they are of little help for deciding what exact features are needed to address the core needs of customers: they mostly rely on the competence and domain knowledge of the product owner. This is an issue of paramount importance in innovative projects with high ambiguity such as digitization projects because such projects require a detailed understanding of customers and their needs. In order to address this gap, we propose to follow a Design Up Front approach and to integrate the Design Thinking methodology, which aims at human-centered innovation, with agile development. Drawing on 25 student and research projects, we report key learnings concerning human aspects, knowledge management, and challenging of assumptions. Moreover, we offer practical recommendations for the integration of the two methodologies.

Keywords: Agile development; Design Thinking; Design Up Front; Requirements Engineering

1 Introduction

Agile methods have attained widespread popularity that continues to grow [Ve17]. Many advantages of agile methods have been identified and investigated in empirical studies. As an example, agile practices have been demonstrated to increase project success [SP15]. As a contingency, adjusting team characteristics can influence different dimensions of performance [LX10]. In addition, agile practices are found to interact with other phenomena such as subgrouping [La17, PWK18]. A core aspect of agile methods is reacting flexibly to changes and the admission that the course of a project cannot be fully controlled in advance [Di12]. To embrace this fact and effectively attain the project goals, an iterative approach in which the developed artifacts are repeatedly presented to the customer and evaluated is used [Di12].

The preceding description does, however, implicitly state a condition for an agile project to be successful: The goal of development has to be sufficiently known. Agile approaches such as Scrum typically employ roles for managing responsibilities and workload within the development team [Ki07]. Formally, the product owner is responsible for what should be developed, while the rest of the team is mainly focused on how the aim can be achieved. Agile development is thus beneficial in cases when the project goals are known by the product owner, but is of little use if the goal as such is unknown. To illustrate this potential gap, Augustine et al. [Au05] propose to first describe the product vision in the development team – without addressing how this vision has been developed. Extant literature underlines the benefits and new challenges of adequate require-

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ments engineering in agile development [In15]. In the development of an update release or an incremental improvement of an existing product, specifying the goal of development may be straightforward. In the case of radical innovation in a domain characterized by high uncertainty, the project goal itself is not yet known and cannot be as readily established–which may render the advantages of agile methods moot. An exemplary domain that illustrates this lack of goal clarity is the digital transformation of industrial value creation: In theory, there is a multitude of application areas, yet what exactly a valuable solution should look like is unknown [An18]. In this context of high uncertainty, the fundamental question is what features are exactly of value to the customer and user.

While there is research on user-centricity in agile development, it is mostly focused on achieving adequate usability and improved user experience in interacting with the UI (e.g., Da Silva et al. [Si11]). The pivotal question of what should be developed can hardly be answered by these approaches. A possibility to align the goal of a highly innovative project with maximum utility for users is offered by the Design Thinking methodology. While combining Design Thinking with agile development has been proposed before [AMC13], we focus on the integration of Design Thinking and Scrum and the handover between the two methodologies. To this end, we report on learnings and evidence drawn from 25 heterogeneous projects in an academic context.

2 Related Works

In the following, we will give a brief overview of agile development methodologies, Design Thinking, and research on combining user-centered development with agile methodologies.

2.1 Agile Development

Driven by the dissatisfaction with then-current methods of software engineering, a group of people put forth a manifesto for agile software development [Be01], which now forms the basis of agile development methods. Among other propositions, the manifesto calls for prioritizing people over process, usable software over documentation, and to integrate customers in development. Building on these propositions, several different agile development methods such as Crystal, eXtreme Programming, or Scrum, have been developed [Di12]. Within these methods, multiple agile practices such as daily stand-ups or retrospectives at the end of sprints are harnessed [Ve17]. In the following, we will mostly focus on Scrum as a commonly used implementation of agile development.

Scrum heeds the call for customer integration put forth in the agile manifesto for example through repeated testing and evaluation of artifacts by customers at the end of sprints [RJ00]. The basic notion of agile response to change also transcends to requirements engineering: Instead of collecting all requirements beforehand, based on several case studies it is reported that they are detailed iteratively throughout the project [RCB10]. Agile requirements engineering relies on several practices that on the one hand address and ameliorate challenges of traditional requirements engineering but on the other hand result in new challenges that are only partly addressed by agile practices [In15]. As an example, Inayat et al. [In15] raise the issue of a lack of traceability brought about by little documentation, considering non-functional requirements, or the inability of customers to make decisions. While no panacea, Design Thinking as a methodology to achieve human-centered innovation can help especially with the latter challenge.

2.2 Design Thinking

Design Thinking is at its core focused on developing human-centered innovation, that is, innovation that addresses needs and wants of the user, while ensuring technical feasibility, and economic viability [Br08b]. As a methodology, Design Thinking encompasses several individual methods and tools, which originally have been used by designers and are now applied to managerial problems [Br08b, JWC13, Ma09]. The methodology is appropriate for wicked problems that cannot be pinpointed and to which no optimal solution can be found [Bu92], e.g. for improving health care provision using digital means [Kl17, Pr18]. Typically, a Design Thinking project is divided into work on the problem space and the solution space. As can be discerned in figure 1, both are first broadened before converging, which leads to a double-diamond shape [De15]. Attributing equal size to the problem and solution spaces signifies that much time is spent on furthering the understanding of the actual problem to be solved.

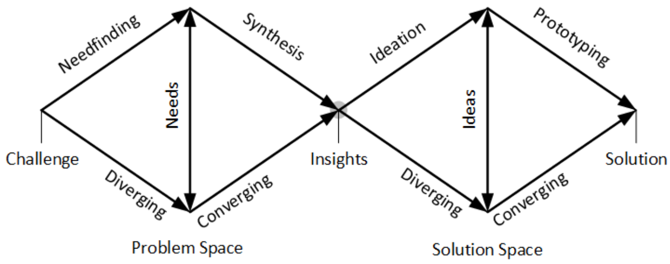

Fig. 1: Design Thinking Project as Double Diamond, adapted from [De15]

Formulating a challenge initiates the diverging part of the problem space through needfinding, which is transferred to the solution space through synthesis. The solution space is opened up through ideation and converges towards a final solution through prototyping and testing activities. A multitude of different methods can be harnessed within these phases. For example, interviews [KB09] or ethnographic observations [EFS11] can be used in needfinding, whereas development of first rough prototypes and their iterative refinement towards a detailed prototype characterize the solution space [He18].

2.3 Human-centered Software Development

Integrating human-centered development with software engineering has been described in several areas. In addition to calls for using Design Thinking in Requirements Engineering [Ve13a], there are several overviews of human-centered or usability-centered agile development [Br08a, SNP14, SPC14, Si11]. A key result of these literature reviews is the identification of a core of methods and practices that are utilized repeatedly. An example from the area of project organization is the Design Up Front principle. This principle entails that resources are dedicated to investigating users before development starts [Si11]. Examples of common artifacts include personas or user stories [Br08a], whereas customer integration and testing are used for evaluation [Br08a]. The main focus of extant research is on the usability of a solution and the related UX design. Defining the core functionality is, however, not within this scope. Further adding to the lack of guidance in this critical phase, while Design Up Front has been proposed as a potential integration mechanism, most evaluations and tests are conducted at the end of development [SNP14].

Drawing on the assertion that combining human-centered methods with agile development is advantageous, we will report on using a Design Up Front approach to improve customer value [Br08a]. In this realm, we draw on earlier suggestions to combine Design Thinking with Scrum. While Vetterli et al. [Ve13b] provide an extensive overview on how the two methodologies can be combined contingent on project factors, we report on empirical learning regarding the handover between Design Thinking and agile development, which has been described as problematic [He18].

3 Three Areas of Learnings to Address for Integration

We will report main learnings on the handover between Design Thinking and agile development. The learnings are derived from a heterogeneous sample of 25 projects in an academic context. Projects include both student projects aiming at radical innovation and research projects seeking to develop prototypical solutions for digitization of specific industries (e.g., [Sc18]). This heterogeneity of projects allows for deducing basic patterns with high generalizability. The key learnings can be grouped in the three categories: human aspects, knowledge transfer, and challenging assumptions (figure 2). These three categories emerged through inductive analysis of observations by the authors and are not meant to be mutually exclusive. Learnings are categorized based on the authors' perception of the most relevant aspect.

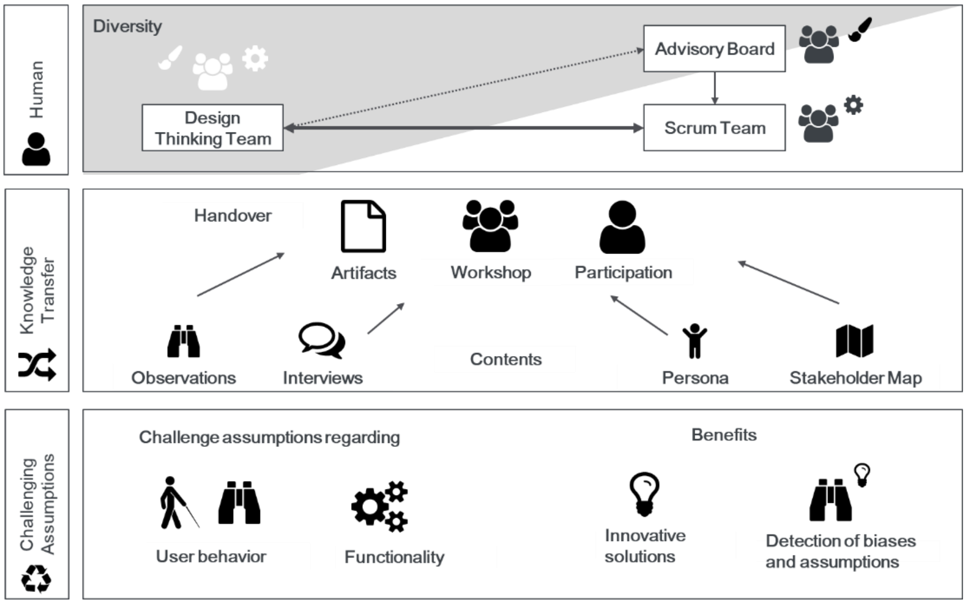

Fig. 2: Overview of Key Areas of Learnings

3.1 Human Aspects

This section summarizes learnings that pertain to organizational aspects in planning and managing teams and the interaction within them. The learnings thus should be considered at the planning stage before embarking on the project.

The main learning on a human level is **that at least one project member**, for example the product owner, should **participate in both the Design Thinking part as well as in the Scrum implementation phase**, mirroring the practice of having a designer on an agile team to improve outcomes [Br08a]. We observed that projects in which both phases were run completely independently, using only artifacts for knowledge transfer and handover, showed problems due to a lack of information. As an example of a communication challenge [In15], in one project the implementation team did not understand the product vision and the underlying customer needs that drive this vision. This was due to a lack of direct customer observations and not being able to retrace the evolution of the preceding prototypes [He18]. Having at least one group member take part in both phases helps tremendously with guarding the product vision as the output of Design Thinking throughout the project. Albeit arguably not as good as direct involvement in both phases, it is advantageous to have participants of the Design Thinking phase at least available in an **advisory board** so that the implementation team can ask for insights. This learning is closely related to the category of knowledge transfer.

Participation of several people in both project phases has the additional benefit of **attenuating potential decision-making biases** that may sprawl if only one person links the two phases. In the case of a single person link, the balance between human desirability, technical feasibility, and economic viability as the cornerstone of Design Thinking

[Br08b] may be distorted. Including several people forces them to ponder the underlying project objectives and thus to reduce the chance of biases.

A second aspect on the human level to consider is **team composition**. In the projects in our sample, **functional diversity** had a very positive effect–especially during the Design Thinking phase. It is worth highlighting the valuable contributions made by participants from domains far from the problem domain that greatly advanced the projects. As an example, the perceptions and ideas of nursing scientists were of prime importance for a case of industrial maintenance: With their experience in time-critical flexible care they could relate very well to the situation of use. This led to a very focused feature set and stopped feature creep. Another example are the valuable contributions of mechanical engineers to service projects. The returns on functional diversity diminish over the course of the project. In the end of the Design Thinking phase and in the agile implementation phase, we found diversity to play a lesser role. It is from our experiences thus possible to organize teams in a cascading manner with diverse disciplines participating in the beginning of projects and diversity receding over the course of the project.

3.2 Knowledge Management

Adequate management and transfer of knowledge have emerged as main topics of concern in the projects comprised in our sample. These are especially of relevance in the handover between Design Thinking and agile implementation. While knowledge management is enabled by human factors discussed in the preceding section, the focus in the following is on learnings concerning a shorter timeframe that should be considered while executing projects.

In order to enable a successful and effortless **handover** between Design Thinking and agile implementation, it is recommended to **conduct a handover workshop** in addition to passing on **artifacts** created in the process. This is particularly important if only part of the implementation team participates in the Design Thinking phase–see the preceding learnings on human factors. Doing so can build trust between the participants, which in turn helps with implementing the product idea. A key activity for this workshop is to specify the functions of the envisioned product and their implementation details. Naturally, this is not to say that a complete waterfall-style project plan should be worked out. One option for feature specification would be having Design Thinking participants report on their findings and experiences in detail while simultaneously implementation team members use these reports to fill their backlog. In this setting, if questions arise, the Design Thinking participants would be readily available for clarification. This opportunity of direct interaction is crucial if only few people are involved in both project phases. If the entire team participates in both phases, another aspect should be prioritized: **Changing the team's mindset**: it should progress from the completely open, explorative mindset of Design Thinking to the agile but focused approach to implementation. As much as early fixation on a solution is to be avoided in Design Thinking, questioning core features in implementation should be avoided as well. Agile implementation should focus on the "how" of implementation–"what" to implement should have been established in the Design Thinking phase.

The most important piece of knowledge to be safeguarded and managed is **the detailed**

and concise specification of the product vision–the "what" that is to be implemented in an agile manner. To achieve adequate quality, the paramount value of iterative user studies has been observed throughout the projects. Detailed **observations** are well worth the large amount of time invested. As a positive example, in a project with craftsmen the project team was able to identify early on that the planned solution would generate no value but that there was a worthwhile alternative. To further stress this point, two negative examples are provided by projects in which developers engaged only in a short user study before implementing requirements on their own without another test. The resulting prototypes were deemed useless by the users, which could have been known earlier through repeated testing on the conceptual level. While user stories are a common tool in agile development for achieving usability [Br08a, Si11], we strongly warn against deriving them from anything else than real customer needs. To achieve this aim, the methods **ethnographic studies, in-depth interviews, and focus groups** have proven especially useful in our sample of projects, (e.g., [SWK17, Sc16]). **Personas** as a condensed representation of stakeholder characteristics [PG03] allowed for detailed yet concise transfer of knowledge. This enables the team to evaluate their implementation against the needs of the customer without necessarily running out for testing.

For creating and analyzing personas, details that at first sight seem unimportant can make or break value and acceptance of the solution. As an example, in a project with truck drivers it was found that drivers differ on many more dimensions than originally thought. In the following, general characteristics without direct relevance to the challenge turned out to be most important for developing a solution. Moreover, it was very helpful to include not only direct users but also to survey additional stakeholders. To attain this goal, the broader context of use should be identified and observed. To keep different personas manageable and provide structure it is helpful to organize them in a **stakeholder map** [CGL15]. In addition to including more stakeholders for analysis, it has been very beneficial in several projects to **benchmark related processes or problems** in other–sometimes completely unrelated–domains. As an example, the well-known "Tupperware parties" provided helpful information on onboarding mechanisms of platforms.

3.3 Challenging Assumptions

In nearly all projects it was surprisingly important **to challenge or even reverse assumptions** of the team–some of which had been made implicitly. To achieve this goal, the Dark Horse phase proposed in Design Thinking has been very beneficial. In the Dark Horse phase, teams are challenged to relax or even invert their assumptions in order to develop solutions that at first sight seem infeasible [Bu13]. This approach is especially well-suited for wicked problems that can only be treated after the problem has been understood [Bu92]–such as innovation projects. As discussed in literature [Bu13], two beneficial results have been observed: First, the **solutions developed in this phase can turn out to be feasible** and move directly into the final product idea. Second, trying to overcome assumptions helps with **reducing biases and fixation on existing solutions** that are due to overly restrictive assumptions. It is, however, extremely important to document the nature of these results for handover if no personal involvement in both phases is given. If this is insufficient, implementers may discard ideas altogether as infeasible. As an example, in a project on vehicle lighting, overturning the assumption that light has to be emitted from headlights was part of the final prototype.

In addition to testing assumptions relating to the solution space and degree of innovation, **assumptions on addressing and communicating** with customers are to be challenged. Again, challenging these assumptions can present handover problems if the underlying rationale is not evident to implementers. In one project, for example, the targeted group in principle welcomed the solution idea. This was, however, not evident in early field tests during the concept phase since the team had chosen a description based on scientific data that customers obviously did not understand and consequently rejected. It is thus recommendable to also challenge assumptions pertaining to customer communication in testing since they can directly affect results and thus indirectly idea generation.

4 Recommendations for Integrating Design Thinking with Agile Development

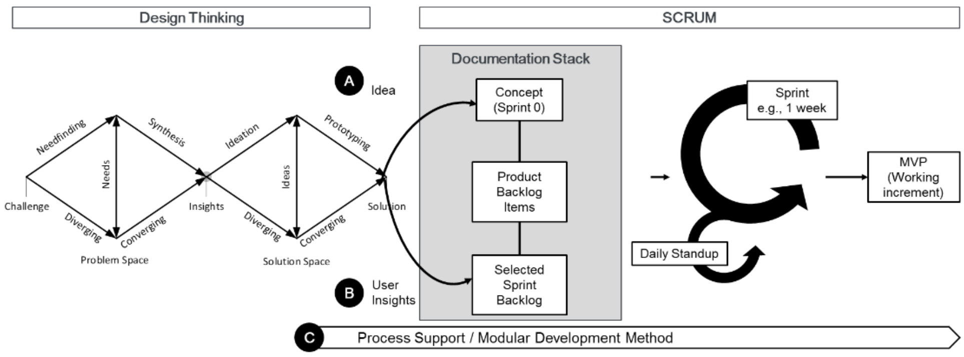

Fig. 3: Overview of Integration of Design Thinking (based on [De15]) with an Exemplary Scrum Process

In addition to the key learnings described in the preceding section, we would like to offer some practical recommendations for integrating Design Thinking as a methodology for product scope definition with agile methods for implementation. From the experiences made, it is recommendable for **highly innovative projects to conduct a complete Design Thinking project before the Scrum process**. This allows for clearly identifying the goal of development. As shown in figure 3, **three key items are handed over from the upfront Design Thinking Project to the Scrum process**: the core idea of what should be developed (A) supported by the user insights (B) explaining, justifying and providing traceability. The user insights provide the explanations of why this idea came into existence and help the team in prioritizing aspects and thus in managing the spring backlog. Moreover, we have found upfront Design Thinking to support the agile implementation from a process perspective (C): Experienced or at least documented customer needs can preempt lengthy discussions on the direction to take.

The most important recommendation that can be derived from our experience is the **willingness to experiment** and to leave the beaten path. Even when having established a Design Thinking-infused process, it is recommendable to reflect on the practices applied. In nearly every project, we ponder the specifics and evaluate which methods could be advantageous at least once every couple of months.

We recognize the scarcity of resources and propose to **tailor integration** according to project needs. For highly innovative projects, it is recommended to conduct an entire Design Thinking project and to have all developers engage in the corresponding activities as described above. While at first sight this procedure violates the principle of delivering working code fast [Be01], implementing a solution that is not what is really needed and has to be adjusted in final testing or fails altogether is even more costly than doing thorough needfinding in the beginning to grasp the core problem. Involvement of all developers helps with more agile implementation since the shared problem understanding arguably reduces the need for formal documentation and thus implements an agile principle [Be01].

This being said, not all projects need or provide the opportunity for the same level of Design Thinking activities: Projects with defined goals that are not wicked may not need an entire Design Thinking project [HU18]–especially since excessive application of techniques can lead to negative outcomes [WSK13]. Since all projects in our sample were highly innovative and exhibited the corresponding level of ambiguity, not all of our learnings and recommendations may be generalizable to other project settings. If, however, some aspects of the project scope are not clearly defined it is beneficial to engage in at least some Design Thinking upfront. Even having just a few people spend some time, e.g. half a day, on structured needfinding, rapid prototyping, and testing can in our experience go a long way towards improving project outcomes. If only a limited subset of developers takes part in Design Thinking, thorough documentation regains paramount importance to starve off communication lapses.

5 Conclusion

Agile methods have been established as mainstream approaches to development. While they work well in implementing solutions, they fail to answer the question of what should be implemented. This is especially problematic for highly innovative projects such as digitization efforts in which the exact project goal is not yet known (see e.g. [SW17, SWK18]). To overcome this problem, we propose to follow a Design Up Front approach using the Design Thinking methodology. We report on key learnings on integrating Design Thinking and agile methodologies obtained in 25 student and research projects–focusing on issues of handover between the phases. They pertain to the three categories human aspects, knowledge management, and challenging assumptions. These have been observed to be important for the fruitful integration of Design Thinking with agile development. In addition to the case-based learnings we offer practical recommendations for tailoring and integrating the two methodologies.

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