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Shared Artefacts and Virtual Worlds in Computer-Mediated Creative Collaboration

Pekka Alahuhta

Aalto University

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Shared Artefacts and Virtual Worlds in Computer-Mediated Creative Collaboration

Pekka Alahuhta

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Abstract

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Abstract

Virtual teams are becoming an increasingly common phenomenon within the globalizing surroundings of corporations. The communication between virtual team members is predominantly based on information and communication technology. The question, how different ICT collaboration environments can support different virtual team activities, has gained attention in research and practice. However, collaboration environments' role to foster creative virtual team collaboration is not entirely understood.

This dissertation addresses the topic by focusing on the potential of artefacts and three-dimensional virtual worlds. Artefacts – shared visual representations – have been considered necessary for co-located creative collaboration. Though, the entire ecology of artefacts in distributed, computer-mediated creative collaboration has thus far remained unclear. While previous studies have suggested virtual worlds as beneficial for creative team collaboration, a systematic effort to characterize and describe this potential has not been undertaken. The four essays of this dissertation utilize real-life observational data of interaction between technical experts, decision-makers, and engineering designers. Either a web conferencing tool or a virtual world was employed as a collaboration environment during the observed interaction sessions.

The first essay outlines virtual worlds' eight affordances towards creative team collaboration. The second essay investigates the question, how the two-dimensional web conferencing tool and virtual world differ in terms of supporting the use of shared visual artefacts. The third essay broadens the observation of the artefacts by studying their roles as boundary objects, which mediate communication within an intersection of different social worlds. Grounding on these results, the fourth essay addresses the artefacts' role in distributed teams' different collaborative activities within creative virtual world collaboration.

Findings of the study demonstrate virtual worlds' potential to foster team creativity. Meanwhile the findings indicate a variety of artefacts that are utilized within creative virtual team collaboration, ranging from epistemic to technical objects. Grounding on the observed contrast between the virtual world and web conferencing tool, the results end up in suggesting an expansion of separated auditory and visual channel information to the concept of boundary objects. While the study conveys practical relevance for virtual teams that engage in creative collaboration, it also outlines potential directions to future ICT collaboration environments development path.

Keywords Boundary objects, creative collaboration, distributed teams, epistemic objects, technical objects, virtual worlds

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Tiivistelmä

Virtuaalitiimit yleistyvät liiketoiminnan globalisoituessa. Virtuaalitiimien jäsenet viestivät pääosin tieto- ja viestintäteknologian välityksellä. Tutkimuksessa ja käytännön työssä on havaittu, että eri tieto- ja viestintäteknologiset vuorovaikutusympäristöt voivat tukea virtuaalitiimien eri toimintoja. Vuorovaikutusympäristöjen roolia virtuaalitiimin luovan työn tukemisessa ei kuitenkaan ole täysin ymmärretty.

Väitöskirja käsittelee aihetta suunnaten huomion artefaktoihin ja kolmiulotteisiin virtuaalimaailmoihin. Artefaktat – yhteiset visuaaliset dokumentit – on aiemmin mielletty välttämättömiksi samanpaikkaisessa luovassa yhteistyössä. Artefaktojen rooli monipaikkaisessa, tietokonevälitteisessä luovassa yhteistyössä on kuitenkin vielä selvittämättä. Aiemmat tutkimukset ovat arvioineet virtuaalimaailmojen olevan suotuisia luovalle tiimin vuorovaikutukselle; näkökantaa ei kuitenkaan ole luonnehdittu tai kuvattu järjestelmällisesti. Väitöskirjan neljä esseetä hyödyntävät dataa teknisten asiantuntijoiden, päätöksentekijöiden ja teollisten suunnittelijoiden tosielämän vuorovaikutustilanteista. Vuorovaikutusympäristöinä käytettiin web-konferenssityökalua tai kolmiulotteista virtuaalimaailmaa.

Ensimmäinen esseistä linjaa kahdeksan kolmiulotteisen virtuaalimaailman ominaispiirrettä, jotka tukevat luovan tiimin vuorovaikutusta. Toinen esseistä selvittää, miten visuaalisesti kaksiulotteinen web-konferenssityökalu ja kolmiulotteinen virtuaalimaailma eroavat toisistaan artefaktojen käytön osalta. Kolmas essee tarkastelee artefaktoja rajaesineinä, jotka välittävät viestintää erillisten sosiaalisten maailmojen leikkauskohdassa. Tuloksiin perustuen neljäs essee tarkastelee visuaalisten artefaktojen roolia monipaikkaisten, hajautettujen tiimien erilaisissa yhteistyöaktiviteeteissa luovan virtuaalimaailma-vuorovaikutuksen yhteydessä.

Tutkimustulokset havainnollistavat virtuaalimaailman potentiaalin edistää luovaa tiimitason vuorovaikutusta. Tulokset esittelevät luovien virtuaalitiimien hyödyntämien artefaktojen kirjon, ulottuen episteemisistä teknisiin objekteihin. Havaittuihin virtuaalimaailman ja web-konferenssityökalun eroavaisuuksiin perustuen esitetään visuaalisen ja auditiivisen viestintäkanavan eroon pohjautuvaa laajennusta rajaesineiden käsitteeseen. Siinä missä tutkimus on merkittävä luovaan vuorovaikutukseen osallistuvien virtuaalitiimien kannalta, se myös linjaa mahdollisia suuntia tulevaisuuden tieto- ja viestintäteknologian kehityspolulle.

Avainsanat Episteemiset objektit, hajautetut tiimit, luova yhteistyö, rajaesineet, tekniset objektit, virtuaalimaailmat

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List of essays included in the dissertation

This doctoral dissertation consists of the following four essays:

Essay I. Alahuhta, P., Nordbäck, E., Sivunen, A. & Surakka, T. (2014). Fostering Team Creativity in Virtual Worlds. *Journal of Virtual Worlds Research, 7*(3), 1-22.

Essay II. Alahuhta, P. & Vartiainen, M. (2014). Artefacts Supporting Distributed Design Collaboration. In *Proceedings of NordDesign 2014 Conference,* 222-232. Design Society & Aalto University.

Essay III. Alahuhta, P., Fruchter, R. & Vartiainen, M. Emergence and Evolution of Epistemic and Technical Boundary Objects in Web Conferencing and Virtual World Environments. Unpublished manuscript.
38 pages

Essay IV. Alahuhta, P., Fruchter, R. & Vartiainen, M. Visual Artefacts in Virtual Worlds Supporting Distributed Design Collaboration. Unpublished manuscript.
24 pages

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The Finnish humanist, former Minister of Defence, and a widely known public speaker Yrjö Kallinen has been told to have characterized the essence of man as “a spark in a bigger fire”. While academic achievements are often seen as remarkable efforts of an individual, the quote allows inspecting this dissertation as a more or less collective achievement. Adopting this viewpoint, the finalization of this thesis privileges me to express my gratitude to several people and organizations.

First, I want to thank Professor Matti Vartiainen for his contribution and a vast amount of hard work as the supervisor of this dissertation. The frequent co-operation with him and Dr. Renate Fruchter from Stanford University allowed a swift start of the dissertation project, involving a well-planned and promptly executed data collection, insightful iterations of data analysis, and finally, multiple review rounds of this dissertation’s essays.

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In Punavuori, Helsinki
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Pekka Alahuhta

Author's contribution

Essay I. Mr. Alahuhta was the primary author of the paper. Mr. Alahuhta produced the final wording of the paper with Mrs. Nordbäck. Mr. Alahuhta conducted the literature review, including searching of the journal articles and reviewing them together with Mrs. Nordbäck. Dr. Sivunen and Mr. Surakka scrutinized the publication in general and participated in joint discussion on the contents and the structure of the publication.

Essay II. Mr. Alahuhta was the primary author of the paper and produced the final wording of the paper. Data analysis was a joint effort of Mr. Alahuhta and Prof. Vartiainen. Prof. Vartiainen also scrutinized the publication in general.

Essay III. Mr. Alahuhta was the primary author of the paper and produced the final wording of the paper. Prof. Vartiainen participated in the review of literature. Mr. Alahuhta and Dr. Fruchter collected the data. Data analysis was conducted as a joint effort, Mr. Alahuhta having the responsibility of the analysis process. Processing the paper within the review rounds has been a joint effort.

Essay IV. Mr. Alahuhta was the primary author of the paper and produced the final wording of the paper. Planning and reviewing the data analysis was a joint effort between Mr. Alahuhta and Prof. Vartiainen, while the analysis was conducted by Mr. Alahuhta. Prof. Vartiainen and Dr. Fruchter also scrutinized the publication in general.

1. Introduction

1.1 Background and research environment

Globalization and the rapid development of new collaboration technologies have altered global corporations' operational environments within recent decades. Parallel to an increasing need for a short-term expert workforce with diversified skills, this development has proliferated the emergence of expert teams working globally (Majchrzak, Rice, Malhotra, King & Ba, 2000; Malhotra, Majchrzak & Rosen, 2007). These teams, comprising geographically and culturally diverse team members, have been studied within the concept of virtual teams. According to a widely recognized definition, virtual teams are composed of geographically distributed, electronically dependent, dynamic and diverse members working remotely (Gibson & Gibbs, 2006).

Instead of occupying a shared physical space that represents a connecting factor between the members, the members strive to accomplish an interdependent task (Martins, Gilson & Maynard, 2004). Although a team might be considered to be virtual even if only one of the team members works in a different location than the others (Maznevski & Chudoba, 2000), electronic dependence means that ICT (Information and Communication Technology) tools are the virtual teams' primary communication method (Axtell, Fleck & Turner, 2004). Notably, virtual team members do not necessarily work from different locations all the time: the degree of virtuality varies (Kratzer, van Leenders & Engelen, 2006). It has been even argued that typically all teams are virtual to some extent (Martins et al., 2004).

Creativity can be defined as the production of novel and useful ideas (Amabile, 1983). Several studies have noted virtual teams' potential for creative interaction (e.g. Curseu, Schalk & Wessel, 2008; Garfield, Taylor, Dennis & Satzinger, 2001; Malhotra et al., 2007; Martins & Shalley, 2011; Nemiro, 2002). As a particular virtual team characteristic, the diversity between team members has been considered to nourish creative interaction (Boland, Lyytinen & Yoo, 2007).

Virtual teams foster diversity in terms of the distributed team members' expertise, cultural backgrounds and locations, for instance. This diversity is highlighted in global virtual teams that operate in multi-national enterprises (Araujo, 2009). Meanwhile, the fostered diversity within virtual teams may also create challenges for creative collaboration. These challenges include an increased potential for conflicts and communication difficulties (Martins &

Shalley, 2011) and the need for greater efforts to establish trust between team members (Chang, 2011). Therefore, it is not surprising that recent empirical studies have introduced both successful results (e.g. Malhotra, Majchrzak, Carman & Lott, 2001) and challenges (e.g. Kirkman, Rosen, Tesluk & Gibson, 2004) related to creative virtual team collaboration.

It is argued that virtual team members communicate and coordinate their work predominantly via ICT collaboration tools (Hertel, Geister & Konradt, 2005). Thus, ICT mediated communication and knowledge sharing within virtual teams is becoming increasingly important worldwide (Klitmøller & Lauring, 2013). The collaboration medium used by a virtual team may either support or hinder the teams' capability for creative collaboration (Hewett, 2005; Nemiro, 2002). As outlined by Bink and Beverlein (2007), the level of innovation in virtual teams depends on the utilized electronic communication technology and on the social and psychological limitations of that technology. Although compelling efforts toward entirely ICT-mediated creative interaction for virtual teams were realized in the early 1990s (see e.g. Taylor & Saarinen, 1994), more research is still needed to understand the role and potential of different collaboration technologies to support creative virtual team collaboration (Nemiro, 2002; Thatcher & Brown, 2010).

Meanwhile, the role of shared artefacts is also considered to be important for creative interaction (e.g. Bødker, 2009; Carlsen, Clegg & Gjersvik, 2013; Henderson, 1991; Luck, 2010). In a design context, artefacts are conceptualized as visual externalizations that help to explore, develop, and evaluate design ideas and facilitate the presentation of these ideas to others (Rahman, Cheng & Bayerl, 2013; Suwa & Tversky, 1997). Therefore, engineering designers do not operate with actual materials, but provide artefacts as transformed versions of constructed representations (Glock, 2003).

As argued by Carlsen, Clegg, Mortensen and Gjersvik (2013, p. 143), getting physical with artefacts involves transporting creative work from the realm of individual contemplation to visual interaction and co-creation, while ideas become objects for joint attention and development. These artefacts can be two-dimensional sketches (Henderson, 1991), mock-ups and prototypes (Saad & Maher, 2006), documents or other visual objects that are shared, observed, and possibly edited during collaboration. Notably, these artefacts may be used as boundary objects (Star & Griesemer, 1989), when they facilitate collaboration in the intersection of two different social worlds. As boundary objects, the artefacts are flexible enough for differing interpretations within social worlds, while also robust enough to convey a shared meaning in both social worlds.

Although the role of artefacts is widely studied, especially in the context of co-located design activities, more research is called to address the potential of artefacts to foster creative collaboration in virtual teams. (e.g., Luck, 2010). In addition, given that virtual teams communicate via various ICT tools, it is argued that the role of these different collaboration environments in supporting the presentation of design artefacts needs deeper exploration (Thatcher & Brown, 2010).

Concurrent web conferencing tools are a typical option for distributed creative collaboration. While they include functions for audio and video connection and the potential for application sharing, they can be seen as a good example of a synchronous collaboration medium (Olson & Olson, 2000). Recently it has been suggested that three-dimensional virtual worlds could potentially benefit creative collaboration (e.g. Koles & Nagy, 2014; Roberts, Heldal, Otto & Wolff, 2006; Vosinakis & Koutsabasis, 2013). Virtual worlds are described as communication systems through which multiple interactants share the same three-dimensional digital space while being able to navigate the space, manipulate objects, and communicate with each other through easily transformable digital self-representations (Yee & Bailenson, 2007). Compared with traditional videoconferencing and teleconferencing environments, virtual worlds might foster creative collaboration through enhanced, three-dimensional visual communication space (Bosch-Sijtsema & Sivunen, 2013), the potential to edit three-dimensional objects (Merrick, Gu & Wang, 2011), and users' enhanced possibilities for non-verbal communication (Ringo, 2007). However, the findings of virtual worlds' potential to support team creativity are mainly anecdotal. More research is, therefore, needed to address virtual worlds' potential to foster team level creativity (Bosch-Sijtsema & Sivunen, 2013).

1.2 Objectives and study context

In this dissertation, I explore synchronous, creative collaboration within distributed teamwork. The context of this exploration is framed as engineering design. Because this collaboration occurs over a distance and is mediated by ICT, it is relevant to study, how different collaboration environments can support the collaboration. In particular, I am interested in studying the differences between a state-of-the-art, two-dimensional collaboration environment, and a three-dimensional, emerging collaboration environment. In terms of ICT tools' support for creative collaboration, I direct my focus especially on the essence and role of artefacts in creative collaboration.

The exploration of this dissertation is grounded on three active research streams, including creative collaboration, artefacts, and virtual worlds. This dissertation attempts to combine these streams in a theoretical framework. Intersections of the framework's research streams involve virtual worlds' potential to support distributed team creativity, artefacts' role in creative collaboration, and virtual worlds' support of the use of shared artefacts within distributed, creative collaboration. Each of these intersections are depicted in Figure 1, and described below.

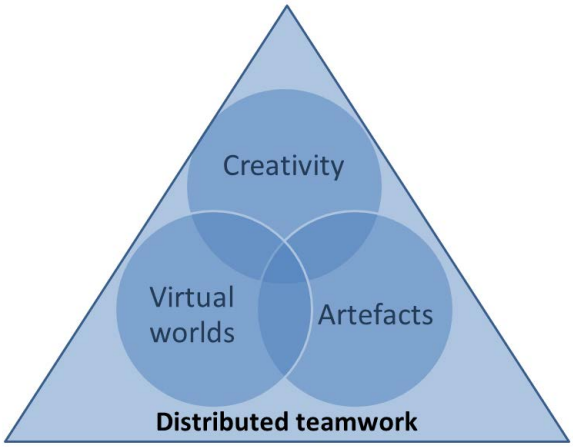

Figure 1. Theoretical framework of the dissertation

First, previous studies have widely addressed collaborative creativity at a team level. Creative collaboration refers to a creative activity that is performed by interdisciplinary teams (Mamykina, Candy & Edmonds, 2002); in other words, the individuals who engage in creative collaboration should possess different professional or scientific backgrounds (Herrmann, 2009). It has been declared that team creativity does not necessarily require co-located interaction (e.g. Malhotra et al., 2007; Nemiro, 2002). While the research concerning virtual teams' creativity is considered to be scarce (Ocker, 2005), some existing research efforts have reported finding successful encounters of distributed creative activities. Examples of these include the contexts of collaborative design (Iorio, Peschiera, Taylor & Korpela, 2011), and collaborative innovation processes (Bink & Beverlein, 2007; Malhotra et al., 2001). However, Chang (2011) noticed that this stream of research typically targets asynchronous virtual teams instead of synchronous distributed collaboration. Synchronous collaboration has been considered to be beneficial for virtual teams' collaborative decision-making and the development of shared meaning (Duranti & de Almeida, 2012). Hence, it is relevant to address the concurrent synchronous collaboration technologies' potential for virtual teams' creative interaction.

Moreover, creative collaboration is oftentimes connected only in ideation activity. This dissertation expands this view by adopting Koen and his co-authors' (2001) widely recognized conceptualization of creativity within the innovation process front end. The front end involves elements of opportunity identification and analysis, idea genesis, idea selection, and concept and technology development. This dissertation views the early phases of new product development to be composed of these activities, which are the focus of the empirical research.

Second, creative collaboration within virtual teams is primarily realized via ICT, because virtual teams collaborate predominantly via technological collaboration media (Hertel et al., 2005). While virtual team members are often highly educated people who are particularly selected for a certain task, the collaborative task is central to the use and selection of technology (Bjørn & Ngwenyama, 2010). Collaboration environments differ in terms of their func-

tionalities, features, and applicability to different tasks (Olson & Olson, 2000), thereby providing different affordances towards the collaboration. The affordances are formed as a combination of the technology's material features and its user's subjective perceptions and goals (Gibson, 1979; Gibbs, Rozaidi & Eisenberg, 2013).

However, the current state of research lacks an understanding of how media selection and the team's adaptation to different media affect the virtual team's success (Han, Hiltz, Fjermestad & Wang, 2011). Therefore, it is not surprising that Thatcher and Brown (2010) identified the creativity fostering potential of mediated communication as a future research topic. It is therefore relevant to ask, what type of ICT tools – in terms of their affordances – can support virtual teams' creative activities?

Established theories have addressed the appropriateness of collaboration tools for different tasks. For instance, media richness theory (Daft & Lengel, 1986; Daft, Lengel & Trevino, 1987) asserts that richer media are more suitable for complex tasks than leaner media. Previous research has advocated for the richness of three-dimensional virtual worlds in this regard (Lui, Piccoli & Ives, 2007; Suh & Lee, 2005). Moreover, previous studies have suggested virtual worlds as potential tools for collaborative creativity (Bhagwatwar, Massey & Dennis, 2013; Kohler, Fueller, Matzler & Stieger 2011a, Kohler, Fueller, Stieger & Matzler 2011b; Merrick et al., 2011; Vosinakis & Koutsabasis, 2013). While these studies indicate that virtual worlds could support team creativity, a systematic effort to describe, how virtual worlds actually do support team creativity has not been undertaken.

Finally, artefacts have been considered to be beneficial for collaborative creative interaction, especially within a design context (e.g., Fischer, 2001; Luck, 2010). Several studies investigate artefacts in synchronous, co-located collaboration. For example, Carlsen and his co-authors (2013) argue for co-located interaction via serendipitous visual artefacts, instead of distributed, computer-mediated collaboration. In a recent study, Rahman and her co-authors (2013) considered artefacts' role in synchronous, distributed interaction to be an important future research line leading towards understanding distributed design collaboration. In addition, empirical research is called for based on computer-supported collaborative design (Saad & Maher, 2006), including the role of shared artefacts (Tory, Staub-French, Po & Wu, 2008). As recently argued by Alin, Iorio and Taylor (2013), while different lines of research address face to face interaction and virtual interaction via boundary objects, a scant amount of research addresses integratively, how boundary objects might function in three-dimensional virtual world settings that emulate face-to-face interaction.

Grounded on the aforementioned discussion, the research gap is formed according to the three themes. First, building on previous studies that suggest three-dimensional virtual worlds' potential to act as a nourishing platform for creative collaboration, this dissertation addresses, how virtual worlds can foster team creativity, and how they differ from conventional synchronous web conferencing environments. Second, building on the existing studies of shared artefacts' contribution towards co-located creativity, it is worth asking, what

types of artefacts could foster creative, ICT-mediated distributed team collaboration. Finally, these two themes are connected by seeking to understand, how virtual worlds differ from concurrent web conferencing tools for distributed interaction in terms of utilizing artefacts within distributed teams' creative collaboration.

This research gap is addressed in the all four essays of this dissertation. Essay I is a literature review that connects the themes of virtual worlds and creativity. The review discusses virtual worlds' potential to foster creative collaboration in distributed settings. As a result, the review outlines eight affordances, the virtual worlds' concepts or features that are argued to foster distributed creative teamwork.

Building on the results of the literature review, the focus is directed to the affordances of rich visual information and multimodal communication. Hence, essay II investigates the role and essence of artefacts in distributed, creative collaboration. The essay contrasts observations of real-life interaction sessions in a web conferencing environment and in a virtual world. The essay introduces differences that exist between these environments when they act as platforms for a distributed team's shared visual artefacts.

Essay III continues this discussion by addressing the artefacts' potential to manifest as boundary objects during collaboration. While functioning as boundary objects, the artefacts assist team members from different social worlds to overcome their mutual knowledge barrier. Moreover, the essay connects information from the visual communication channel to the auditory communication channel, which involves speech acts.

Finally, essay IV connects the themes of virtual worlds and artefacts in the context of distributed creative collaboration. Essay IV classifies visual artefacts according to their contents. The classification is based on theories of epistemic and technical objects, hence taking into account the artefacts' content and the level at which the artefact represents an object. The usage of artefacts in a virtual world is connected to the collaborative activities of exchanging information and opinions, generating ideas, and solving problems.

Essays II, III and IV involve empirical observations of real-life collaborative, distributed interaction within the engineering design context. The selection of context is elicited as a study of distributed teams of professionals who are engaged in engineering design related tasks. The selection of context restricts the investigation from certain sources of creativity, such as musical creativity and serendipitous forms of art (e.g. Barrass & Barrass, 2006). However, the selection attempts to gather an understanding of concurrent and emergent collaboration practices within surroundings that are becoming increasingly common in global industrial corporations.

1.3 Structure of the thesis

This doctoral dissertation is structured as follows. In chapter 2, I outline the theoretical foundations of this thesis. The theoretical discussion is grounded on the aforementioned three research streams. First, I present some central

insights regarding creativity within the context of virtual team interaction. Second, I address the role of collaboration environments in virtual team interaction, particularly focusing on the contrast between web conferencing tools and three-dimensional virtual worlds as potential collaboration media for the creative, synchronous collaboration of virtual teams. Finally, I present theoretical foundations regarding artefacts and their potential to support creative, computer-mediated collaboration.

Based on the theoretical discussion, Chapter 3 articulates the research questions of this dissertation. Chapter 4 introduces the research approach of this dissertation, including the rationale that directed my methodological decisions. I describe the research site and the data collected. The analysis procedure is outlined at a high level and then is complemented with a more fine-grained discussion in each of the essays. Chapter 5 reviews the empirical results of this dissertation, first in terms of each essay and then outlining a brief overview of the results. Finally, Chapter 6 answers the research questions based on the essays. The aforementioned research streams are investigated by first providing a high-level discussion of the role of collaboration environments' and practices' in supporting distributed team creativity in light of the proposed theoretical framework and problem statement. Thereafter, the research streams of collaboration environments and shared artefacts within creative collaboration are connected by discussing a variety of different artefacts that are used within distributed teams' creative collaboration. Using this discussion as a lens, virtual world and web conferencing tool are contrasted in terms of acting as platforms for different types of shared artefacts. Finally, these artefacts' potential to manifest as boundary objects is brought into the discussion. The chapter ends by suggesting the theoretical and practical implications of this dissertation. The study is also evaluated regarding its reliability, validity, and potential limitations. At the conclusion, I present some possible departures for future research efforts.

2. Theoretical foundations

This dissertation attempts to understand how different collaboration environments and collaboration practices could support distributed, synchronous team creativity. In this manner, this section presents the existing discussion regarding the theoretical framework, which is formed as a combination of three research streams.

First I address the research stream of creativity. I attempt to connect this discussion to distributed teamwork and virtual teams, which are relevant to the knowledge gap that this dissertation attempts to fill. Moreover, I also address creativity's emergence in innovation and engineering design activities, which are observed empirically in this dissertation's essays. Second, the research stream of virtual worlds is approached by first discussing the role of collaboration environments in distributed teamwork. Media richness and media synchronicity theories are used in this inspection. Based on these theories and existing empirical research, audio and video conferencing tools are contrasted with virtual worlds as platforms for virtual team collaboration. The third research stream of the theoretical framework encompasses the theory of artefacts. The artefacts' role in design collaboration is discussed, expanded by the theories of epistemic objects, technical objects and boundary objects Finally, the artefacts' potential presence in web conferencing collaboration and virtual world collaboration is reviewed.

2.1 Creative team collaboration

Several studies have attempted to author a theoretical definition for creativity. A widely recognized definition framed creativity as the *production of novel and useful ideas* (Amabile, 1983). Subsequently, creativity has been conceptualized to involve the development of a novel product, idea, or problem solution that is of value to the individual or to a larger social group (Hennessey & Amabile, 2010). This novelty is furthermore divided into psychological creativity, meaning an idea's novelty to the organization in charge of the creative process, or historical creativity, meaning the idea's novelty in the history of world (Boden, 1990; see also Johnson & Carruthers, 2006). Notably, the novelty of an object does not guarantee its creativity: the object needs to also be interesting by the relevant criteria (Boden, 1990, p. 76). Finally, Johnson and Carruthers (2006) argued that a universally accepted definition that is relevant for all contexts will probably never exist.

Creativity has been studied at both the individual and team levels. At the individual level, personality, skills, motivation, expertise, and knowledge have been suggested as antecedents of creativity (Sternberg, 2006). Team level creativity is influenced by the involved individuals' creativity as a combination of team members' individual characteristics, team characteristics, and social influences, which comprise team interaction (Ocker, 2005). Meanwhile, the potential for idea generation and creativity within a team is believed to exceed the corresponding potential of individuals (Paulus & Huei-Chuan, 2000). In other words, instead of isolated reflective practitioners (Fischer, Fiaccardi, Eden, Sugimoto & Ye, 2005), much human creativity is argued to arise from activities that take place in a social context. These findings articulate the need to address creativity within a team setting.

Fluent group processes (Taggar, 2002) and perceived individual presence within group members (Heldal, Roberts, Bråthe & Wolff, 2007) are considered to be important for collective creativity. In addition, empirical studies have found that artefacts that embody the team's collective knowledge contribute towards team creativity (e.g., Fischer, 2005; Tory et al., 2008). As concluded by Hargadon and Bechky (2006), collective creativity can be framed as a moment when individuals come together to find, redefine, and solve problems that not one of the involved individuals could have solved alone easily, if at all. Finally, the physical environment and social climate have been considered to facilitate or hinder creative activities at both individual and organizational levels (Hunter, Bedell, & Mumford, 2007).

Typically, creative team interaction has been observed in co-located settings. For instance, the idea of a design studio (Vosinakis & Koutsabasis 2013) as a platform to teach and learn creativity is largely grounded on co-located interaction. However, the proliferation of virtual teams is renewing the conception of creativity as a co-located team's collective effort. In other words, creative processes are becoming more complex and demanding in modern organizations because teams and networks are increasingly engaged in a globally distributed mode of operation (Salter & Gann, 2003). As discussed by Kratzer and his co-authors (2006), the varying stages of physical proximity, communication modality within the creative tasks, and structuration and coordination of the team's task are leading the operations of creative, co-located teams into a more virtual direction. Therefore, these creative teams increasingly illustrate the characteristics of virtual teams.

2.1.1 Creativity in virtual teams

Participants in virtual teams who engage in creative interaction may operate in separate geographic locations and time zones across temporal, spatial and technological boundaries (e.g., Fischer et al., 2005; Gibson & Gibbs, 2006; Ocker, 2005). In other words, teams potentially benefit from "pockets of excellence" that involve specialized skills and talents required for a particular creative task and that are located around the company or even around the globe (Kratzer et al., 2006). On these occasions, virtual teams are an appealing way to utilize distributed talent. Virtual teams might, in addition, provide benefits

that are beyond the reach of the desired expertise, notwithstanding the physical boundaries. For instance, when engaging in ideation and brainstorming tasks, it has been suggested that virtual teams outperform co-located teams, primarily due to fewer interruptions during interactions (Martins et al., 2004).

Team diversity is advocated by the widening pool of creative team members within their applied technology, tasks, expertise and physical proximity (Griffith, Sawyer & Neale, 2003). Cross-functional, diverse teams may broaden the scope of the creative team's input (Bink & Beverlein, 2007). Chang's (2011) empirical study demonstrated that team members' diversity in knowledge and thinking perspectives is beneficial for creative tasks because team members see the solved problem via different perspectives and from different angles. Interestingly, diversity within team members is considered to lower team cohesiveness (Staples & Zhao, 2006). Furthermore, lower cohesiveness is considered to foster the emergence of potentially creative ideas and novel problem solving approaches (Ocker, 2005). Therefore, it is not surprising that virtual team's diversity is considered to be a necessity for creative design interaction (Kvan, 2000).

However, virtual teams also create hindrances towards creative interaction. These hindrances involve the dominance of single individuals within the team, technical and functional domain knowledge, members reducing their performance level to match the least productive team member, lack of shared understanding within the team members, time pressures encountered by the team, and technical difficulties (Ocker, 2005). Meanwhile virtual team communication lacks the features of face-to-face collaboration, which contribute towards effective understanding, establishing an interpersonal influence, communication coordination, and intentionality (Bink & Beverlein, 2007).

Added to the aforementioned communication difficulties, diversity may hinder virtual teams' creative performance. As shown by Martins and Shalley (2011), diversity in the form of demographic differences makes it harder to work together in the short run, which potentially reduces the common creative performance. Meanwhile, increasing diversity exposes teams to more internal conflicts, lack of trust between team members, and an increased need for work coordination efforts (Chang, 2011).

To conclude, the virtual team setting and its tendency to empower team diversity conveys both advantages and hindrances for creative collaboration. In this manner, it is relevant to empirically address the actual creative collaboration that takes place in real-life virtual teams. An interesting venue for examining these teams' activity is generated within innovation and engineering design activities.

2.1.2 Creativity in relation to innovation and design activities

Creativity is argued to be linked with innovation (Amabile, Conti, Coon, Lazenby & Herron, 1996), intertwined with innovation (Nemiro, 2002), or a pre-condition for organizational innovation (Hennessey & Amabile, 2010). As Anderson, Potocnik and Zhou (2014) connected creativity to idea generation, they conceptualized innovation process as a key component to implementing

ideas during the subsequent stages to create products, practices, and procedures that are better than the existing ones.

In addition, creativity and design activities can be seen as being strictly intertwined with each other, as discovered by Warr (2007). Routine design follows a defined, predictable schema, while creative design comprises more non-routine operations that produce unexpected and incongruous results that are still understandable in the current or shifted context (Gero, 1996). In this regard, Johnson and Carruthers (2006) consider it important to distinguish the creative process itself from the creation of an artefact. The results of design processes that display substantial amount of creativity are widely discussed (see e.g., Berente, Baxter & Lyytinen, 2010 and Carlsen, Clegg & Gjersvik, 2013). Parallel to creativity in general, the complexity of design problems requires communities rather than individuals to address, frame, and solve them (Fischer, 2004).

It should be noted that in design interaction and innovation processes, certain activities may involve a substantial amount of creativity. However, these creative activities might not necessarily lead to creative results. For instance, a fruitful interaction between a technical expert and a business decision-maker might include a substantial amount of creativity, when the collaboration is directed to figure out possible uses for a planned product. However, as a result of this creative collaboration, the technical expert and business decision-maker might end up cancelling the product's development path. In this case, the process has definitely been creative, although the result does not meet Amabile's (Amabile, 1983; Hennessey & Amabile, 2010) definitions of creativity. This practical observation has directed this dissertation's focus towards investigating the interaction events themselves instead of only assessing those results that are considered to be creative.

2.2 Collaboration environments in distributed interaction

The recent, rapid development in communication technology facilitates intra- and inter-organizational communication: this development has made virtual teams possible (Bink & Beverlein, 2007). Parallel to the development of communication technology, companies are increasingly engaging in global operations. Global enterprises leverage the distinct knowledge among their customers, suppliers, and business partners while integrating their resources (Gal, Lyytinen & Yoo, 2008). Although knowledge has been argued to be "sticky" (von Hippel, 1994), this is, expensive and difficult to transfer from one place to another (Lakhani & Panetta, 2007), an extensive number of studies have reported the advent of global, distributed collaboration. In addition, neither location, time zone, nor organization is an unconditional limitation when engaging a domain expert in a distributed design team. At least potentially, teams that operate in distributed settings are allowed to leverage the best globally available knowledge resources within their tasks. The distributed collaboration setting, which allows frequent team meetings, may also contribute towards the team's capability for integrative thinking (Gestwicki & McNely, 2012).

In contrast, empirical studies have also noted hindrances within these emerging distributed team collaborations. First, collaboration technologies do not necessarily support team members' awareness of other members' remote and local conditions, since these conditions are seldom made visible (Bosch-Sijtsema, Fruchter, Vartiainen & Ruohomäki, 2011). In addition, time, space, culture, infrastructure, and resource asymmetries among the local conditions of globally distributed team members often lead to challenges triggered by communication misunderstandings, technical difficulties hindering interaction and the lack of informal pre- and post-meeting communications (Bennett & Karat, 1994). Although these hindrances to distributed collaboration and challenges to knowledge sharing span the entire product lifecycle from early phase design to product maintenance operations, they are suggested to be overcome by developing communication competences, supporting information technology (Bailenson, Yee, Blascovich & Guadagno, 2008) or developing patterns for these technologies' use (Bostrom, Anson & Clawson, 1993).

The collaboration environments' role in distributed team's knowledge sharing is discussed in the following sections. I start the discussion by outlining the relevant viewpoints on ICT mediated virtual team collaboration in general. In particular, I review media richness and media synchronicity theories. These theories are used as a point of departure for highlighting differences that reside between conventional audio and video conferencing tools and virtual worlds. The discussion is continued by investigating how these collaboration environments are known to contribute towards virtual teams' creative collaboration.

2.2.1 ICT-mediated virtual team collaboration

The role of computer-mediated collaboration in the virtual team context has been widely addressed within the previous research efforts, likely because technology-mediated communication is considered to be necessary for virtual team interaction (Hertel et al., 2005). Meanwhile, the development of electronic communication technologies has fostered the emergence of cross-functional virtual teams (Ocker, 2005).

Existing research efforts have also addressed collaboration environments' potential to affect virtual teams and their behavior. For instance, Andres (2006) posited that technology-mediated communication can significantly impact the extent to which a virtual team can function as a collective group and the extent to which information can be effectively pooled and redefined within the virtual team's internal dialogue. Collaborative software may also offer potential for facilitating virtual teams' creative collaboration (Bink & Beverlein, 2007). For example, computer-mediated collaboration environments can be seen as being conducive to creativity because they prevent production blocking, filter irrelevant information, and direct the interacting team members to the task at hand (Thatcher & Brown, 2010). In addition, the reductive capabilities of computer-mediated collaboration, when compared to face-to-face interaction, have been found to be beneficial for newly formed, diverse teams (Carte & Chidambaram, 2004; Staples & Zhao, 2006).

Instead of selecting only a particular collaboration tool for a virtual team's communication medium, virtual teams are recommended to use a variety of media during their communication history (Kock & Lynn, 2012). Meanwhile, longitudinal studies of virtual team collaboration indicate that the collaboration tool used initially impacts the rest of the virtual team's interaction process (Han et al., 2011).

Based on the aforementioned research, it is relevant to ask what type of collaboration environments and what types of features support different virtual team collaboration tasks. Established theories of media richness and media synchronicity provide a rationale for answering this question.

Media richness theory (Daft & Lengel, 1986; Daft, Lengel & Trevino, 1987) addresses communication media's varying capacities for processing information. Different media can be classified according to a continuum, ranging from face-to-face communication as the richest and unaddressed documentation as the leanest medium (Daft, Lengel & Trevino, 1987). The media's capacity for immediate feedback, potential to convey multiple cues via different communication channels, language variety as the range of meaning that can be conveyed with language symbols, and personal focus as the message's potential to be tailored to the current situation differ between different communication media (Daft & Lengel, 1986; Daft, Lengel & Trevino, 1987).

Originally, it was suggested that a richer communication medium facilitates the processing of complex, subjective messages, while a leaner medium was considered to be effective for processing well-understood messages and standard data (Daft & Lengel, 1986). In a virtual team context, empirical evidence has been found regarding the contribution of rich media to team development during communication efforts (Ocker, 2005) and its stimulation of creative interaction (Kohler et al., 2011a). In a similar manner, Griffith and her co-authors (2003) noticed rich communication media's contribution towards forming collective knowledge. It is argued that virtual teams with a high cultural difference benefit from richer media compared to leaner media when undertaking equivocal tasks because richer media allows members to address misinterpretations and any lack of necessary information immediately during the interaction (Klitmøller & Lauring, 2013). Therefore, a richer collaboration medium might not be necessarily be the better collaboration medium for any communication task. Instead, a richer medium can be considered to be more suitable than a leaner media for certain tasks within certain circumstances, such as complex communication tasks within a diverse virtual team.

The classification scheme from rich to lean media has been applied to more recent collaboration tools. For instance, e-mail communication is argued to share fewer cues and therefore to be constraining compared to audio conferencing or face-to-face interaction (Malhotra & Majchrzak, 2005). Meanwhile, virtual worlds are suggested to be rich media, as they approach face-to-face communication (Messinger, Stroulia & Lyons, 2009). Therefore, virtual worlds allow richer communication than the traditional collaboration tools used by virtual teams (Alin et al., 2013).

Subsequently, media synchronicity theory (Dennis & Valacic, 1999; Dennis, Fuller & Valacic, 2008) was formulated to better address the capabilities of new media. Media synchronicity theory views communication as being composed of the conveyance of information and a convergence of meaning (Dennis et al., 2008). Five media capabilities are considered to influence information transmission and information processing, which respectively realize the conveyance and convergence activities. The physical media capabilities include transmission velocity, indicating the immediateness of message transmission and feedback; parallelism, representing the number of possible simultaneous transmissions; symbol sets, representing different encoding options for the exchanged information; rehearsability, representing the sender's potential to fine tune the message before delivering it; and reprocessability, representing the sender's ability to review previously transmitted content (Dennis et al., 2008). A task that emphasizes information conveyance benefits from media with low synchronicity; to the contrary, when aiming towards convergence within a team, high synchronicity media is the most appropriate (Dennis et al., 2008; Han et al., 2011).

The notion of synchronous and asynchronous communication media has been investigated further in the virtual team context. On the one hand, virtual teams' asynchronous communication environment, composed of web-based text conferencing tools such as intranets and bulletin boards, is considered to support the dissemination of information, and the receivers are expected to need time to process and respond to the message (Gaan, 2012). On the other hand, asynchronous communication media has been indicated as a barrier within virtual teams' problem solving and decision-making activities (Rosen, Furst & Blackburn, 2007). Therefore, Duranti and de Almeida (2012) consider synchronous collaboration environments to be favorable when virtual team members are expected to simultaneously focus their attention on a certain task involving the development of shared meaning and agreement.

The most widely established collaboration environment genres for synchronous virtual team collaboration involve audio and video based teleconferencing tools (Han et al., 2011). Meanwhile virtual worlds are becoming more popular as a virtual team collaboration medium. The forthcoming sections address these collaboration media in light of the previous discussion.

2.2.2 Audio and video conferencing tools for virtual team collaboration

Olson and Olson (2000) divide audio and video conferencing into meeting room and desktop conferencing options, while an option for application sharing is not included in audio and video conferencing tools. This dissertation adopts Olson and Olson's (2000) view by outlining audio conferencing tools as a collaboration environment that only employs an audio communication channel. Correspondingly, video conferencing tools include an audio communication channel and a visual communication channel that transmits video of the meeting participants (see also Malhotra & Majchrzak, 2005). Finally, web conferencing tools include an option for application sharing via visual communication channels. Audio conferencing and video conferencing tools have

often been viewed as typical collaboration tools for concurrent virtual teams. In the light of media richness theory, video conferencing and audio conferencing tools are both often labeled as rich media, and video conferencing tools are considered to be richer than audio conferencing tools (e.g., Klitmøller & Lauring, 2013; Setlock, Quinones & Fussell, 2007).

Existing studies have addressed both collaboration environment genres in the virtual team context. On the one hand, the video conferencing tools utilized in virtual team interactions have been considered to be a good substitute for face-to-face meetings when the interactants have a prior history of collaborating together (Gaan, 2012). On the other hand, Malhotra and Majchrzak (2005) and Davis with her co-authors (2009) argue that video conferencing technology shifts the virtual team members' focus to "talking heads" rather than shared content.

It has been suggested that audio conferencing offers a personal touch in communication via voice exchange, although the lack of non-verbal cues and difficulties in recognizing voices may result in confusion and distrust between interactants (Gaan, 2012). Despite the distractions of vocal cues and unfamiliar accents, audio conferencing has been observed to mitigate the negative impacts and to support positive impacts on virtual teams with cultural diversity (Shachaf, 2008).

As posited by Majchrzak, Malhotra and John (2005), a shared voice channel does not involve contextualization. Therefore, teleconferencing applications without a shared visual view may hinder the presentation of a message's contextual information, which contributes towards the message's easier absorption. For instance, highlighted annotations that others have made to documents, linked summaries, and detailed documents that connect an overview with its associated details allow members to contribute informal documents, to comment on others' contributions, and to attach evolving keywords to contributions to make retrieval easier (Majchrzak et al., 2005; Malhotra & Majchrzak, 2005). The potential for contextualization is highlighted, especially in virtual teams that engage in nonroutine tasks, hence assisting virtual team members to gather domain-related knowledge from the other interactants (Malhotra & Majchrzak, 2005). Therefore, virtual team members that engage in audio conferencing are advised to create written summaries of agreements during or immediately after teleconferencing and, therefore, complement the missing communication channels (Shachaf, 2008).

Despite the concurrent, wide adoption of web conferencing, audio conferencing, and video conferencing tools within virtual team collaboration, Malhotra and Majchrzak (2005) questioned whether these collaboration technologies can adequately support virtual team interaction, or do virtual teams need new technologies that provide a richer communication flow between participants? The same issue is addressed within the theory of social presence (Short, Williams & Christie, 1976; Biocca, Harms & Burgoon, 2003). Arguably, the extent of social presence associated with a communication medium is a function of the available communication channels for transmitting rich information, such as verbal cues, facial expressions, gaze, and physical proximity (Andres, 2006).

Media's fitness to certain communication tasks determines how the media's social presence matches the requirements of the task (Duranti & de Almeida, 2012).

It is argued that virtual team members that collaborate via video conferencing technology perceive low social presence, which may lead to a tendency to remain stubborn and to refrain from the negotiation of individual viewpoints, while reappraisals from outgroup members are not anticipated (Andres, 2006). Meanwhile, Biocca and his co-authors (2003) and Sivunen and Nordbäck (2014) outlined three-dimensional virtual worlds as evolving technologies for social presence. Subsequently, co-presence has been defined as an important aspect necessary to consider virtual worlds as a medium for professional workgroups (Bosch-Sijtsema & Sivunen, 2013). Therefore, it is relevant to digest whether and how virtual worlds might benefit virtual team collaboration.

2.2.3 Virtual worlds for virtual team collaboration

Virtual worlds are defined as communication systems through which multiple interactants share the same three-dimensional digital space despite occupying remote physical locations. Interactants can navigate the digital space, manipulate objects, and communicate with one another via avatars that are flexible and easily transformable digital self-representations in a graphic three-dimensional form (Yee & Bailenson, 2007). Because the definition outlines certain focal differences between virtual worlds and web conferencing environments, Bell (2008) clarifies that virtual worlds are synchronous but persistent communication systems that also enable asynchronous collaboration.

More than a decade ago, virtual reality applications were considered to be potential but preliminary options for synchronous virtual team collaboration (Olson & Olson, 2000). Recently, virtual worlds have evolved as a result of combined innovations within electronic gaming and social networking (Messinger et al., 2009). Therefore, a vast number of empirical studies have addressed virtual worlds in the context of a "second reality" (e.g., Halvorson, 2011; Partala, 2011) or gaming (e.g., Ducheneaut, Moore & Nickel, 2007 and Warburton, 2009). Additionally, van der Landt (2013) provided in her dissertation an extensive and thorough examination of 3D virtual environments' potential towards effective team collaboration and decision making at the group level. Meanwhile, it is argued that virtual worlds will become more pervasive and widely adopted over a longer time span because they lie at the forefront of web-based technological evolution (Riordan & O'Reilly, 2011). It has even been proclaimed that this development will lead to replacing the user interface of the Internet (Wyld, 2010).

Major differences exist between virtual world interaction and concurrent, two-dimensional collaboration environments. As an extreme, a recent research stream has conceptualized virtual worlds themselves as third places (see Oldenburg & Brissett, 1982; Oldenburg, 1999; also Gursimsek, 2012, p. 16) instead of as a communication device that connects individuals from various locations (Ducheneaut et al., 2007; Halvorson, 2011; Koles & Nagy, 2014).

As opposed to audio conferencing, video conferencing and web conferencing tools, which are characteristically considered to be synchronous media for distributed interaction, it has been suggested that virtual worlds foster interaction that occurs in co-located settings. For instance, virtual worlds have been utilized as a virtual context that fosters collaborative learning (Antonietti & Cantoia, 2000; Ketelhut, Nelson, Clarke & Dede, 2010) notwithstanding the physical context that surrounds the interactants. In this manner, 3D virtual worlds might foster certain collaborative activities instead of only enabling or providing decent surroundings for collaboration.

2.2.4 Creativity in ICT-mediated virtual team collaboration

As outlined by Bink and Beverlein (2007), the occurrence of creative collaboration is related to the extent to which virtual teams use the collaboration technologies effectively and how well the technology supports the natural processes of creative collaboration. When computer-mediated collaboration is used to perform creative tasks, technologies may also encourage more spontaneous interactions compared to co-located, face-to-face interaction (Kratzer et al., 2006). Therefore, it can be assumed that different collaboration environments may provide different affordances towards team creativity.

Nemiro (2002) presented two factors of collaboration technology that distinguish the creative process of virtual teams from co-located, traditional teams. First, distributed teams that engage in creative interaction may form an electronic archive of the creative process (Nemiro, 2002). This recorded history informs the decisions that have shaped the object of design while also containing a record of the design alternatives that were considered but not implemented during the creative process (Fischer, 2004). Second, virtual teams can also widen the creative pool of members through electronic links (Nemiro, 2002). Because technology contributes towards involving team members who otherwise would not attend the collaboration, it generates the potential to expand team members' expertise and diversity.

Previous research (e.g., Fischer, 2005; Kappel & Rubenstein, 1999) has reviewed collaboration environments, which are particularly tailored for distributed team's creative collaboration. Interestingly though, a scant number of studies have explicitly addressed web conferencing tools as a collaboration platform for virtual teams' creativity. A potential reason for this scarcity is introduced by Kappel and Rubenstein (1999), who claimed based on their review that it is difficult to determine how video conferencing and audio conferencing technologies have facilitated the creative process in design.

However, successful applications of web conferencing technologies to virtual teams' creative collaboration exist. On the one hand, Bower (2011) noted that the different communication modalities of web conferencing tools may support creative collaboration. For instance, a feature for text chat supports the simultaneous sharing of factual information within a large group, audio connection affords the rapid contribution of extensive descriptions from one person, a modality for screen sharing is beneficial for sharing information related to computing, and whiteboards support the development of conceptual

knowledge (Bower, 2011). On the other hand, Rutkowski and her co-authors (2002) suggested that creative virtual teams should utilize video conferencing only to resolve conflicts that arise within teamwork instead of using it to provide an all-the-time connection with lower quality.

In addition, some existing studies (e.g., Koles & Nagy, 2014; Koutsabasis, Vosinakis, Malisova & Paparounas, 2012) have noted the potential of virtual worlds to foster creative collaboration. This tendency has, furthermore, been divided into the features of virtual worlds and the characteristics of virtual world mediated communications that enhance abilities for creative collaboration. Virtual worlds' support of visual collaboration has been noted as facilitating collaboration around visual artefacts within a sketching task (Rahimian & Ibrahim, 2011). Meanwhile, virtual worlds can anonymize users by ensuring that the user feels comfortable and safe while collaborating as him- or herself within the virtual environment (Bosch-Sijtsema & Sivunen, 2013). Finally, virtual worlds' support for multimodal communication can enhance the development of trust between participants, which contributes to creative interaction (Fuller et al., 2012).

Virtual worlds can also act as favorable context for creativity even in a co-located setting. The virtual environment can contain elements that prime creativity (Bhagwatwar et al., 2013), comprise an entire design studio for learning collaborative creativity (Vosinakis & Koutsabasis, 2013), or present objects that are impossible in the real world while identifying and therefore challenging real-life implicit conventions and assumptions (Riordan & O'Reilly, 2011). Few studies have addressed innovation in a virtual world context (Helms, Giovacchini, Teigland & Kohler, 2010; Kohler et al., 2011a; Kohler et al., 2011b; Ringo, 2007). However, it is still unclear how virtual worlds' affordances can actually support team creativity (Bosch-Sijtsema & Sivunen, 2013).

This section has contrasted virtual worlds and web conferencing tools in terms of their potential to act as a medium for creative collaboration within distributed teams. Meanwhile, it is suggested that the three-dimensional virtual space within which virtual world users collaborate alters the users' potential to utilize shared representations compared to traditional, two-dimensional collaboration environments (Bailey, Leonardi & Barley, 2013). These representations', or visual artefacts', essence and relation to ICT-mediated collaboration are next addressed.

2.3 Artefacts and boundary objects in collaboration

Remote collaborative knowledge work is largely accomplished in and through objects and artefacts (Luff et al., 2003). Existing theoretical efforts have digested the concept of artefacts in relation to objects and boundary objects. First, an artefact is considered to refer to such implements and tools that are used to achieve ends; an activity is targeted to an object via a mediating artefact (Engeström, 1996). As formulated by Bødker (1997), artefacts are objects in the world around us that allow reflection; while artefacts mediate interaction within the world, they are not objects of the activity in use.

More specifically, Engeström (1987) connected Wartofsky's (1979) conceptualization of primary artefacts as being those artefacts that are used in the production of means of existence and the reproduction of things, while secondary artefacts are representations of such modes of action. These representations are considered to address any features of activity environments such as physical objects, processes and people or ideas and thoughts in one's mind needed to process objects towards more concrete forms. Therefore, a representation is something that stands for something else as its sign (Vygotsky, 1978, Bailey, Leonardi & Barley, 2012).

Added to Engeström's (1987) relatively tangible example of a hammer as an artefact, less concrete entities such as a focus of design that represents an idea can be referred to as artefacts (e.g., Schön, 1983, p. 136). Finally, computer-based content (Bødker, 1997) and internet communication tools are also argued to convey the potential to be artefacts (Thorne, 2003).

Finally, boundary objects are defined as objects that contribute towards knowledge sharing between two different social worlds (Star & Griesemer, 1989). While any artefact can be a boundary object, not all artefacts are boundary objects (Pennington, 2011). In other words, boundary objects can, but do not necessarily always, manifest as material artefacts (Ackerman, Dachtera, Pipek & Wulf, 2013).

In this section, artefacts are observed through three interconnected lenses. First, I discuss artefacts' essence and role in design, which align with the empirical context of this dissertation. Observing artefacts' role in the design context is relevant because design activities are conventionally connected to creativity. On the one hand, design quality is argued to hinge largely on creativity (Goldschmidt & Tatsa, 2005). On the other hand, creativity is considered to be a significant aspect of good design (Dorst & Cross, 2001). Thereafter, I address artefacts' tendency to represent certain content through the concepts of epistemic and technical objects. Finally, the artefacts' contribution to overcoming those barriers that are manifested during distributed teams' interaction is discussed through the concept of boundary objects. Table 1 below presents an overview and examples of the concepts of epistemic, technical, and boundary objects. The concepts will be discussed in a more detail within the next sections.

Table 1. Overview of epistemic, technical, and boundary objects

Object	Description	Example
Epistemic object	Visual or intangible object. Due to the dynamic, temporary and incomplete essence, potential to change via work practices. The signifying entity allows multiplicity of interpretations.	A sketch of a planned product
Technical object	Typically visual and static object. Stable, concrete and transparent essence: not subject for short-term changes. Accurate knowledge representations that do not allow multiple interpretations.	A detailed CAD drawing of the product's planned structure
Boundary object	Often visual artefacts that are used for sharing knowledge between different social worlds. Plastic enough to allow different intepretations, yet robust enough to maintain a common identity within the representations. Potential to change during collaboration.	An animated video of the product's intended functionality

2.3.1 Artefacts in design

Artefacts can be conceptualized as shared visual externalizations (Rahman, et al., 2013). Artefacts' different manifestations in design interaction are widely addressed in previous studies. These manifestations are suggested to occur in tangible but also in ICT-mediated environments. Examples of artefacts include sketches, databases, and CAD models (Henderson, 1991), images, documents and spreadsheets (Saad & Maher, 1996), three-dimensional models and prototypes (Tory et al., 2008) and even document collections (Pipek, Wulf & Johri, 2012). Moreover, an existing taxonomy of visual representations in engineering design divides two-dimensional visual artefacts as sketches and drawings, whereas three-dimensional visual artefacts encompass models and prototypes (Pei, Campbell & Evans, 2011). While collaborative sketching highlights an artefact's potential to develop within a short time span (Henderson, 1991), artefacts may also develop during a longer time span and are therefore not instantly authored to their final format (Fischer, 2004; Lutters, & Ackerman, 2002).

Artefacts can be viewed as representations that focus on individual and shared contexts. The individual view was articulated, for instance, by Berente and his co-authors (2010) as object worlds that describe the unique, personal context within which the designer engages in design practices. The world is composed of physical artefacts, tools and instruments, as well as formalisms, design principles, methods and practices that are associated in design (Berente

et al., 2010; Bucciarelli, 1994). By aligning the object worlds of participating designers, knowledge sharing is expected to occur more smoothly.

A parallel conceptualization of design artefacts as tools to share these representations was articulated in Schön's (1983) conceptualization of the reflective practitioner. In his example (Schön, 1983; pp. 79-85), Schön described a problem solving process in an engineering design context within which shared artefacts contribute towards reflection-in-action between a student and a master (Schön, 1983; Fruchter & Cavallin, 2006). This reflective process is nourished by shared artefacts that can make transparent practices visible through the researchers' reconstructive interpretation (Ecker & Boujut, 2003).

While the aforementioned studies have outlined artefacts' potential to articulate more or less individual knowledge, artefacts can also be seen as objects that represent a team's knowledge (Boland & Tenkasi, 1995). Therefore, artefacts can mean different things to different actors and can hold specific significance for particular groups based on the groups' practices (Pipek et al., 2011).

Within the great variety of artefacts' essence and contents, the artefacts' purpose remains the intent to share knowledge between the design team's members and stakeholders (Fruchter & Courtier, 2010; Gestwicki & McNely, 2012; Hewett, 2005). The artefacts' potential to share knowledge is articulated in the concept of knowledge artefacts by Cabitza, Colombo and Simone (2013). As outlined by the concept, knowledge artefacts are material but not necessarily tangible, inscribed artefacts; they are created and maintained collaboratively to support knowledge-oriented social processes within or across communities of practice (Cabitza et al., 2013) It has been noted that artefacts act as a starting point for discussions and negotiations, spark inspiration and support the development of mutual understanding (Rahman et al., 2013).

As outlined by Pennington (2010), the construction of an artefact entails learning and creative thinking from both a creator and a recipient, enabling the dynamic flow of information between them and the dynamic creation of mental models that contain linkages between participants. In contrast, artefacts alone are considered to be incomplete embodiments of knowledge: only through the use of artefacts in conversation might the shared understanding of a design situation possibly emerge (Luck, 2010).

The artefacts' role as a facilitator for discussion was also emphasized by Fischer (2004, 2005). In so doing, shared artefacts are argued to foster team creativity (Johnson & Carruthers, 2006; Rahman et al., 2013). Meanwhile, the synchronous manipulation of shared artefacts has been recognized as a potential factor to increase interaction quality in distributed idea generation (Rahman et al., 2013). In a similar manner, collaborative design environment's insufficient potential for a joint development and elaboration of individually authored sketches and artefacts, has been found to hinder teams' abilities for design collaboration (Seitamaa-Hakkarainen, Raunio, Raami, Muukkonen & Hakkarainen, 2001).

The emerging variety of types of artefacts is reflected in various design process stages (Rowe, 1987) that are, correspondingly, nourished by different types of artefacts (Gestwicki & McNely, 2012). Design typically begins with a

series of sketches; in latter phases, more structured drawings such as plans and sections are included (Suwa, Purcell and Gero, 1998). The development of artefacts' representation aligns with details that are typically open at the beginning of the design stage and become more rigid as the design process proceeds (Suwa et al., 1998.). Because artefacts are representations of certain knowledge (Comi & Eppler, 2011), it can be assumed that the artefacts' way of representing the knowledge or content varies. This assumption is addressed within the theories of epistemic and technical objects.

2.3.2 Epistemic and technical objects

Ewenstein and Whyte (2009) connected the research streams of epistemic and technical objects to describe visual representations that can be utilized in collaborative knowledge work. The following sections discuss the existing research on epistemic and technical objects and their roles in a design collaboration context.

Epistemic objects

Epistemic objects are considered to be dynamic and incomplete objects of knowledge work (Knorr Cetina 2001). They comprise cascades of unfolding instantiations while typically being transient and internally complex entities (Knorr Cetina, 2001; Maio, 2013; Rheinberger, 1997). Summarized by Knorr Cetina (2008), epistemic objects are characterized by their unfolding, dispersed and signifying character. These dimensions are discussed below.

Knorr Cetina (2001, 2008) summarizes unfolding to refer to the objects' temporary nature or existence: a lack of 'object-ivity', an incompleteness of being, and a non-identity with itself. The objects continually explode and mutate into something else and are as much defined by what they are not as by what they are. Therefore, epistemic objects are, according to Knorr Cetina (2008, p. 183), counter-intuitive to the everyday conceptualization of an object. Moreover, the dispersed characteristics relate the epistemic objects' potential to exist simultaneously in a variety of forms, ranging from figurative, mathematical, and other forms of representation to material realizations (Knorr Cetina, 2008).

Finally, Knorr Cetina (2008) defined epistemic objects as conveying a signifying, or meaning-producing, character. The key characteristic of an epistemic object resides in the pointers that the objects provide to possible further explorations instead of in deriving an immediate practical significance from the real (Knorr Cetina, 2001). Therefore, epistemic objects are not items with fixed qualities: rather, they are open-ended projections that are oriented toward something that does not exist or toward something that is not known for sure (Miettinen & Virkkunen, 2005). As an example of epistemic objects' signifying potential, Knorr Cetina (2008, p. 183) depicted a graph indicating information on increasing system downtime during its lifetime. The graph "represents" information that the system needs repairing at times, while communicating the accumulation of repairing efforts and providing indications, as to when to

replace the system. However, the graph does not provide accurate information or guidelines regarding when to undertake the maintenance operations and what specific operations to do each time.

The possibility for further exploration grounded on epistemic objects reflects, on the one hand, the incompleteness and abstractness of the epistemic objects and, on the other hand, inquiry and pursuit (Ewenstein & Whyte, 2009). An example of material realization can be drawn from a co-authored design sketch, which, in its incompleteness and temporary form of being, coordinates distributed cognition by allowing the manipulation of tacit knowledge between individuals (Henderson, 1991, p. 450).

In their spoken form of existence, epistemic objects can be seen as concepts or metaphors that foster knowledge sharing or the pursuit of knowledge by temporarily signifying something other than the object itself (Ewenstein & Whyte, 2009; Swan, Bresnen, Newell & Robinson, 2007). Corresponding to design sketches, externalizing fuzzy ideas often involves figurative language and symbolism in the form of metaphors (Koskinen, 2005). Moreover, the notion of figurative language can be expanded into narratives, which promote coordination in innovation processes (Bartel & Garud, 2009). In particular, their definition of a provisional narrative, which depicts innovation efforts that are still unfolding and, therefore, provisional in nature, approaches the definition of an epistemic object. Finally, Knorr Cetina (1997, 2001) and Rheinberger (1997) relate scientific work to epistemic objects. As conceptualized by Ewenstein and Whyte (2009), the role of scientific work is to turn epistemic objects into technical objects.

Technical objects

In contrast with epistemic objects' unfolding, dispersed and signifying character (Knorr Cetina, 2001), technical objects are static and material. Technical objects are characterized as fixed, stable, concrete and transparent (Knorr Cetina, 1997; McGivern & Dopson, 2010).

Due to the aforementioned essence, technical objects are considered to fulfill the criteria of being ready-to-hand, complete, unproblematic, and taken-for-granted tools (Ewenstein & Whyte, 2009). Because technical objects are considered to be static, they do not further evolve or change through epistemic work practices (Ewenstein & Whyte, 2009; McGivern & Dopson, 2010). In other words, technical objects do not definitionally convey a signifying and metaphorical nature, which is an essential feature of epistemic objects.

Examples of technical objects include reliability tests, established services provided by an organization, and governance policies adopted in organization (McGivern & Dopson, 2010). In addition, an ICT system can be considered to be a technical object (Salter & Gann, 2003). Previous studies have conceptualized technical artefacts as technical objects that have a technical function and a physical structure and that are consciously designed, produced and used by humans to realize their function (Kroes, 2002; see also Farrel & Hooker, 2012).

Moreover, artefactual representations, such as technical drawings or accurate technical documents, can be considered to be technical objects when they are used as static reference points or as constants in the design process (Ewenstein & Whyte, 2009). In other words, these artefacts are not supposed to change, but they permit change in the other factors surrounding them.

The concept of boundary objects expands the spectrum of epistemic and technical objects. While epistemic objects are subject to multiple interpretations, technical objects typically convey a fixed meaning. On the contrary, boundary objects act within the intersection of two different social worlds (Star & Griesemer, 1989). The flexibility in the interpretation of boundary objects allows social worlds to interpret the object with respect to their existing knowledge (Star, 2010).

2.3.3 Boundary objects

Boundary objects are robust enough to maintain a common identity across different interacting social worlds (Star & Griesemer, 1989). Star and Griesemer emphasize that consensus is rarely achieved when these ill-structured objects are worked on by groups that co-operate without consensus, going back and forth between different forms of objects. Therefore, the boundary objects should be plastic enough to adapt to the local needs and constraints of the several parties employing them and robust enough to maintain a common identity across the different sites (Star & Griesemer, 1989).

Due to the interpretive flexibility gained through robust meaning, boundary objects allow different individuals and groups to work together without a shared consensus (Star & Griesemer, 1989; also Bødker, 1998) by facilitating and stabilizing the collaboration activity (Bossen, Jensen & Udsen, 2014). Two communities can use the same artefact – e.g., a classification system – as a boundary object without necessarily sharing it at a cognitive level (Bowker & Star, 1999; Subrahmanian et al., 2003). Boundary objects facilitate knowledge creation and sharing as representations and foster collaboration between subjects, i.e., individuals and groups. As different communities, disciplines, and worlds interact, boundary objects reflect the knowledge development process that occurs within these communities in an ongoing and dialogical manner (Eckert & Boujut, 2003; Ewenstein & Whyte, 2009). However, this passing of knowledge sharing between different communities of practice while satisfying the various needs of all of them is not necessarily clean and unproblematic (Lee, 2007).

The boundary object is originally modified within a single social world (Karsten, Lyytinen, Hurskainen & Koskelainen, 2001). When a joint field between different social worlds emerges, boundary objects mediate the inter-group knowledge sharing (Bødker, 1998). In other words, the artefact assists each member of the community in satisfying their own informational requirements and, therefore, satisfies the community's collective information demands. Thereafter, boundary objects tend to be persistent features at the intersection of these groups (Kim & King, 2004). Meanwhile, boundary objects have been noticed to arise over time from durable co-operation between com-

munities of practice (Bowker & Star, 1999). Boundary objects may change over time through the joint processing of interacting social worlds (Karsten et al., 2001) and be perceived or used differently on different occasions (Akkerman & Bakker, 2011).

Boundary objects can take numerous types and forms, both concrete and abstract (Bresnen, 2010). Typically, boundary objects are categorized into repositories, such as databases and libraries; standardized forms and methods that provide a shared format and language for solving problems; and objects or models that can be considered to be observable representations (Star & Griesemer, 1989; Carlile, 2002; Maio, 2013). Consequently, artefacts such as pictures, prototypes, graphs, process models, building blocks, or even text can potentially act as a boundary object (Feldman & Khademian, 2007; Subrahmanian et al., 2003).

Accordingly, the concept of boundary objects has been widely studied within computer-supported collaborative work (Bossen et al., 2014). In general, computer-supported cooperative work tools need to convey a meaning to help the participants develop a similar understanding of the object being referred to; this can determine the success of the collaboration tool (Eckert & Boujut, 2003). ICT tools in the form of electronic document archives or enterprise resource planning systems can act as boundary objects (Levina & Vaast, 2005). In addition, it has been noted that the creation of ICT systems involves knowledge sharing, while written use cases of agile research methods can act as boundary objects within software process participants (Cohn, Sim & Lee, 2009).

Collaborative ICT systems that form a part of a team's communication infrastructure can act as a boundary object by generating a platform for processing and modifying the team's other boundary objects (Dirckinck-Holmfeld, 2006). Moreover, Levina and Vaast (2005) stress the need to develop and maintain a common identity for ICT-based objects designed to support knowledge management across boundaries. To help achieve this common identity, companies use 'boundary spanners-in-practice', people who help build common identities across fields, for instance, by negotiating (Levina & Vaast, 2005; also Pennington, 2011). To identify when and where ICT can support knowledge creation most effectively, Kim and King (2004) suggested identifying the key articulation points among knowledge experts.

Noting the aforementioned variety in boundary objects' existence and their role in assisting different social worlds to overcome their mutual barriers, it is not surprising that boundary objects have been studied in various contexts (Ackerman et al., 2013). These contexts include the new product development phase (Carlile, 2002), local maintenance work (Betz, 2010), the development of educational collaboration (Smeds, Suominen & Pöyry-Lassila, 2014), and engineering work in an industrial production process (Bechky, 2003), to name a few. Of a particular interest to this study, several authors (including Bergman, Mark & Lyytinen, 2007; Berente, et al., 2010 and Luck 2010) have connected boundary objects to design interaction and creativity.

In a collaborative design context, artefacts that support design interaction by promoting shared representations, transforming design knowledge, mobilizing for design action, and legitimizing design knowledge have been conceptualized as design boundary objects (Bergman et al., 2007; also Lavikka, Smeds & Jaatinen, 2015). Characteristics for boundary objects, artefacts can, therefore contribute towards mediating communication between different designers' personal object worlds (Berente et al., 2010).

In addition, boundary objects and information relevant to the task at hand have been found to support communities of interest as they undertake collaborative design activities (Fischer, 2001). Within collaborative design settings, the characteristics of boundary objects can be helpful to design situations when communication across disciplines and knowledge domains occurs, for example, within a cross-functional team (Luck, 2010).

2.3.4 Artefacts in computer-mediated collaboration

The previous review discussed artefacts first in the context of design collaboration and then addressed the essence of artefacts via the concepts of epistemic and technical objects. The concept of boundary objects addresses the artefacts' role within the knowledge sharing activity that occurs between two different social worlds. Proceeding from these results, it is relevant to digest how artefacts can manifest in a virtual team setting or, more generally, in computer-mediated collaboration.

In their extensive review, Orlikowski and Iacono (2001) raised the different ways that people engage with various technological artefacts as a central theoretical concern for ICT artefact studies. This theoretical concern has been addressed for both asynchronous and synchronous team collaboration. On the one hand, it has been noted that an asynchronous collaboration system can act as a platform for uploading and editing visual documents within collaborative design (Lahti, Seitamaa-Hakkarainen and Hakkarainen, 2004). Moreover, collaboration within digital, three-dimensional building models can enable interaction within innovators; therefore, IT artefacts act as engines of innovation by enabling the creation and distribution of knowledge (Boland, Lyytinen & Yoo, 2007).

On the other hand, the potential to manipulate an artefact in synchronous collaboration has been argued to be beneficial for joint idea generation (Rahman et al., 2013). As web conferencing environments might enable sharing of a visual artefact, virtual worlds typically support an option to have an individual view of a shared object. This option allows the interactants to move between a collaborative mode and individual work (Gül & Maher, 2009).

Virtual worlds' potential for presenting shared artefacts has been particularly studied in the context of building information modeling (BIM). BIM involves creation and collaboration around a three-dimensional virtual model of a planned building and corresponding databases (see e.g., Dossick & Neff, 2009 and Merrick et al., 2011). The potential to utilize a three-dimensional model of a building – a shared virtual artefact – has been considered to be beneficial to simulating and experimenting with new design-related systems and support-

ing both human-human and human-computer interactions (Merrick et al., 2011). In this manner, Gursimsek (2012) investigated in his dissertation the designing and essence of virtual place as an artefact. The potential of BIM for facilitating collaboration has also received criticism. For instance, Neff, Fiore-Silfvast and Dossick (2010) pinpointed hindrances in the reduced interpretive flexibility of three-dimensional models versus paper artefacts and hindrances in facilitating inter-organizational collaboration.

While ICT systems in general were previously observed to act as boundary objects, shared artefacts within computer-mediated collaboration have also been observed to act as boundary objects between interacting social worlds. Examples include electronic health recording systems (Bossen et al., 2014) and electronic project plans (Bergman et al., 2007; see also Ackerman et al., 2013). In addition, recent research has discovered shared artefacts acting as boundary objects in 3D virtual worlds, structuring the negotiation space, expanding the attendees' knowledge within different aspects that were the focus of negotiation, and justifying the negotiation outcomes by helping the interactants to interpret potential combinations of structured knowledge (Alin et al., 2013).

2.4 Summary: Role of shared artefacts and collaboration environments in distributed creative collaboration

The theoretical framework of this dissertation research is composed of three research streams. The streams include creativity, virtual worlds, and artefacts. The streams are, furthermore, studied in relation to distributed teamwork, targetting distributed team members' creative collaboration. Based on the aforementioned discussion, this dissertation connects these research streams as follows.

This dissertation adopts virtual teams' creative collaboration as its point of departure. Creativity is increasingly performed as a team activity and, vice versa, virtual teams are becoming increasingly popular (e.g., Martins et al., 2004). Instead of co-located teams or lone individuals engaging in creative activities, virtual teams advocate diversity among team members. This diversity might involve differing expertise, cultures, or physical surroundings between the team members. Despite the difficulties and hindrances caused by increasing team diversity, team diversity is considered to encourage creative collaboration (Boland et al., 2007).

To continue, virtual teams are composed of geographically more or less distributed team members. As virtual team members, they collaborate predominantly via ICT collaboration media (Hertel et al., 2005). Existing research has outlined the collaboration medium's potential to affect virtual teams' creative collaboration (e.g., Nemiro, 2002). Meanwhile, existing research on collaboration environments, parallel to media richness and media synchronicity theories, suggest that different collaboration environments might be more or less suitable for different tasks. Adopting these viewpoints, this dissertation contrasts three-dimensional virtual worlds and web conferencing environments in their support of synchronous, distributed team creativity.

On the one hand, web conferencing environments constitute a widely established collaboration environment for today's virtual teams; hence, it is reasonable to expect that they act as a platform for virtual teams' creative interaction. On the other hand, existing studies have suggested that the increasingly popular (Wyld, 2010) virtual worlds may benefit team creativity. For instance, Messinger and his co-authors (2009) offered an overview of a particular virtual world that potentially facilitates creative, serendipitous collaboration, and Koles and Nagy (2014) discuss virtual worlds' potential to foster team creativity, though at a conceptual level. These existing studies provide a starting point for a more detailed and systematic investigation: how – and if – virtual worlds actually support creativity between distributed team members.

Finally, the virtual worlds' rich visual communication channel and three-dimensional virtual space's potential to alter the collaboration around objects and artefacts led to compare virtual worlds' and web conferencing tools' differences via the theory of artefacts. Previous studies have adopted artefacts' central role towards co-located team creativity (e.g., Carlsen et al., 2013; Henderson, 1991; Tory et al., 2008). Moreover, theories of epistemic and technical objects address different characteristics of artefacts, including artefacts' potential to represent their object at a different level. Meanwhile the concept of boundary objects includes the artefacts' potential to support collaboration within interacting social worlds.

Few existing studies (e.g., Rahman et al., 2013) have empirically investigated the artefacts' role in distributed, synchronous creative interaction. This dissertation continues this path by systematically addressing the role and diversity of artefacts within distributed team members' collaboration and, in this manner, the differences that potentially reside between three-dimensional virtual worlds and web conferencing tools as a platform for collaborative creativity.

3. Research questions

Given the advent and proliferation of virtual teams, studies have addressed creativity in distributed team settings for more than a decade. Originated by Nemiro's (2002) study discussing the stages of virtual teams' creative work and suitable tools for each stage, subsequent studies have outlined both advantages of and hindrances to creative collaboration in distributed settings. Based on this research tradition, this dissertation addresses the following problem statement: *How can different collaboration environments and collaboration practices support synchronous team-level distributed creative collaboration?*

This broad-level problem statement is focused on the previously introduced research streams of creativity, artefacts and virtual worlds. I justify this decision to focus the problem statement as follows. First, the dissertation investigates three-dimensional virtual worlds as a collaboration medium. Virtual worlds are contrasted with web conferencing tools for the following reasons. Web conferencing tools represent a current state-of-the-art and widely established medium for global, distributed collaboration (see e.g., Gibson & Gibbs, 2006; Nemiro, 2002, Olson & Olson, 2000). Meanwhile, virtual worlds are an emerging technology that is expected to become widely adopted over time (Riordan & O'Reilly, 2011; Wyld, 2010). Virtual worlds have been considered to be beneficial to creative collaboration (Merrick et al., 2011; Roberts et al., 2006) design-related interaction (Vosinakis & Koutsabasis, 2013), and collaborative work in general (van der Landt, 2013). Potential differences between an established and an emerging collaboration environment genre create an interesting point of departure for empirical research.

Second, the collaboration practices articulated in the problem statement are focused on shared and co-edited artefacts that support creative collaboration. This decision has been driven by artefacts' central role in both creative interaction (e.g., Bødker, 2009; Johnson & Carruthers, 2006) and design processes (e.g., Henderson, 1991; Luck, 2010). The connection between creativity and artefacts is observed in the roles of both web conferencing tools and virtual worlds. This decision was made to address the different collaboration environments' potential to present artefacts within computer-mediated creativity at a broader level instead of only focusing on virtual world interaction. Notably, while virtual worlds are argued to offer a relatively novel, three-dimensional user experience, they act as an interesting venue to contrast with the widely adopted, two-dimensional web conferencing tools when attempting

to understand the connection between artefacts and creativity in computer-mediated collaboration.

The problem statement is divided into three primary research questions and one sub-question that target the intersections of the research streams. The first research question addresses three-dimensional virtual worlds' potential to support team creativity. Because teams operate in geographically distributed settings, they are obliged to communicate via a collaboration medium (Nemiro, 2002). The first research question departs from previous research streams that indicate virtual worlds' potential to nourish team-level creativity (Bhagwatwar et al., 2013; Koutsabasis et al., 2012; Messinger et al., 2009; Roberts et al., 2006). Recently, Bosch-Sijtsema and Sivunen (2013) have called for research addressing the realization of distributed creativity in virtual worlds. To conclude, while previous research indicates that three-dimensional virtual worlds might somehow benefit creative team collaboration, the research question addresses a systematic attempt to discover three-dimensional virtual worlds' potential affordances to support team creativity. Therefore, the concept of affordances particularly highlights the potential differences conveyed by virtual worlds in relation to concurrent web conferencing environments with an option for synchronous, audio-visual communication.

Moreover, previous studies have suggested that artefacts are beneficial for virtual team creativity (e.g., Berente et al., 2010; Fischer, 2005; Lee, 2007, Luck, 2010, Tory et al., 2008). Based on these studies, the second research question explores the role and taxonomy of artefacts in distributed teams members' creative collaboration. Virtual teams are known to convey a tendency to engage diverse members with multiple backgrounds and expertise (e.g., Martins et al., 2004). Meanwhile, boundary objects' are conceptualized as artefacts that contribute towards knowledge sharing between multiple social worlds (Star & Griesemer, 1989). In this manner, the sub-question of the second research question addresses how the studied artefacts are used as boundary objects.

Finally, previous studies of virtual worlds have highlighted possible differences within virtual worlds' potential to act as a platform for shared artefacts compared to traditional collaboration environments involving auditory and two-dimensional visual communication channels. For instance, Bailey and her colleagues (2013) noted the three-dimensional environments' potential to expand users' collaborative operations from acting with and on representations to acting within representations. While the potential of the three-dimensional environment has been addressed in the architecture, engineering, and construction (AEC) context (Gül & Maher, 2009; Rosenman et al., 2007; Tory et al., 2008), it is still unclear how the engineering design domain could utilize this option (see Alin et al., 2013). Therefore, the third research question connects the two main research questions by asking how virtual worlds differ from web conferencing tools in terms of supporting artefacts.

The research questions are as follows:

Research question 1: How can virtual worlds support team creativity?

The first research question is studied in essays I and IV. In essay I, the question is addressed by conducting a systematic literature review on the topic. The literature review addresses existing empirical studies to discover what functionalities and features of virtual worlds are beneficial to creative collaboration. Essay IV investigates virtual worlds' potential to empirically support team creativity during the collaborative activities of exchanging information and opinions, generating ideas and solving problems.

Research question 2: What kind of artefacts can support distributed team's creative collaboration?

The second research question is studied in essays II, III and IV. The question focuses on web conferencing tools and virtual worlds as representing the distributed teams' collaboration environments. In essay II, the question is answered by an examination of different kind of artefacts that are present during distributed collaboration via web conferencing tools and virtual worlds. This examination is continued in essay III, which studies the potential for boundary objects to emerge during interaction events conducted via a web conferencing tool and a virtual world. Finally, essay IV studies shared visual artefacts in a virtual world environment.

Research question 2.1: How are these supporting artefacts used as boundary objects?

Sub-question 2.1 is studied in essay III. The essay addresses the question by investigating the relationship of shared artefacts to boundary objects, as well as boundary objects' different forms of manifestation in auditory and visual communication channels.

Research question 3: How do virtual worlds differ from concurrent web conferencing environments in terms of supporting artefacts?

The third research question is studied in essays II and III. Essay II addresses the question by contrasting web conferencing tools and virtual worlds as collaboration environments in terms of supporting visual artefacts. Moreover, essay III expands this investigation to communication via both audio and visual communication channels.

4. Research design and methods

This section discusses the research design and methods for this dissertation's four essays. First, the underlying ontological and epistemological assumptions of the dissertation and the nature of inquiry are explained. Because three of the essays were conducted as a case study, the rationale behind the decision to undertake a case study is discussed. In addition, the case study environment is described. Finally, the research methods and data sets used in the four essays are described.

4.1 Research approach

I decided to undertake a qualitative research approach for this dissertation. The following arguments provide my rationale for this decision. First, as noted in the literature review, the existing studies indicate a research gap regarding artefacts' potential to support distributed, creative team collaboration within virtual worlds. Meanwhile, the previous literature related to this particular topic and the related research streams do not introduce a solid theoretical framework that could be applied to addressing the research gap. The absence of such a framework directed me to consider a qualitative research approach instead of undertaking quantitative approach to the dissertation study.

Second, several existing studies have relied on qualitative research approach when studying distributed collaboration over different collaboration media. The qualitative research approach has also been widely utilized to study artefacts within creative collaboration. Studies that comprise both of these fields have motivated a qualitative approach given the need for a basic understanding rather than the isolation of factors to prove a hypothesis (Roberts et al., 2006). Thereafter, it can be concluded that a qualitative research approach is in line with the previous research efforts addressing this dissertation's topic.

Finally, based on previous studies, Edmondson and McManus (2007) conclude that qualitative data are appropriate for studying phenomena that are not well understood. As proclaimed by van Maanen (1979), qualitative research methods emphasize the researcher's desire for contextual understanding, in terms of both understanding the context in which a behavior takes place and seeing the behavior from the position of its originator.

The selection of a qualitative research approach is reflected most evidently in the data collection and data analysis practices. The primary data are composed

as observations of recorded interaction sessions. It should be noted, though that a quantitative research approach is not entirely avoided in this dissertation. For instance, essay III uses the average values of observed artefact categories to address differences between the interaction sessions in two collaboration environments. However, the scant quantitative data are used as part of undertaking the qualitative inquiry.

4.1.1 Interpretive approach

Grounding on the dimensions of science's view of society as subjective or objective inquiry; and having a tendency towards radical change or regulation, Burrel and Morgan (1979, p. 22) describe a framework including social science's four paradigms. According to the framework, I connect this study to the interpretive paradigm. I justify this viewpoint as follows.

First, it can be argued that this dissertation does not adopt a critical view of the topic, which could manifest, for instance, as e.g., asymmetrical power relations that are manifested within the studied interaction practices (Alvesson & Deetz, 1996; see also Hatch & Cunliffe, 2006). Moreover, although essay III addresses the artefacts and language that interactants use through a micro level inspection, the analysis is not conducted and findings are not treated within the postmodern paradigm (Chia, 2003). In addition, the underlying conceptualization of an organization does not fulfill the criteria of the postmodern paradigm (see Hatch & Cunliffe, 2006; Boje, 1995).

Compared with the paradigms of radical change, the paradigms of regulation (Burrel & Morgan, 1979) approach the dissertation's essays. While the functionalist paradigm adopts a realist, positivist, determinist and nomothetic standpoint (Burrel & Morgan, 1979, p. 26), it attempts to create general theories about organizations that are reminiscent of the universal laws of the natural sciences (Donaldson, 2003, p. 41). Finally, Lee (1991) argued that, based on Van Maanen's work (1979), the functionalist approach is associated with quantitative research methods.

The interpretive paradigm seeks explanation within the realm of individual consciousness and subjectivity: instead of as a static entity, the world is seen as an emergent social process that is created by the involved individuals (Burrell & Morgan, 1979). While the interpretive approach recognizes intersubjectively created meanings as an integral part of the studied subject, the collected data should describe both the objective, observable aspects of human behavior and the subjective meanings that the subjects have themselves (Lee, 1991). In other words, the interpretive approach seeks to discover what is meaningful to people in the studied social situation (Hatch & Yanow, 2003) or in the social world at the level of subjective experience (Burrell & Morgan, 1979). As this dissertation attempts to gather a deeper understanding of collaboration environments' and collaboration practices' support for distributed, creative teamwork, the interpretive approach to the research topic appeared to be the most appropriate option.

The interpretive paradigm has guided the research process in the form of utilizing observation of real-life situations as the primary data collection method

instead of relying on surveys or laboratory experiments, which would have been alternate methods for data collection and the entire research design. In addition, the collection of corroborating data, which contributed towards an understanding of the interactants' and the case study site's context, helped me to understand the underlying meanings that directed the interactants' observed behavior.

4.1.2 Abductive mode of reasoning

The essays of this dissertation were created through an iterative process. Added to the writing process, the data collection period and the data analysis proceeded somewhat iteratively. Instead of collecting all data at one time, they were collected within a time period from December 2011 to early autumn, 2012. Hence, I was able to process and analyze the existing data while the data collection period was still continuing. In addition, as the interaction sessions were recorded, their analysis was conducted iteratively, at different levels and with different foci. The iterative cycles led to new interesting observations for the next analytical steps that aimed to study facts and devise concepts to explain them.

Guided by the theoretical understanding at the beginning of the dissertation process, I realized that the field that I was studying did not offer an established and widely recognized theory that would provide a straightforward direction to answering to the presented research questions. Therefore, the deductive mode of reasoning did not appear to be the best possible option. In addition, the data collection period signaled that although the case being studied was considered to be representative, the conducted observations, notwithstanding the number of observed interaction events, might not allow the use of inductive reasoning. Instead, I consider my study's mode of reasoning to be abductive. Abduction refers to an inferential creative process that produces new hypotheses and theories based on surprising research evidence (Dubois & Gadde, 2002; Timmermans & Tavory, 2012).

As outlined by Alvesson and Kärreman (2007), the application of abduction as a theory development mechanism involves (1) the application of an established interpretive rule or theory; (2) the observation of a surprising empirical phenomenon; and (3) an imaginative articulation of a new interpretive rule or theory that resolves this surprise. To continue, Mantere and Ketokivi (2013) argued that when seeking theoretical interpretations for the observed empirical tendencies and when choosing between possible theoretical interpretations, scholars always engage in abductive reasoning.

In this dissertation, Alvesson and Kärreman's (2007) outline for applying the abductive mode of reasoning is followed as a composition of the essays. Emerging from the theoretical basis of virtual teams, collaboration environments and artefacts for distributed collaboration, essay I articulates the existing theoretical basis for why virtual worlds could be an interesting venue to study distributed creativity. The observation of a surprising phenomenon is carried out in the form of the interaction events. The interpretations and rea-

soning that I draw based on the findings of the empirical observations are therefore the answers to these findings.

4.1.3 Case study

As outlined by Eisenhardt (1989), case study as a research strategy focuses on understanding the dynamics present within a single setting. In addition, Yin (1994) argued that case study is a suitable venue for empirically investigating a contemporary phenomenon within its real-life context, while the boundaries between the phenomenon and its context are not clearly evident. Therefore, case study is particularly appropriate in novel areas, within which new ideas and the in-depth understanding of existing views is favored in contrast with hypothesis-testing research (Eisenhardt, 1989). Finally, the case study as a research strategy is widely utilized within the qualitative research approach, which I undertake in this dissertation.

The dissertation attempts to understand the collaboration tools and practices that support virtual teams' creative, synchronous interaction. Virtual worlds and artefacts occupy an extensive role in this investigation. Concerning virtual worlds, several recent research efforts (e.g., Koles & Nagy, 2014; Koutsabasis et al., 2012) communicate a need for empirical case-study-based research addressing the topic. In addition, when studying artefacts within the context of design and information systems, an observational case study is considered to be a typical method for understanding artefacts' in depth essence in business environments (Hevner, 2007). Directed by the research topic and existing knowledge of the surroundings that favored the case study approach, I decided to undertake a case study approach towards executing the research.

The case study, which is the focus of this dissertation, was performed in the context of a global corporation. The corporation specializes in the manufacture of industrial products and related maintenance operations. The company is headquartered in Finland and operates in 47 countries with nearly 12 000 employees.

The case company was selected as a case study site for three reasons. First, the company was considered to be a good example of a globally operating enterprise offering the possibility to study distributed work. Second, the industry that the case corporation represented was considered to be a representative example of an industrial engineering design context, therefore enhancing the applicability of the results outside of the specific branch. Finally, the other researchers involved in the studies and I were able to gain good access to the corporation's operations. Our points of contact appeared to be helpful, and their work in arranging interaction events was extensive.

4.2 Data collection and analysis

This section introduces the case company, which was the primary data collection site within the dissertation research. The data sets including their collection and analysis methods are also described at a general level. A more de-

tailed description of the data collection and analysis methods is included in each of the dissertation's essays.

4.2.1 Data sets

The creative interaction sessions that comprise data sets 1 and 2 were organized as a joint effort with university researchers and the company's innovation department. Employers from the innovation department selected topics and invited attendees to the interaction events. The interaction sessions involved technical experts, engineering designers and decision-makers who worked in the company. The attendees were knowledge workers, located in eight different case corporation sites in five countries. English was used as the primary language at every interaction session.

The attendees used a web conferencing system or a virtual world in their interaction sessions. The attendees were instructed not to share a physical space, even if they were located at the same office site. Hence, the participants operated in geographically distributed settings to varying degrees, being electronically dependent on each other during the interaction event. While the teams and individuals engaging in the collaboration events conveyed a varying history of working together, diversity between them was advocated serendipitously through different cultures, expertise and professions. Based on Gibson and Gibbs' (2006) definition of virtual teams, it can be argued that the studied, distributed collaboration approaches the notion of virtual teams. Meanwhile, the interaction sessions can be considered as good examples of engineering design collaboration, involving a varying amount of creativity.

The data that I use in the dissertation consist of two data sets, which are used as primary data. In addition, one of the essays utilizes a supplementary data set. These data sets are described in Table 2 and discussed in the forthcoming sections. In addition to these data sets, corroborating data were gathered as observations and a descriptive background survey.

Table 2. Utilization of data sets in essays

	Data set 1 Web conferencing sessions	**Data set 2 Virtual world sessions**	**Supplementing data**
Essay I			X
Essay II	X	X	
Essay III	X	X	
Essay IV		X	

4.2.2 Data set 1: Web conferencing interaction sessions

Data set 1 consists of nine interaction sessions. A web conferencing environment (Microsoft Lync) was utilized as a collaboration environment during these sessions. The web conferencing environment allowed users to communicate via auditory and visual communications channels. One participant at a

time was able to share his or her desktop and any running applications. All participants were simultaneously able to annotate and co-edit the shared content. Figure 2 presents a screenshot of the web conferencing system's user interface, involving a whiteboard containing a preliminary suggestion for the meeting's agenda.

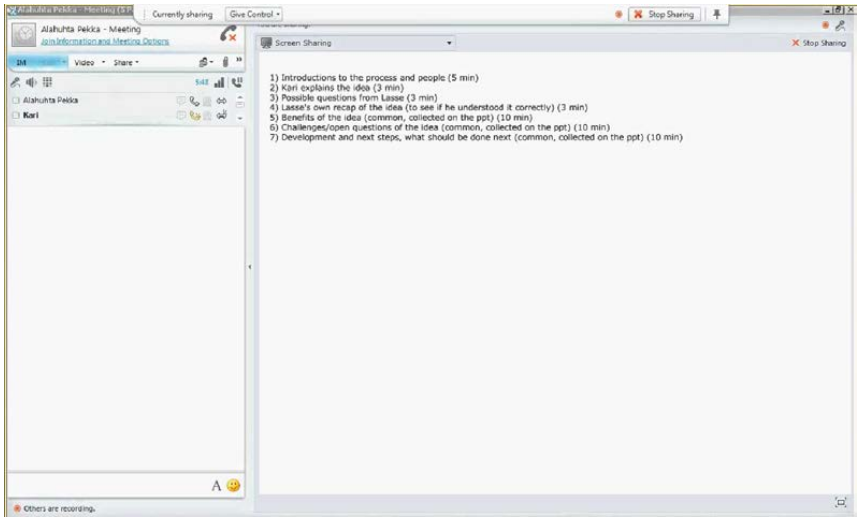

Figure 2. User interface of the web conferencing tool

In addition, the web conferencing environment provided an option to establish a video connection between the collaborators and to communicate via chat with a rich text formatting. However, these features were used only a few times within the observed interaction.

The case corporation's innovation department indicated that the web conferencing environment was broadly adopted in the global organization. Therefore, the collaboration environment was told to be embedded in the case corporation's daily work practices. This notion was clarified in the attendees' background survey responses, which indicated familiarity and, typically, several previous experiences of collaboration via the web conferencing environment.

The innovation department selected four ideas from their corporate idea management system. Each of the ideas was employed as a topic for two to three interaction sessions. The sessions, attendees, duration and number of speech turns are listed in Table 3. The selection of the ideas was driven by two criteria: (1) they were recently submitted to the idea management system and were waiting to be processed; and (2) they were complex enough to require several stakeholders to engage in the decision-making process. The research team, which was involved in data collection, did not participate in the idea selection process.

Table 3. Interaction sessions via the web conferencing tool

Session	Attendees	Duration	Amount of turns
Idea 1 Session 1	Innovator (FIN), one receiver (FIN), corporate representative (FIN)	51 min	166
Session 2	Innovator (FIN), one receiver (FIN), two corporate representatives (FIN), one acting as a silent observer	59min 50s	251
Idea 2 Session 1	Innovator (US), one receiver (FIN), two corporate representatives (FIN)	49min 45s	191
Session 2	Innovator (US), one receiver (FIN), two corporate representatives (FIN)	56min 20s	246
Idea 3 Session 1	Innovator (US), one receiver (FIN), one corporate representative (FIN)	42min 10s	228
Session 2	Innovator (US), one receiver (FIN), two corporate representatives (FIN)	28min 54s	188
Session 3	Innovator (US), one receiver (FIN), one corporate representative (FIN)	49min 10s	214
Idea 4 Session 1	Three innovators (US, DK, LAT), one receiver (FIN), two corporate representative (FIN)	1h 4min 10s	281
Session 2	Two ideators (US, DK), one receiver (FIN), two corporate representatives (FIN)	54min 20s	214

Seven interaction sessions involved dyadic communication between an innovator and a receiver. The innovator had originally fed the idea to the corporation's idea management system. The receiver was either a technical expert who provided technical input for the idea or a decision-maker who assessed the idea's feasibility or business potential. The remaining two sessions engaged an innovator and two to three experts or decision-makers. Added to them, four corporate representatives attended the sessions, one or two at a time. They provided expertise and input related to the company's R&D practices and innovation processes and facilitated the discussion. Thereafter, the collaboration involved workers with multi-disciplinary experience from distributed geographical locations.

Each of the sessions began with the innovator presenting the idea to the receiver. They typically engaged in a dialogue and in the co-editing of shared documents. They used the web conferencing collaboration environment with its functionality to discuss the idea, build a common understanding, identify opportunities and challenges, and determine an action plan based on the discussion.

I attended each session as a silent observer. If a corporate representative asked, I briefly introduced the research project to which the interaction session was related at the beginning of the meeting and remained silent after that. Every meeting was recorded from the beginning to the end by using the collaboration environments' specific functionalities for recording a meeting. The recordings contained the same audiovisual information than every meeting attendee received during the interaction. Therefore, the quality of the recordings was equal to the quality, which was perceived by the meeting attendees. The quality of recordings from both collaboration environments was sufficient for the research purposes. The recordings included unofficial discussions and establishing the technical appliances for the interaction sessions.

4.2.3 Data set 2: Virtual world interaction sessions

Data set 2 consists of five interaction sessions. These interaction sessions utilized a three-dimensional virtual world collaboration space (3DICC) as their collaboration environment. The environment is a proprietary environment, to which the involved universities had a license. Virtual world servers were located outside of the university. The virtual world software was selected for use in the research for the following reasons. First, the selected virtual world technology was considered to be a representative and a good example of state-of-the-art virtual world technologies. Second, the researchers were knowledgeable concerning the functionality of the technology and in terms of operating the virtual world. Two of the involved researchers had used the software for data collection efforts previously. Technical knowledge related to operating the system was easily available within both involved universities and the software vendor. Finally, the case corporation's workers who attended the virtual world interaction events were able to install and run the virtual world client from their work computers. Therefore, technology selection was also convenient from the case corporation's point of view.

The virtual world allowed users to collaborate via auditory and visual communication channels in a shared virtual space that emulates the physical world. The interaction participants were represented by three-dimensional objects (avatars). Participants were able to create, share, co-edit, and annotate parallel content. Figure 3 depicts a screenshot of the virtual world, involving meeting attendees as avatars in a shared three-dimensional space.

Figure 3. User's view to the virtual world

The case corporation's innovation department invited five teams to interact in the virtual world. The invited product development teams were each engaged in a different ongoing project. Each team was composed of four to five experts who had a history of a few months working together. The attendees were from various sites of the corporation. According to the descriptive background survey, it became apparent that the virtual world was new to all attendees. Hence, operating the collaboration environment required learning and the transformation of the teams' existing work practices.

In addition to the team members who attended the meeting, an experienced facilitator who was part of the research team attended each meeting. Her task was to provide technical assistance for the virtual world so that the interactants could overcome possible technical hindrances and receive ad-hoc guidance for virtual world operation. When needed, the facilitator also supported each team leader in meeting process interventions. For instance, she reminded the team about the next action item on the agenda. The facilitator avoided addressing the content of the team discussion. The session attendees, the durations of the sessions and the number of turns per session are listed in Table 4.

Table 4. Interaction sessions via the virtual world

Session	Attendees	Duration	Amount of turns
Team 1	5 members (FIN), Facilitator (US)	50min 20s	111
Team 2	4 members (FIN), 1 member (CH), Facilitator (US)	1h 08min 37s	118
Team 3	4 members (FIN), Facilitator (US)	55min 8s	136
Team 4	4 members (FIN), Facilitator (US)	40min 0s	105
Team 5	2 members (FIN), Facilitator (US)	40min 40s	106

A loosely defined agenda for each virtual world interaction session included a brief stand-up progress report from the team members, followed by discussing current challenges, presenting models, brainstorming new ideas and solutions and solving problems.

Parallel to data set 1, the interaction events in data set 2 were also recorded by utilizing the collaboration environment's functionality for recording the meeting activity. The recording contained the audio-visual contents of the meeting as seen by one participant's avatar. The recording's quality was equal to the quality during the interaction session.

4.2.4 Supplementing data: Literature review

The supplementing data set, consisting of published, empirical research articles, was employed in essay I. The data were gathered as a result of a systematic literature review protocol. A systematic literature review was selected as a data collection method because it provides methodologically rigorous and collective insights by obtaining a theoretical synthesis of a particular research field (Tranfield, Denyer and Smart, 2003). Moreover, systematic literature reviews attempt to identify relevant and high-quality reviews with a decent audit trail and minimized bias in the literature selection (Moustaghfir, 2009).

To compose the supplementing data set, the systematic literature review protocol was utilized as follows. After formulating the research question, search keywords were constructed. These keywords were composed into search strings. The search strings were used to search for articles from the main electronic journal databases, including Ebsco, Scopus, Science Citation Index, and Social Science Citation Index. In addition, a vast number of journals in psychology, information systems, and communications were scanned separately using the same keywords.

Articles that (1) were peer-reviewed, (2) were published in an academic journal or conference proceedings, and (3) conveyed an empirical research setting, were included in the literature review. Correspondingly, those articles that were thematically related to essay I's topic but not relevant to the study's focus were excluded from the review. For instance, we excluded those studies that discussed intellectual property rights (IPR) and those that utilized hardware-based 3D virtual reality environments as their contexts.

The initial search yielded a total of 485 articles. The abstracts of the papers were read and the exclusion and inclusion criteria were applied to determine the paper's relevance. Those articles that met the inclusion criteria and that did not meet the exclusion criteria were collected in a database (Mendeley). The articles were scanned for backward citation and, partially, for forward citation. Via backward and forward citations, a selection of papers that were outside the scope of the search strings were identified. Relevant papers that were found during the backward and forward citation searches were added to the article database. Finally, overlapping articles were removed from the database. The entire procedure of conducting the literature review took nearly three months, while the data base searches were executed within one week.

The procedure yielded 47 articles, which compose the supplementing data set. The number of reviewed articles is considered to be appropriate and comparable to other reviews on the topic of virtual worlds (see, e.g., Kim, Lee & Thomas, 2012; Sivunen & Hakonen, 2011; Stendal, 2012).

4.2.5 Corroborating data

Added to the primary data that composed data sets 1 and 2 and the supplementing data set, I collected a vast amount of secondary data in different formats. These include formal and informal communication with the case corporation's representatives, the contents of the corporation's idea management system, and a descriptive background survey.

The formal and informal meetings involved approximately 15-20 hours of workshops, more than 10 hours of meetings and other joint discussions. Typically, the workshops were attended by the case corporation's Innovation Manager, one to three case corporation's Innovation Specialists, and other technical experts, engineering designers, and senior executives from the case corporation. I contacted the case corporation's representatives with numerous phone calls and e-mails before, during, and after the data collection period. These discussions and the memos created based on them contributed towards my understanding of the context of the research, foremost toward the corporations' innovation process and certain research and development operations that were related to the interaction events.

The corroborating data were expanded by the data stored in the corporation's idea management system for the ideas that were discussed within the data sets 1 and 2 interaction sessions. Via the output of the idea management system, I tracked the discussed ideas proceeding in the corporation's innovation funnel for more than a year after ending the primary data collection period. These data also involved original descriptions of the idea and written

comments that might have been given regarding the ideas. Together, collaboration with the case corporation representatives and tracking the proceeding of the ideas contributed towards understanding the context of the research, although these data were not systematically analyzed.

Finally, a descriptive background survey was executed after the meeting. Each interaction session attendee was asked to fill in the survey as soon as possible. The survey's questions were related to the (1) attendees' perceived engagement in the meeting, (2) expectations towards the meeting, and global outcome judgements of the meeting including (3) the perceived feeling of fair participation, (4) System Usability Scale and (5) mutual relationships between the participants. I received more than 30 survey answers. Eventually, the survey results were not systematically analyzed. However, the survey answers helped me to understand the interactants' backgrounds, own feelings, and perceptions of the interaction sessions.

4.2.6 Data analysis

The data sets 1 and 2 were comprised of recorded interaction sessions, and the supplementing data set of articles that were selected by means of the systematic literature review. Due to this difference, I applied different types of analysis methods to the data sets. The next sections depict each of the data analysis procedures briefly, emphasizing the early analysis phases that were not related to a particular essay. More detailed descriptions are presented in essays I, II, III and IV.

Data sets 1 and 2

According to the terminology of video analysis, the data sets 1 and 2 can be seen as fourteen events (Derry et al., 2010), each interaction session constituting an event. The analysis of data sets 1 and 2 was initiated by transcribing the auditory contents of the recordings verbatim. I transcribed the entire set of material on my own. This decision allowed me to both re-visit the interaction sessions of data set 1 and to gather a concise understanding of the data set 2 sessions. In terms of the entire set of material, authoring the transcriptions allowed me to conduct preliminary notifications of the interaction sessions, also including events via visual communication channels. Therefore, I authored field notes from the transcriptions during the transcription period. The transcriptions were then divided into turns, meaning an action switch between the participants that shares a specific functional content in the discourse (Fruchter & Cavallin, 2006; Jordan & Henderson, 1995; also Derry et al., 2010). The transcriptions were also coded as a joint effort of the involved researchers.

Each of the interaction sessions was coded according to two coding schemes. One was an established coding scheme (Andriessen, 2003; Rice & Love, 1987; Short, Williams & Christie 1976) that divides communication into tasks that involve the processing of socio-emotional content (Rice & Love, 1987). The coding scheme was originally utilized in early teleconferencing studies (Short

et al., 1976). Furthermore, the coding scheme is considered to be a standard form to study group co-operative tasks (Andriessen, 2003). The coding scheme involves the following codes: *exchanging information, exchanging opinions, generating ideas, problem solving, resolving disagreements, bargaining, persuasion,* and *getting to know someone.*

Another was Fruchter and Cavallin's (2006) coding scheme, which investigates distributed team interaction at a micro level. This coding scheme contributed towards a more fine-grained understanding of the interaction events. The coding scheme involved the following codes: *presentation, explanation, clarification, exploration, problem solving, feedback, negotiation, resolution, acknowledging, checking,* and *inquiry.*

Atlas.ti, Microsoft Word and Microsoft Excel software were used in coding. The reliability of the coding was determined inter-subjectively by discussing through the coding differences (Neuendorf, 2001). While contents of the verbal interaction were coded according to established coding scheme, I would relate this phase of the qualitative content analysis as theory-driven. However, the next phases of the data analysis process were increasingly data-driven.

In addition to the coding of speech from the interaction sessions, I systematically analyzed the visual content present during the interaction events. Notably, the systematic analysis effort covered the entire material and all events, instead of a applying a sampling procedure (Derry et al., 2010). The analysis of the visual communication content proceeded iteratively. The recorded interaction sessions and their transcriptions were used during this analysis phase. Each of the analysis phases addressed all interaction sessions in both collaboration environments. Atlas.ti, Microsoft Word and Microsoft Excel were utilized as analysis software.

During the first round of visual content analysis, I focused on changes in the virtual world avatars' space, their mutual proximity, and those occurrences that involved the co-editing of shared content in web conferencing and virtual world interaction session data sets. Parallel to the analysis of visual contents, I applied the linkography method (Goldschmidt, 1995; Kan & Gero, 2008) to the entire transcribed data of web conferencing and virtual world interaction sessions. The linkography method connects interlinked turns, or design moves, under shared topics, creating a graphical representation of the interaction. The linkographic representations contributed towards identifying those excerpts of discussion that were either very active or passive, compared to the other discussion within the same interaction session.

While it became apparent that the interacting workers utilized visual artefacts extensively in both collaboration environments, analyzing the transcriptions allowed me to notice potential differences in the artefact-related speech. Therefore, during the next round of analysis, I sharpened my focus to all shared content that was present as shared visual information while also being referred to in speech. Because this round of analysis revealed the apparent richness of the speech communication within the interaction events, I finally directed my focus to artefacts inside of artefacts and single utterances that were produced in the interactants' speech.

Supplementing data

The data synthesis (Tranfield et al., 2003) phase of the systematic literature review process was initiated by reading each of the reviewed papers carefully. The researchers authored short memos based on the articles. The articles and memos were also discussed actively between the essay I co-authors.

Based on the reading of the articles, writing memos, and joint discussions, a set of higher-order categories emerged during the analysis phase. This set of categories was iterated during the analysis, parallel with sharpening the category definitions. Finally, the procedure yielded a set of eight categories that answer the essay's research question.

4.2.7 Research procedure

The aforementioned sections have provided a description of the research approach for this dissertation. This description includes discussion of the data collection efforts, the data analysis, and the underlying methodological assumptions of the research. Finally, this section provides a chronologically presented overview of the phases within which this dissertation was created.

Phase 1: Getting started (October 2011 – December 2011)

The research project, within which the data for this dissertation were collected, started in July 2011. I became involved in the project as a part-time researcher at the beginning of autumn 2011. The first phase involved getting to know the representatives of the case corporations and early planning for data collection. I started to get myself familiar with the literature, addressing the topic with intensity and enthusiasm.

At that time, I labeled the topic of my research broadly under the theme of computer-mediated ideation within synchronous virtual team collaboration. In the middle of December 2011, we arranged the first two interaction sessions for data set 1 with the case corporation; these involved web conferencing tool collaboration. At the beginning of the data collection, it was appropriate for me to record the interaction sessions, author field notes for the sessions, and conduct transcripts by myself right after the interaction sessions.

Phase 2: Intense data collection and literature review (January 2012 – June, 2012)

From the beginning of 2012, I was able to conduct the research full-time. Therefore, phase 2 was active and enthusiastic within the following three different lines of work. First, the initial data collection efforts intermingled with becoming increasingly familiar with the body of literature regarding creativity, virtual teams, and computer-mediated collaboration.

Second, I tried to attend as many classes and guest lectures as possible that addressed qualitative research methods and the philosophy of science. I also participated in several classes and seminars that introduced topics that I considered to be at least partially relevant to my research. These included leadership, organization studies, and collaborative learning environments, for in-

stance. Together, these two lines of work contributed towards forming a more holistic picture of my topic and establishing a preliminary understanding of how I should proceed with my data collection to obtain relevant and interesting data.

As a third line of work, I continued with the data collection efforts. It became apparent that the representatives of the case corporation were helpful and willing to contribute to the research efforts. Data set 1, comprising the interaction sessions with a web conferencing tool, was completed at the end of phase 2 in early summer 2012. Parallel with collecting data set 1, our research team introduced two more collaboration environments to the case corporation as a suggestion for further study. One was a synchronous, text-based tool for team brainstorming, and the other was a three-dimensional virtual world.

Phase 3: Finalizing data collection and moving to data analysis (July 2012 – December 2012)

The lines of work articulated in phase 2 continued in the latter half of the year 2012, although I switched my attention increasingly to the data collection efforts. During the summer and early autumn of 2012, data set 2 from the virtual world interaction sessions was collected within the case corporation. Parallel to the completion of data sets 1 and 2, I started to become familiar with the knowledge-sharing literature and the concept of boundary objects (Star & Griesemer, 1989; also Bechky, 2003; Lee, 2007 and Karsten et al., 2001).

Phase 3 also involved coding the transcribed interaction data. I also conducted the first data analyses of the different codes' mutual frequencies during that time. While proceeding with the data analysis, it became apparent that the web conferencing tool and virtual world interaction sessions differed somehow in terms of the ways in which meeting attendees shared knowledge with each other. Building on the existing knowledge of boundary objects, my co-authors and I started to examine the manifestation of boundary objects in these two collaboration environments.

Phase 4: Starting to write the first essay (December 2012 – June, 2013)

While finalizing the first round of analysis, I decided together with my co-authors that it would be interesting to write a journal article concerning the differences noted in visual artefacts' varying manifestations as boundary objects. Meanwhile, we noticed a call-for-papers in a special issue of a top-tier journal. Because we considered our broad theme as being suitable for the issue, we decided to submit our manuscript there. Within the ongoing literature review, I was becoming even more confident of the novelty of my topic and the results' interconnectedness to a variety of domains. The manuscript compared web conferencing tools' and virtual worlds' potential to act as platforms for boundary objects and the significance of facilitation practices (Bostrom, Anson & Clawson, 1993; Goel, Junglas, Ives & Johnson, 2012) towards the rapid adoption of novel collaboration environments. The manuscript was submitted in February 2013.

Although the submitted manuscript focused on the concept of boundary objects, the results of the data analysis and the reviewed literature raised a ques-

tion: whether and how three-dimensional virtual worlds can contribute towards a distributed team's creative collaboration. Therefore, my colleagues and I decided together to start conducting a systematic literature review of the virtual worlds' creative affordances. The literature was searched and read and the first versions of essay I were written during the spring of 2013. The collection of corroborating data with the case company was also finalized through a final workshop arranged in June 2013.

Phase 5: Turn-around with the topic and re-analysis (June, 2013 – January, 2014)

At the beginning of June 2013, we received the review feedback concerning the manuscript that was sent in February. The extensive feedback indicated that our topic and theoretical discussion were timely and interesting. Though, the data analysis was suggested to be deepened. As an interesting insight, the reviewers noted that the paper was confusing due to its multiplicity of themes. Review feedback suggested drop off facilitation because it was an uncontrolled variable within the studied collaboration environments. On the one hand, the reviewers found the comparison between two-dimensional web conferencing tools and three-dimensional virtual worlds to be interesting. On the other hand, only virtual worlds themselves were considered to be a novel and promising subject to study. The journal editor suggested that we digest the feedback carefully and re-submit the manuscript after the necessary corrections.

The second round of analysis was conducted during autumn 2013. The round was initially directed by the review comments. In addition, I became familiar with theories of epistemic and technical objects and the concept of artefacts. During this analysis round, we realized the differences between the utilization of visual and auditory channels in knowledge sharing activities that occurred in the observed collaboration environments. As a result, I analyzed the entire data word to word, addressing each word's and each sentence's potential to act as a transient boundary object or a linked boundary object to a visual representation. This effort took nearly three months. During this work, essay I was accepted for publication.

Phase 6: Writing essays II, III and IV (February, 2014 – July, 2014)

The results of the second data analysis round were combined into a manuscript at the beginning of the year 2014. The manuscript, essay III, was resubmitted to the journal in February. While finalizing the data analysis and writing essay III, it became apparent that based on the original version of the manuscript and the new analysis procedure, certain valuable and interesting sections of the previous work were excluded from the new manuscript. Building on these results, essay II was composed during spring 2014 and submitted to an interesting conference.

While writing essay II, I continued to familiarize myself with the literature on artefacts. Bailey and her colleagues' (2012) study on virtual teams working with and on representations, or their potential to work within representations in simulated reality, led me to consider how design collaboration could actually occur in virtual reality. Meanwhile, novel studies concerning virtual worlds

(Hakonen & Bosch-Sijtsema, 2014; Koles & Nagy, 2014) indicated the relevance and potential of the topic. This consideration resulted in a decision to re-analyze the virtual world data. Attention was now directed at visual artefacts, their differences, and their potential to act as platforms for artefacts in the context of an engineering design activity. Based on this work, essay IV was submitted for review in summer, 2014.

Phase 7: Integrating the essays' results (July, 2014 – December, 2014)

The final phase of this dissertation involved parallel work regarding the integration of the essays' results and managing the review process for essays III and IV.

After three review rounds and extensive review feedback from eight different reviewers, essay III was eventually rejected by the journal. The editor, however, strongly recommended to submit the essay to a journal of a particular genre, which two out of the three final round reviewers also considered to be a more appropriate venue for the article manuscript. Therefore, the essay III was submitted to *Computer Supported Cooperative Work* at the end of the year 2014. Meanwhile a revised version of essay IV was submitted to *Design Studies* in December 2014.

I initiated the writing of this dissertation's compilation by becoming familiar with the theories on creativity and virtual teams. Although these themes were central to the studies and also discussed in the essays, I felt that they should be discussed at a deeper level to better integrate the essays with their underlying themes. The writing process for the compilation proceeded iteratively, the first version being ready in early October. I received valuable comments and suggestions concerning the various versions of the dissertation from colleagues that work in my research group, different Ph.D. student seminars, and certainly from this dissertation's supervisor.

5. Results overview

This section presents the key results concerning each of this dissertation's essays. The results are described in a more detail in each of the essays. In addition, this section presents a brief summary that combines the results of each essay with a larger entity within this dissertation's context.

5.1 Essay I: Virtual worlds' eight affordances towards team creativity

The first essay addressed three-dimensional virtual worlds' potential to support team creativity. As a literature review, the essay summarizes the results of previous empirical studies that address virtual worlds as a context or a communication device for team collaboration involving creativity. The systematic literature review protocol yielded 485 articles from major electronic journal databases. The articles were, furthermore, narrowed down to 47 relevant articles. These articles form the supplementing data set of this dissertation.

As a result, essay I proposed eight virtual worlds' affordances, being environmental properties that create consequences for individual behavior (Greeno, 1994; Olapiriyakul & Widmeyer, 2009). These affordances were suggested to support team creativity in virtual world settings. The affordances include (1) avatars that allow team members to express themselves and their insights to others, virtual worlds (2) changing the users' frame of reference as a modifiable context that supports the creative task at hand, (3) a perceived feeling of co-presence with the other team members, (4) the user's personal experience of immersion, (5) multimodal communication and (6) a particularly rich visual communication channel, (7) simulation capabilities that allow the environment to simulate a new kind of reality, and (8) a selection of supporting tools that can be utilized during the creative team collaboration.

Concerning the dissertation and the other essays, the literature review in essay I provides the following viewpoints. First, the list of affordances and reviewed existing studies indicate the relevance of studying team-level creative interaction in a virtual world context. Second, the lack of a systematic effort to conceptualize the specific features of virtual worlds that contribute to team creativity highlights the relevance of this dissertation. Although the affordances are not explicitly tested in essays II-IV, the affordances directed the study's focus towards multimodality and visual channel information's role in collaboration and, more specifically, towards artefacts that manifest via the visual communication channel.

5.2 Essay II: Different visual artefacts in web conferencing tool and virtual world supported design collaboration

Essay II empirically examined the artefacts that are used during distributed design collaboration events. Shared visual artefacts have previously been found to potentially support distributed team interaction in the context of collaborative design (e.g., Fischer, 2001; Saad & Maher, 2006; Tory et al., 2008). Using this research stream as a point of departure, essay II investigated the types of artefacts that can be used to support distributed design interaction. To continue, essay II builds on the findings of essay I by asking how virtual worlds and web conferencing environments differ in terms of the artefacts that are utilized during distributed design collaboration. While the research questions of essay II advocate distributed design as the context of the studied interaction events, the context typically includes at least some level of creativity (e.g., Gero, 1996; Johnson & Carruthers, 2006; Warr, 2007). Essay II used data sets 1 and 2 as research data.

The data analysis in essay II recognized the visual artefacts that were utilized within the observed interaction events. These artefacts were, furthermore, classified into three categories. The classification categories were based on the artefacts' contents. An artefact was observed to be primarily composed of either (1) written content, such as a requirement specification document; (2) pictorial contents such as a sketch or an image of a certain design detail; or (3) a combination of written and pictorial content, such as an entry in the company's idea management system consisting of images and a clarifying text excerpt.

The observed visual artefacts were also described with respect to the design thinking cycle phase within which they were most often used during the interaction events. In addition, essay II provided a description of a typical activity concerning each of the artefacts.

Essay II's classification scheme of written, combined and pictorial artefacts, and its comparison of the typical activities for each artefact led to the following observations. First, pictorial artefacts were favored in virtual world interaction sessions, whereas artefacts with written contents were preferred in web conferencing environments. Combined artefacts with written and pictorial contents were used in both collaboration environments.

The virtual world was found to potentially impact the users' collaborative activity. In an example, the virtual world's switching space changed the interactants' mode of collaboration from experimental to work and collaboration. In this manner, essay II suggested that the virtual world potentially acted as an artefact that directed the users to new modes of operation. Finally, in line with Gül and Maher's (2009) experimental finding, essay II highlighted the virtual world's potential to support the interactants' parallel engagement in the observation of multiple different artefacts. This potential was also observed to extend to the possibility of editing the artefacts.

To conclude, essay II addressed the differences in the two collaboration environments as regards the shared visual artefacts that are processed during design collaboration. Essay II also provided empirical evidence of the affordanc-

es that Essay I suggested characterize creative collaboration in virtual worlds. Especially, multimodal communication and particularly rich visual communication are affordances that might be connected to the priming of pictorial contents. In addition, changing the users' frame of reference was observed to alter the teams' mode of operation. These findings are more deeply digested in essay III.

5.3 Essay III: Epistemic and technical boundary objects in computer-mediated collaboration

Essay III continued the results of essay II regarding shared artefacts in design collaboration. As a point of departure, essay III noticed the potential of collaboration environments to enable communication via both auditory and visual communication channels or via only either one of them. Therefore, essay III suggested that objects beyond the conceptualization of visual artefacts but with a similar purpose might be transmitted through speech. In this manner, essay III introduced verbal and visual, epistemic and technical objects.

Moreover, the concept of boundary objects, which contribute towards collaboration between two or more different social worlds, was brought to the discussion. As a result, essay III introduced the concepts of epistemic and technical, visual and verbal boundary objects. The verbal boundary objects were argued to emerge in transient or linked forms of existence. Finally, essay III examined the development of these boundary objects within interaction events with differing topical distances. Essay III used data sets 1 and 2 as the research data.

As a point of departure, essay III contrasted web conferencing and virtual world collaboration environments. Regarding the shared visual artefacts, essay III observed that these artefacts might actually appear as boundary objects. The web conferencing interaction events included interaction between decision-makers and technical experts with varied expertise. The virtual world interaction events, correspondingly, included the interactions of multidisciplinary design teams, whose members also had various backgrounds and areas of expertise. Therefore in essay III, it was considered fruitful to inspect the shared artefacts' potential to contribute towards crossing knowledge barriers between the more or less diverse team members.

To contribute to the discussion related to boundary objects, essay III sharpened the level of observation and data analysis to micro-level interaction events. The analysis also included the separation of communication activities that occurred via the visual and auditory communication channels. This approach contributed towards discovering boundary objects that were present only in a verbal format via the auditory communication channel or in a visual artefact via visual communication channels. The approach revealed differences in how the two studied collaboration environments differed in terms of the utilization of communication channels.

Essay III introduced the epistemic and technical nature of boundary objects. Epistemic boundary objects were conceptualized as representations that are

changing and unfolding and that lack completeness of being (Ewenstein & Whyte, 2009; Knorr Cetina 1997, 2001). An example of an epistemic boundary object in its visual form was drawn from a co-authored sketch that contributed towards collaborative ideation between multi-disciplinary experts. Regarding the epistemic objects' verbal form, essay III introduced a conceptual metaphor that was used in a discussion between an ideator and a technical expert to illustrate the layout of the planned product.

Technical boundary objects were, to the contrary, conceptualized as fixed, stable, concrete, and transparent artefacts (Ewenstein & Whyte, 2009; Knorr Cetina 1997; McGivern & Dopson, 2010). As an example of technical boundary objects in their visual form of existence, essay III described collaboration between two design team members based on two 3D CAD images. Meanwhile, an example of a verbal technical boundary object was introduced within a discussion between an ideator and a technical expert regarding a technical solution for an LCD display. While the discussion involved an accurate description of the solution and its details, the dialogue excerpt was considered to be a technical boundary object.

Moreover, building on these points of departure, essay III argued that technical and epistemic boundary objects may emerge as linked or transient forms based on their appearance during interaction. First, linked boundary objects were defined as utterances that manifest a parallel in both the visual and auditory communication channels. For instance, a shared image that is referred to in a speech utterance might be a linked boundary object. To the contrary, transient boundary objects are present only in either one of the observed communication channels. Essay III described a typical example of a transient boundary object from a metaphor that is used in speech to share particular knowledge (see also Koskinen, 2005). While the metaphor contributes towards transmitting knowledge, it allows flexible interpretations in both social worlds. However, the robustness of a metaphor conveys the original meaning from the transmitting member to the receiving member.

The micro-level analysis in essay III discovered that epistemic and technical boundary objects appeared nearly equally in both collaboration environments. However, in virtual world interaction, more boundary objects manifested via the visual communication channel than in the web conferencing interaction sessions. Meanwhile, interaction sessions via web conferencing tools favored more transient boundary objects that manifested via the auditory communication channel.

To conclude, essay III continued with essay II's theme of distributed design collaboration. Essay III contributed to this investigation by observing that shared artefacts can manifest in speech utterances in addition to their visual form of existence. When contrasted with the web conferencing interaction, the references to visual content within spoken interaction are observed to be more common in virtual world. In addition, the web conferencing interaction favors transient boundary objects that exist in speech without a reference to a visual object. Therefore, the findings are also related to essay I's results regarding

virtual worlds' potential to foster distributed team creativity via extensive visual channel information.

5.4 Essay IV: Variety of artefacts in virtual world design collaboration

Essay IV connected the results of essay I regarding virtual worlds' affordances towards team creativity, to essay II's and III's findings of virtual worlds in engineering design collaboration. Moreover, essay IV contributed on the artefact classification scheme developed in previous essays. While essay II classified visual artefacts according to their contents, essay III expanded the classification scheme with dimensions of epistemic and technical objects. Building on these findings, essay IV aimed towards connecting the classification scheme to particular collaborative design activities. Since essay IV is focused on distributed design collaboration which occurs in virtual world, only data set 2 was used within the essay. The study was directed to find out, what kind of visual artefacts support design collaboration in virtual worlds.

Within the data analysis of essay IV, design collaboration was divided into four sub-activities. The activities of exchanging information and opinions, generating ideas, and solving problems, are used according to a widely established coding scheme (Short et al., 1976) that addresses processing of socio-emotional contents within group collaboration. Moreover, the analysis was directed to visual artefacts, noticing both the artefacts' visual form of contents and the level of artefacts' completeness. Therefore, essay IV suggested a classification scheme around two dimensions. First, essay IV adopted essay II's suggested classification scheme of artefacts' pictorial, combined or written contents. Second, essay IV utilizes essay III's results to classify artefacts' according to their contents' epistemic, technical or semi-structured (Anaby-Tavor et al., 2009) forms of representation.

As an outcome of the analysis, essay IV conducted the following observations related to each design collaboration activity. First, it became apparent that different visual artefacts were utilized within the collaborative activities of exchanging information and solving problems, exchanging opinions and generating ideas. The connections of different artefacts to the activities are introduced below in brief.

During information exchange, artefacts of all investigated visual forms and levels of completeness were used. However, artefacts that were composed of written and pictorial contents and semi-structured in terms of their completeness were used at most. As indicated in essay IV, the variety of artefacts in information exchange might on one hand reflect the multiplicity of design information which is represented by artefacts, and on the other hand, the artefacts' potential to develop within collaborative design process. Meanwhile a wide range of artefacts was used during problem solving activity. As argued in essay IV, this might signal that when the team engages in problem solving activity, the activity and the contents, which the artefact represents, dictates the usability of an artefact. In this manner, the actual form of contents, or the level

of representation, are not as focal. Exchanging of opinions was noticed to be performed via technical and semi-structured artefacts. However, the contents of these artefacts were mainly pictorial. Within collaborative idea creation, pictorial artefacts were even more common, while the artefacts' completeness was increasingly epistemic.

As suggested in essay IV, these findings together might be related to epistemic objects' incomplete nature as objects of pursuit and inquiry (Ewenstein & Whyte, 2009; Knorr Cetina, 1999, 2001), and technical objects' static, ready-to-hand and unproblematic nature (Ewenstein & Whyte, 2009; McGivern& Dopson, 2010). Therefore, the technical artefacts are increasingly used in more defined and close-ended tasks of exchanging information and also exchanging of opinions. When moving towards more open-ended and loosely defined activities, such as collaborative idea generation, the activity is increasingly supported by epistemic than technical artefacts.

As a result, essay IV deepens essay II's and III's insights regarding role of shared visual design artefacts. The work is contributed by addressing different kinds of artefacts' potential to foster different collaborative activities within distributed design collaboration. Meanwhile essay IV demonstrates empirically three-dimensional virtual worlds' potential to act as a context for real-life distributed engineering design collaboration.

5.5 Summary of the results

The results of the essays are summarized as follows.

Essay I reviewed the existing research addressing virtual world's applicability to distributed team members' creative collaboration. A virtual world's potential to support creative interaction was conceptualized under eight affordances. While the list of affordances provides a systematic effort to describe how virtual worlds could support team creativity, they also ground the research and findings of the remaining essays.

Notably, essays II, III and IV do not empirically address the entire list of affordances in a systematic manner. Instead, the results emphasize the affordances of rich visual information and multimodal communication. In addition, certain other affordances are indirectly addressed in the remaining essays. For instance, the affordances of presenting users as avatars and changing the user's frame of reference are used to motivate essays II and III's argument that virtual worlds are an artefact directing the users' behavior.

The decision to avoid a systematic study of all of the affordances was directed by three reasons. First, the research data were composed as serendipitous real-life interactions instead of controlled laboratory experiments. To properly address certain affordances, such as the users' perceived feeling of immersion, more systematic experiments should be arranged to overcome the potential bias generated by real-life engineering design encounters. Recognizing the affordances of observing real-life interaction, I did not find the research setting favorable for a strict experimental setup. Second, some of the affordances,

such as supporting tools for creative work, can be seen as high-level concepts that would certainly need an in-depth investigation to develop an extensive understanding of their contribution towards creativity. I decided to keep this investigation outside of the scope of this dissertation's essays. Finally, the dissertation's objective was to digest synchronous creative collaboration within distributed teams. Because the objective is addressed by investigating web conferencing tools and virtual worlds as two different collaboration environment genres, it is apparent that some of the affordances are irrelevant within the other genre. For instance, because avatars are not present in web conferencing interaction, it would not have contributed towards the research objective to extensively digest the mechanisms through which avatars actually contribute to team creativity.

In line with the proposed list of affordances, essays II, III and IV were directed toward the shared visual artefacts that are used during the creative collaboration and virtual world interaction sessions.

Essay II studied differences that existed between a two-dimensional web conferencing tool's and a three-dimensional virtual world's potential to support artefacts. The purpose of the study was to contrast two collaboration environments that could be used for distributed team collaboration. As an outcome, essay II creates a preliminary artefact classification scheme ranging from written, to combined, and to pictorial artefacts. Artefacts are connected to a typical design thinking activity within each collaboration environment and for each type of an artefact. This classification scheme is used as a point of departure for the further artefact classification in essay IV as well as for the use of epistemic and technical objects and boundary objects in essay III.

Essay III divided the distributed creative collaboration, which was supported by artefacts, into visual and auditory channel information. Essay III connected the concepts of epistemic and technical objects and boundary objects in the context of distributed, computer-mediated collaboration. Based on the connected concepts, essay III introduced a taxonomy of epistemic and technical, visual and verbal, boundary objects, while last of them can manifest as linked or transient. The developed theoretical framework was utilized to contrast web conferencing tools and virtual worlds. Based on this inspection, essay III outlined the differences in web conferencing tools and virtual worlds in relation to distributed collaboration. In addition, essay III demonstrated the potential development of boundary objects within interlinked topics and topics with a longer mutual time span.

Finally, essay IV concluded with a framework of artefacts, ranging from technical, to epistemic and pictorial, to written, and observed distributed collaboration in a virtual world. While essay III addressed the interaction events within the activities at a broad level of knowledge sharing and distributed collaboration, essay IV furthered the results of essay II by identifying the virtual world interaction events as creative, distributed collaboration. As a result, essay IV outlined the differences between the collaborative activities of exchanging opinions and information or generating ideas and solving problems in relation to the artefacts that could support these activities. Essay IV concluded

with practical implications related to the virtual worlds' potential for creative distributed design collaboration.

6. Discussion

This study shows that virtual worlds can act as a potentially nourishing context for distributed team creativity. The objective of this dissertation was to explore synchronous, distributed collaboration. Because engineering design forms the context for this collaboration, the collaboration arguably involves creativity to a varying extent.

I consider the major contribution of this dissertation to reside in its empirical observation of real-life team collaboration and its contrast of two different collaboration environments. One environment was a traditional web conferencing tool, which is currently a widely adopted option for audio and video conferencing systems in synchronous, distributed teamwork. The other environment was an emerging, three-dimensional virtual world. Observation of the differences between how these environments act as platforms for creative team collaboration led to key findings concerning (1) virtual world's affordances towards distributed team creativity, (2) a taxonomy of objects mediating the interaction between distributed collaborators, and (3) a three-dimensional virtual world's differing potential to support visual artefacts for creative collaboration compared with the two-dimensional web conferencing tool.

The following section first answers the problem statement of this dissertation. Next, the answers to each of the research questions are discussed in light of essays I-IV. Finally, I address the theoretical and practical implications of this study, present an evaluation of this study, and provide recommendations for further research efforts.

6.1 Collaboration environments and collaboration practices supporting distributed team creativity

This dissertation addresses the following problem statement: how can different collaboration environments and collaboration practices support synchronous team-level distributed creative collaboration? The problem statement was focused on the research streams of creativity, artefacts, and virtual worlds, which form the theoretical framework proposed in this study.

Building on these research streams, this dissertation demonstrates that a three-dimensional virtual world can act as a creativity-enabling collaboration environment within the context of engineering design. The finding is relevant, since concurrent virtual teams typically utilize web conferencing, audio conferencing, and video conferencing tools as their synchronous collaboration environments (e.g., Ko et al., 2011; Kock & Lynn, 2012; Rosen et al., 2007).

The differences between virtual worlds' and web conferencing tools' applicability for creative team collaboration are next discussed. The discussion is framed according to the intersections of the theoretical framework's research streams. These intersections include (1) virtual worlds supporting team creativity, (2) artefacts mediating creativity in distributed collaboration within an engineering design context, and (3) artefacts' essence in the virtual world context. These observations are summarized in Figure 4.

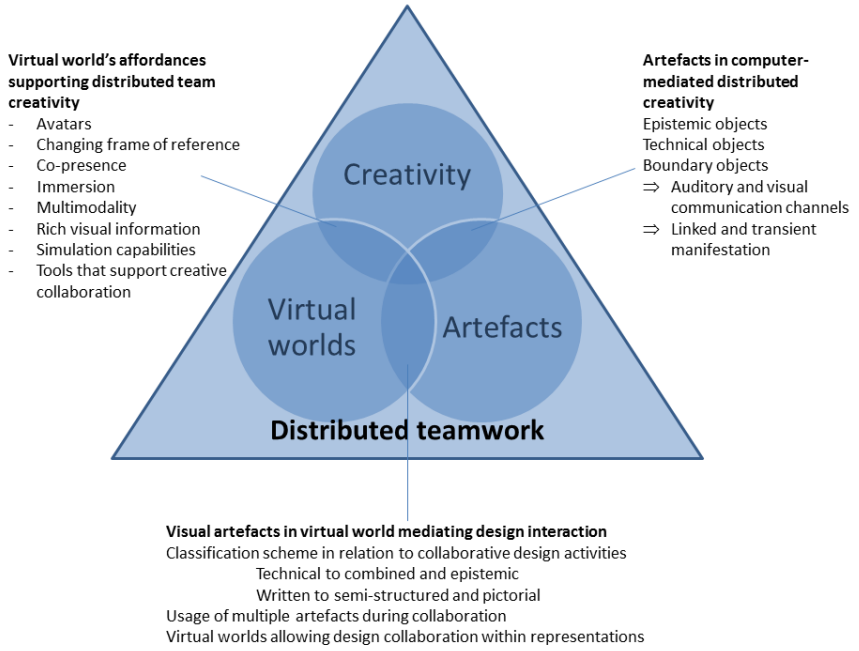

Figure 4. Key results of the dissertation in the frame of the theoretical framework

First, virtual worlds' potential to support distributed team creativity was characterized under eight affordances. These affordances represent features that, characteristics of virtual worlds, may not be as strongly present in conventional synchronous collaboration environments. From the viewpoint of this dissertation's engineering design context, the affordances of rich visual information and multimodal communication appeared to be the most relevant and applicable affordances to discover the differences between creative collaboration in two-dimensional web conferencing and three-dimensional virtual world environments.

This study observed that the collaboration in web conferencing and virtual world environments involved similar collaborative design activities. Nevertheless, the realized collaboration differed between the environments in terms of the utilization of communication channels and the processing of shared artefacts. The web conferencing environment was observed to prime visual artefacts with written content; in knowledge sharing, communication relied extensively on the auditory communication channel.

To the contrary, virtual world collaboration favored pictorial artefacts; during knowledge sharing, interactants used more visual artefacts as boundary objects to ground their argumentation. This finding is in line with previous knowledge of virtual worlds' visual richness (e.g., Iorio et al., 2011; Rahimian & Ibrahim, 2011). The finding also aligns with a previous suggestion that virtual worlds provide a richer visual communication channel compared with web conferencing environments (Messinger et al., 2009).

Second, based on empirical observation, this dissertation argues that artefacts can, indeed, mediate creative collaboration within distributed settings. This dissertation develops a taxonomy of shared objects involving (1) a classification scheme for shared artefacts and (2) a suggested extension to the concept of boundary objects. While the taxonomy indicates the variety of artefacts that may be used during during collaboration, it expands the taxonomy suggested by Pei, Campbell and Evans (2011). The suggested taxonomy is used to find differences between web conferencing tools and virtual worlds as collaboration media for distributed creativity.

Previous studies have connected shared visual artefacts to collaborative creativity: oftentimes, this team-level creative collaboration has been viewed only in co-located settings. Widely adopted examples involve Schön's (1983) viewpoint that artefacts mediate reflection-in-action within collaboration between a student and a master and Henderson's (1991) study of sketches as shared visual artefacts that facilitate collaborative design activity. This viewpoint is summarized by Carlsen and his co-authors' (2013, p. 150) conceptualization of getting physical with the materialization of ideas in artefacts and the interaction with them. They indicate that shared, physical project spaces are potential places to touch, sketch, dwell over, and wonder about the visual artefacts while seeing how things connect. In a similar way, Jacucci and Wagner (2007) advocate the role of physical, tangible artefacts in collective creativity. Though, since remote collaborative knowledge work in general is largely accomplished in and through objects and artefacts (Luff et al., 2003), recent examples (e.g., Luck, 2010; Tory et al., 2008) have provided evidence of artefacts' role in distributed collaboration. This research stream is continued by the taxonomy, which was developed based on real-life distributed team collaboration.

Finally, this dissertation addresses artefacts' essence in a three-dimensional visual context, which differ virtual worlds from two-dimensional web conferencing tools. The discovered differences can be summarized as twofold. First, based on the observed interaction events, it became apparent that the virtual world allowed the processing of multiple visual artefacts within the discussion. Second, the virtual world as a three-dimensional context was observed to direct the interacting team members' mode of operation.

While previous studies have recognized virtual worlds' potential to act as a platform for design collaboration (Rahimian & Ibrahim, 2011; Vosinakis & Koutsabasis, 2013), it has been suggested that virtual worlds' three-dimensional appearance potentially alters the use and presence of boundary objects as artefacts mediating knowledge transfer (Alin et al., 2013). Meanwhile, virtual worlds have been observed to allow collaboration within three-

dimensional representations, which can be added to the conventional collaboration environments' potential to support collaboration with or on shared visual representations (Bailey et al., 2012).

Therefore, the artefact classification scheme created within this dissertation is an effort to understanding the variety of artefacts that are and could be employed within creative virtual world collaboration. Together with the suggested taxonomy of objects, the scheme describes the ways in which the three-dimensional collaboration space might alter creative interaction compared to two-dimensional collaboration environments.

6.2 Virtual worlds and shared artefacts in computer-mediated creative collaboration – answers to the research questions

This dissertation presented three main research questions and one sub-question. These questions were answered within the four essays. A summary addressing each of the research questions and the essays, which specifically answer each question, is presented in Table 5 below. A more detailed discussion of each of the research questions' answers is then provided.

Table 5. Research questions and essays

	Essay 1	**Essay 2**	**Essay 3**	**Essay 4**
RQ1: How virtual worlds can support team creativity?	X			X
RQ 2: What kind of artefacts can support distributed team's creative collaboration?		X	X	X
RQ 2.1: How these supporting artefacts are used as boundary objects?			X	
RQ 3: How do virtual worlds differ from concurrent web conferencing environments, in terms of the supporting artefacts?		X	X	

6.2.1 Virtual worlds convey potential to support team creativity

The findings of this dissertation confirm that virtual worlds can support team creativity. This support is, on the one hand, characterized under a conceptualization of eight affordances. On the other hand, shared visual artefacts can be connected to different activities within creative virtual world collaboration.

The review of existing empirical studies in essay I is a systematic effort to describe and crystallize previous knowledge of three-dimensional virtual worlds' potential to support creative team collaboration. The reviewed studies were

conducted within a variety of different domains ranging from teaching to large commercial innovation projects. Based on the review, eight virtual worlds' affordances are observed to foster team creativity. The list of affordances included (1) avatars as three-dimensional representations of users, (2) the potential to change users' frame of reference, (3) the user's perceived feeling of co-presence, (4) the three-dimensional virtual world's potential to foster immersion, (5) the potential for multimodal communication between users, (6) the transmission of rich visual information, (7) virtual worlds' simulation capabilities, and (8) virtual world tools that support creative interaction.

These affordances can be viewed as characteristic features of virtual worlds. Meanwhile, they enhance an individual's potential for creative interaction with other individuals. For instance, an avatar as a user's self-representation, the increased perception of co-presence, or a changing context that surrounds the user might contribute to the individual's ability to creatively interact with others. Notably, the existence of these affordances does not imply that virtual worlds are a guaranteed success towards creative team collaboration. For example, factors that are known to hinder creativity in computer-mediated communication (Hewett, 2005) might certainly impede the potential of the virtual world affordances.

Instead of addressing the entire list of affordances in a systematic and empirical manner, I directed my focus on the affordances of multimodal communication and rich visual information. While the decision contributed towards finding differences between virtual worlds and web conferencing tools in a meaningful manner, it also directed the data analysis process toward the observation of visual artefacts. Previously, the processing of shared artefacts has been observed to increase design teams' ability to yield creative results (Lemons, Carberry, Swan, Jarvin & Rogers, 2010; Rahman et al., 2013). Building on these results, essay IV found differences between the visual artefacts that are used during the virtual world collaboration activities of exchanging information and opinions, generating ideas, and solving problems.

To conclude, the list of affordances summarizes the previous findings of virtual worlds' support for creative collaboration. Moreover, the empirical investigation of two of the affordances within the concept of shared visual artefacts focused on a more fine-grained level of creative collaboration activities in virtual worlds.

6.2.2 Classification scheme of artefacts supporting distributed teams' creative collaboration

This study suggests a classification scheme for visual artefacts to illustrate what kind of artefacts support creative distributed team collaboration. The classification scheme ranges from technical to semi-structured and epistemic representations; from pictorial to combined and written forms of content.

The classification scheme can be seen as an answer to Berente and co-authors' (2010) call to explore the entire ecology of artefacts embedded in designers' activities to understand designers' employed object worlds. Meanwhile, the classification scheme departs from the existing efforts to integrate

the concepts of epistemic and technical objects (Ewenstein & Whyte, Knorr Cetina, 1997; McGivern & Dopson, 2010). The dimensions of the classification scheme emerged during the analysis process as follows.

Pictorial artefacts, such as sketches (Henderson, 1991; Rahimian & Ibrahim, 2011), technical images (Saad & Maher, 2006), graphs and written accounts (Cabitza, Colombo & Simone, 2013) have previously been the focus of design collaboration research. Essay II built on this knowledge by observing a variety of shared visual artefacts during the collaboration events. While the artefacts' content varied from pictorial artefacts to written artefacts, essay II posits a class of combined artefacts between both ends of the classification.

Concerning the artefacts' tendency to represent its content in various manners, another stream of research has addressed artefacts as being technical (Knorr Cetina 2001; Kroes, 2002; Salter & Gann, 2003) and epistemic (Knorr Cetina 2001, 2008; Maio, 2013; Rheinberger, 1997) objects. The major distinction between epistemic and technical objects resides primarily in the object's signifying nature, potential to change within collaborative work, and different forms of manifestation (e.g., Knorr Cetina, 1997).

Moreover, essay IV classifies the artefacts between epistemic and technical artefacts as semi-structured artefacts. Introduced by Anaby-Tavor (2009) and his colleagues, semi-structured artefacts align within a long continuum of artefacts ranging from drawings to standards. The classification scheme suggested in this dissertation integrates these concepts with the different content of the artefacts.

The developed classification scheme ranging from pictorial to written visual artefacts, epistemic to technical representations, raises a question: do these artefacts differ in terms of how they support creative collaboration? As indicated by Henderson (1991) and Carlsen, Clegg, Mortensen and Gjersvik (2013), free-form sketches are particularly favorable for fostering collaborative creativity. The notification is confirmed in essay IV, which indicates that in the virtual world context, epistemic and pictorial artefacts were particularly used in idea generation activities. Meanwhile, technical artefacts were especially used when exchanging information, which aligns with Ewenstein and Whyte's (2009) results. Finally, the developed classification scheme signals the usability of combined and semi-structured visual artefacts, which essay IV notes is applicable to multiple creative collaboration activities.

6.2.3 Linked and transient boundary objects in visual and auditory communication channels

While previous research has typically investigated boundary objects as micro-level constructs, this study suggests that the richness of boundary objects exists within micro-level interaction events. Boundary objects may appear in visual and auditory communication channels, being mutually linked or transient auditory entities. Finally, parallel to Ewenstein and Whyte (2009), this study integrates boundary objects with epistemic and technical objects.

Figure 5 below depicts the boundary object taxonomy and corresponding examples for each of the boundary object type, as suggested in essay III. Arrows

of the figure represent connections between the suggested boundary object types and their sub types. They also indicate linked verbal boundary objects' connections to both verbal and visual boundary objects.

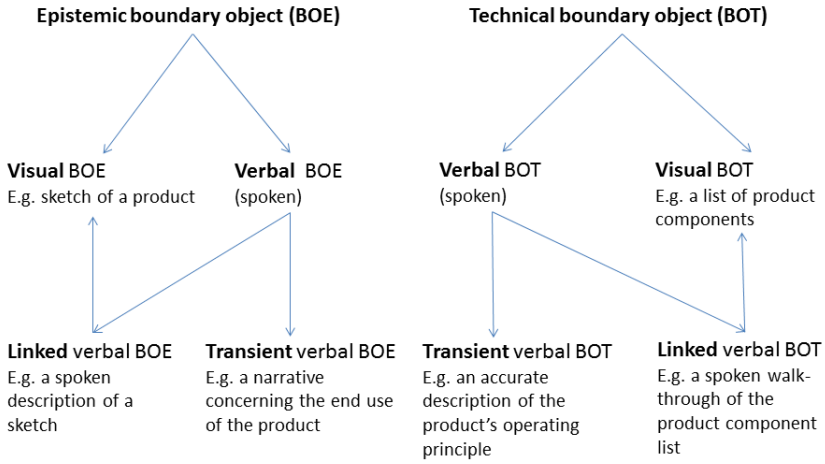

Figure 5. Suggestion of different boundary object types

Boundary objects have been previously addressed in various domains. Of particular interest for this dissertation, previous studies have discovered boundary objects' essence as shared visual artefacts. Visual artefacts as boundary objects can, for instance, mediate negotiation practices (Lee, 2007) while contributing towards perspective taking (Boland & Tenkasi, 1995) between interacting groups (Karsten et al., 2001). These visual artefacts can be used as boundary objects even in a digital form (Bergman et al., 2007; Whyte & Lobo, 2010). Interestingly, while boundary objects can be defined as material artefacts (Pennington, 2010), the tendency to define boundary objects as material artefacts is seen as a delimiter for the concept (Ackerman et al., 2013).

Departing from Ackerman and his co-authors' viewpoint, essay III uses the contrast between web conferencing tools and virtual worlds to discover that introduced boundary object types can manifest in either the visual or auditory communication channels. A boundary object that is manifested in one communication channel can be linked to an utterance in another communication channel. Additionally a boundary object can manifest as transient via the auditory communication channel, for instance, as a metaphor.

Previously, transient cognitive artefacts have been conceptualized to represent most of the observable human communicative actions within collaborative activity, such as speech, gestures, other non-verbal communication and interfaces with input devices (Blackburn, Swatman & Vernik, 2006). Essay III expands the essence of shared visual artefacts by digesting their potential to manifest also in transient form while acting as boundary objects.

Finally, the concept of boundary objects is suggested to be integrated with epistemic and technical boundary objects. While epistemic boundary objects are argued to be changing and unfolding, lacking completeness of being and potentially existing simultaneously in a variety of forms, technical boundary objects are fixed, stable, concrete, and transparent artefacts that remain un-

changed within a restricted time span. Both epistemic and technical boundary objects convey the potential of boundary objects to cross knowledge barrier between two interacting social worlds. This connection appears to be relevant when considered as a further effort following Carlile's (2002) and Ewenstein and Whyte's (2009) work to classify boundary objects in an attempt to discover their essence.

6.2.4 Differences between virtual world and web conferencing tool when supporting artefacts

This dissertation crystallizes the two primary differences between web conferencing tools' and virtual worlds' support of artefacts. First, the collaboration environments appear to foster interaction via different types of artefacts. Second, unlike the web conferencing environment, the virtual world as a collaboration environment may potentially act as an artefact itself and enable the parallel processing of multiple artefacts.

First, essays II and III pinpoint that, based on empirical observation of real-life design interaction, virtual world environments differ from web conferencing environments in terms of supporting artefacts. Essay II introduces differences between web conferencing tools and virtual worlds in terms of the artefacts' content as used in distributed design collaboration. The essay argues that while web conferencing tools favor the utilization of written artefacts, virtual worlds appear, in contrast, to favor artefacts with pictorial contents. This difference is consistent with previous knowledge of virtual worlds' enhanced possibilities for presenting visual content (Bosch-Sijtsema & Sivunen, 2013) and their affordance of rich visual information, as presented in essay I. As indicated in Antonietti and Cantoia's study (2000) and in the experiment of Bhagwatwar and his co-authors (2013), the visual appearance of virtual worlds might impact users' behavior by fostering the presentation and usage of pictorial content instead of written content.

Essay III observes this notification at a micro level. Arguably, while verbal communication linked to a visual artefact is more common in the virtual world, the web conferencing environment favors more transient communication that is not directly linked to the visual communication channel's content. In other words, this notification highlights the virtual world's potential to foster the presentation of visual content when contrasted with the web conferencing environment. Previously, it was understood that information presented orally might be received differently than information presented in a written format (Thatcher & Brown, 2010). Therefore, the authors called for continuing to explore of the interactions between all forms of communication to understand how they impact important organizational outcomes.

Second, essays II and III suggest that virtual worlds have the potential to act as an artefact and enable the parallel processing of multiple artefacts. It is argued that these viewpoints differentiate virtual worlds from web conferencing environments in terms of supporting shared artefacts. As summarized by Bailey and her colleagues (2012), while virtual worlds and web conferencing tools

both allow distributed collaboration with and regarding representations, virtual worlds also support operations within the representations.

The notification has been touched on by some studies of building interface modeling; these studies have observed building designers' and users' potential to immerse themselves in a virtual space that corresponds to the end result of a planned building (Alin et al., 2013; Merrick et al., 2011; Neff et al., 2010). Moreover, Gursimsek (2012) addressed in his dissertation the co-creation process of a virtual world's space as a shared, collaborative design activity. Recent research efforts have demonstrated that in this manner, virtual worlds could also be used as a potential context for creativity (Bhagwatwar et al., 2013). In other words, the results of essays II and III corroborate the potential embodied by a physical context for creative work – as outlined by Carlsen, Clegg, Mortensen and Gjersvik (2013) – that could actually appear virtually in the three-dimensional virtual world context.

As argued in essay III, the virtual worlds' three-dimensional space might compose a meta artefact that is constructed by the team and, correspondingly, that acts with the space's artefacts in a similar manner as a physical space would. Bailey and her colleagues (2012) discuss collaboration environments as platforms, within which individuals work with representations that substitute the object or person, which is being signified by the representation.

The potential for the parallel processing of multiple artefacts allows individuals to switch from collaborative to individual modes of working by themselves (Gül & Maher, 2009). The presence of this option in virtual world collaboration was noticed in both essays II and III. Correspondingly, the web conferencing environment was observed to direct collaborators' attention and operations toward a shared artefact at time.

6.3 Theoretical implications

This section summarizes the theoretical implication that I suggest this dissertation to convey, based on the essays I-IV and the aforementioned discussion. The theoretical implication is outlined under the proposed theoretical framework's components of creativity, virtual worlds, and artefacts. The implication regarding each of these components is next discussed.

First, the theoretical contribution of this research towards creativity is formed as a composition of applying the proposed theoretical framework in the empirical settings of this study. As argued by Rahman and her co-authors (2013), the design process performed in distributed teams has to date received only scarce attention in the design community, although it is an increasingly common phenomenon. To overcome virtual teams' knowledge sharing difficulties, technologies should adapt to the virtual teams' needs (Rosen et al., 2007). In this manner, different collaboration environments can be used within virtual team communication (e.g., Olson & Olson, 2000). The understanding of how computer-mediated communication can foster team creativity has previously been identified as a future research topic (Thatcher & Brown, 2010).

This dissertation describes collaboration between distributed experts and decision-makers who engage in the creative activities of engineering design by using two different collaboration environments. Thereafter, the results act as corroborating evidence that (1) parallel to Nemiro's (2002) account, virtual teams can engage in creative interaction and (2) as noticed by Bink and Beverlein (2007), different collaboration environments might suit the collaborations in a different manner. While several studies (e.g., Lahti et al., 2004; Ocker, 2005) address asynchronous creative collaboration, this study observes distributed, computer-mediated creativity in synchronous settings. The viewpoint is relevant because synchronous collaboration environments have been considered to be beneficial for creative collaboration (Herrmann, 2009). Meanwhile, asynchronous collaboration environments may form knowledge barriers within virtual team problem solving and decision making (Rosen et al., 2009).

Second, this dissertation targets the question of distributed collaboration environments' potential to foster virtual teams' creative activities at a detailed level by investigating three-dimensional virtual worlds as a context for virtual team creativity. Previously, only a limited number of studies have addressed virtual worlds potential for team-level creative efforts (Bhagwatwar et al., 2013; Kohler et al., 2011a; Kohler et al., 2011b; Koutsabasis et al., 2012). This dissertation provides a twofold contribution towards this research stream. First, it suggests that certain virtual world affordances foster team creativity. Second, real-life creative team collaboration within a virtual world is observed in practice.

On the one hand, the proposed list of virtual world affordances is arguably one of the first systematic efforts to articulate virtual worlds' affordances towards team-level creativity. While Koles and Nagy (2014), for instance, address virtual worlds' tendency to foster creativity at a generic level, the list of affordances drawn from the existing body of literature is a subject for experimentation and re-iteration. On the other hand, the empirical evidence that virtual worlds support creativity with respect to the activities of exchanging opinions and information, generating ideas, and solving problems, is an addition to the scant literature empirically addressing virtual world mediated creativity in real-life intra-organizational corporate surroundings.

Finally, a theoretical contribution is suggested to be generated from the taxonomy of objects involving the artefact classification scheme and the conceptual extension to boundary objects. A vast amount of previous research has addressed the role of artefacts in collaborative design and has presented different forms of artefacts supporting creative interaction (e.g., Carlsen, Clegg & Gjersvik, 2013; Gestwicki & McNely, 2012; Henderson, 1991; Saad & Maher, 1996). However, further research has been called for to discover the potential of artefacts in distributed teams' creative collaboration (Luck, 2010), to determine shared artefacts' role in computer-supported collaborative design (Saad & Maher, 2006; Tory et al., 2008), and to explore the ecology of artefacts in a design context (Berente et al., 2010).

According to the reviewed literature, a systematic effort to establish a classification scheme for artefacts that are present in computer-mediated creative

collaboration has not been undertaken. Moreover, according to the essays of this dissertation, the collaboration environments appear to differ in terms of how the collaborating teams utilize the different artefacts. Finally, different artefacts are seen being used in different creative activities within the virtual world context. These differences signal the potential usability of the classification scheme in a theoretical manner.

Added to the theoretical knowledge of artefacts, the theoretical contribution of this dissertation builds upon the previous studies of boundary objects and an adoption of the concept based on micro level observations of collaborative interaction. Based on the foundational work of Star and Griesemer (1989) defining the concept of boundary objects and subsequent efforts to combine the concepts of boundary objects with epistemic and technical objects (Ewenstein & Whyte, 2009), this dissertation investigates the role of epistemic and technical boundary objects in computer-mediated communication.

Star (2010) discussed the potential of a single word to fulfill the criteria of a boundary object with respect to the dimensions of scope and scale. First, the dimension of the boundary objects' scale incorporates Star's (2010) viewpoint of boundary objects' applicability at an organizational level. However, this dissertation expands this knowledge by suggesting that the micro-level investigation of boundary objects may actually be valuable when attempting to understand the differences between two collaboration environment genres for virtual team interaction. While boundary objects are divided into visual and transient manifestations in the micro-level interaction analysis of employed communication channels, the differences between collaboration environment genres are brought under investigation. Therefore, the use of boundary objects in this extent can be seen to contribute to Star's (2010) concept of scope, meaning the co-operative work arrangements as boundary object's context of study.

6.4 Practical implications

This study empirically addresses engineering design in real-life corporate surroundings. Therefore, the results potentially convey the relevance of planning and executing these activities and, therefore, respond to Shachaf's (2008) call for studies that guide the media selection process within global virtual teams. Meanwhile, this dissertation also provides information regarding virtual worlds, which also offers utilization potential outside of the engineering design context. Finally, the practical implications can be discussed from the viewpoint of knowledge sharing practices within virtual teams.

First, this study highlights the consideration and relevance of task-technology fit (Goodhue & Thompson, 1995; see also Aiken, Gu & Wang, 2013) in engineering design activities. Therefore, instead of providing recommendations for the usage or avoidance of a certain collaboration environment for all tasks in virtual team collaboration, this study suggests carefully considering the nature of the task at hand and the artefacts that will be utilized within the task. This consideration allows the virtual team to select the collaboration medium that will support the task in the best possible manner.

Two different collaboration environments were observed to foster different types of interaction. A virtual team that is supposed to process pictorial content or multiple parallel artefacts during its synchronous, collaborative work might benefit from using a virtual world as its collaboration medium instead of a web conferencing tool. The team could also benefit from virtual worlds' indicated potential to act as a modifiable context for the interacting individuals. This context could be used to facilitate the interaction in an expected direction. Correspondingly, when the virtual team's focus is expected to be directed toward artefacts with written content or toward a single, shared artefact, web conferencing tools might better support the collaboration.

Second, the dissertation provides guidelines for virtual world collaboration. The presented list of the virtual world's affordances can be applied for use by virtual world practitioners that aim for creative, virtual collaboration. For instance, the richness of avatar-based communication and multimodal interaction possibilities may be used purposefully to foster creative team interaction. The virtual world platform and user experience designers can utilize the results of this dissertation to develop novel virtual world products and services that enhance team creativity. Notably, this contribution may also be applicable in other collaboration environment genres outside of virtual worlds.

To continue, the list of affordances and the results of significance of artefacts could be utilized when planning emerging collaboration technologies and their functionalities. For instance, the supporting tools that were listed as one of the virtual worlds' affordances towards team creativity, involving artificial intelligence that facilitates creative interaction or potential to rapidly restore the meeting, might also convey potential for practical application in collaboration environments other than virtual worlds. In addition, the potential to foster users' immersion and co-presence might be taken into account in various types of collaboration environments.

Finally, the observed interaction sessions may offer input to knowledge-sharing practices within virtual teams. The web conferencing interaction sessions demonstrate a potential way to resolve whether a complex idea from the corporation's innovation funnel should be selected for development. The presented procedure for involving global experts in a joint, loosely structured discussion of an idea might convey a potential application outside of this study. Additionally, the usage of virtual worlds – or a different collaboration environment – for a meeting on a project that involves design activities might be a potential approach to fostering team creativity. While the context of the team changes, the collective knowledge of the team can be temporarily expanded by involving expertise outside of the team while also advocating diversity within the team.

6.5 Evaluation of the study

The data sets that compose the empirical part of this dissertation consist of fourteen observed interaction sessions. The interaction sessions were arranged within a case corporation and involved real-life corporate teams and dyads.

The research design of this dissertation, including the data collection from these sessions and the undertaken data analysis, can be assessed in terms of its validity and reliability. In addition, I present a summary of the primary limitations that I have identified concerning this dissertation research.

6.5.1 Validity of the study

The dissertation undertakes a qualitative research inquiry. Therefore, I assess the dissertation's validity using Maxwell's (1992) widely recognized classification of qualitative research validity types. These include the study's descriptive, interpretive and theoretical validity, generalizability and evaluative validity. However, concerning the interpretive approach that I adopt for my dissertation, evaluative validity as the final type in Maxwell's (1992) classification is beyond the scope of my dissertation and is therefore ignored.

Descriptive validity is divided into primary and secondary types. The primary type involves the accuracy of the actual events that the researcher reported having seen or heard, and the secondary type addresses the validity of accounts of things that could have been observed but were inferred from other data (Maxwell, 1992).

In the dissertation, the concern of descriptive validity is addressed, on the one hand, by recording the observed interaction events. Therefore, I was able to revisit the observed interaction events when needed. On the other hand, the use of corroborating data involved informal discussions with case corporation representatives. While these discussions were not recorded and the author did not write accurate memos for all of them, they contribute towards establishing an understanding of the study's context. Therefore, they were independent with respect to analyzing the recordings, while they certainly impacted the researcher's interpretation of observed events.

Interpretive validity is related to researchers' understanding of the observed participants' perspective: what the observed objects, events and behaviors mean to the participants (Maxwell, 1992). Notably, interpretive validity is potentially threatened in a research setting because the attendees of real-life interaction events might have had different motivations and aims for the collaboration. In addition, the interaction events were not controlled in any way for these concerns. An attempt to diminish this threat involves using several researchers to interpret the results of the data analysis and to relate the analysis results to previous theoretical findings. In addition, a good connection to the case corporation's innovation department allowed me to ask about matters that I recognized could lead to potential misunderstanding.

Theoretical validity refers to the studied account's validity as a theory of the studied phenomenon. Because the study was undertaken in the form of a single-case study, it is relevant to inquire whether it can form the basis of a theoretical explanation. As outlined by Eisenhardt (1989), however, the validity of case-study-based research can be enhanced by tying the emergent theory to the existing literature. This effort is present in this dissertation as essay I's realization as a systematic literature review that covers virtual worlds' role in creative team interaction in light of previous empirical studies. This back-

ground together with the theoretical approaches derived in essays II, III and IV from the related literature contributed toward increasing the study's theoretical validity.

Generalizability is related to the extent to which the studied account of a particular situation can be extended to other persons, times, or settings that were not directly in the study's focus (Maxwell, 1992). Moreover, generalizability can be internal, referring to the study's generalization to other persons, events and settings within the same organization or to institutions that were not observed; or external, referring to the potential to generalize to other organizations or institutions (Maxwell, 1992). Thereafter, the definition of generalizability approaches the concept of external validity (e.g., Calder, Phillips & Tybout, 1982).

The question of this study's generalizability is relevant because the empirical data for this dissertation were gathered from only one case corporation. However, the careful selection of a case corporation that was as representative as possible attempts to overcome the potential bias of the single case study setting. Two senior scholars led the selection of the case study corporation, and each had several decades of experience conducting research. In addition, by involving corporate employees from different sites, countries and even continents and with differing professional backgrounds, I tried to overcome this potential bias. Finally, several previous and widely recognized studies that address computer-mediated collaboration (see e.g., Bergman et al., 2007; Karsten et al., 2011; Malhotra et al., 2001) are conducted similarly as single-case studies. These efforts comprise attempts to increase the study's generalizability.

6.5.2 Reliability

The concept of a study's reliability can be assessed by the extent to which the data collection and data analysis efforts would lead to same findings if the study was repeated (Yin, 1994). On the one hand, this dissertation undertakes a major effort to achieve reliability of the results by recording the observed interaction events. These recordings allowed the co-authors of the essays to become familiar with the material, which Yin (1994) considered as a common procedure for increasing a study's reliability. In addition, the systematic literature review protocol for the essay I was carefully documented.

On the other hand, the interaction events can be considered to be more or less serendipitous interaction sessions. As is characteristic of qualitative research, the role of context certainly affects the observed events. For instance, although one or more researchers attended the interaction sessions as silent observers, the researchers' presence might alter the interaction. I attempted to overcome the threat of this type of "Hawthorne effect" by, first, conducting a series of interaction sessions with different attendees from different cultures, locations and sub-organizations of the case corporation. In case the presence of a researcher impacted the interaction session, the variability within the attendees would potentially diminish the impact. Second, the analysis phases of essays II, III and especially IV excluded the interventions made by the facilita-

tor. Finally, efforts have been made to present the research results to the case company and to base them on related theoretical foundations.

6.5.3 Summary of the main limitations

Based on the aforementioned discussion of this dissertation study's validity and reliability and the review feedback for the essays, following limitations are noticed to exist in this research effort.

First, data sets 1 and 2 involve the observation of collaborative creativity within engineering design interaction. It should be noted that the interaction sessions' results are not measured in terms of their creativity. Creativity research has employed techniques such as the consensual assessment technique (Amabile, 1983) and the measurement for idea quality (Dean, Hender, Rodgers & Santanen, 2006); these could have been utilized to assess the creativity of the teams within and between the collaboration environments. When conducting the research, however, it became apparent that these techniques might not be applicable to the particular research setting because the ideas varied in terms of their maturity and the applied technologies. Therefore, several experts from different branches would have been needed to assess the results of individual teams' level of creativity. To continue, it can be questioned, whether the use of these experts would have substantially contributed to the objectivity of the research results. Therefore, I decided to focus on the interaction patterns and behaviors common to each of the collaboration environments and interacting teams.

Second, the selection of of case corporations' workers who were involved in the observed interaction sessions was not controlled by the researchers nor were the ideas and projects that were the focus of collaborative efforts. These factors might appear to be limitations concerning, for instance, how familiar the attendees were with the topic or how well they knew – if they did know – each other beforehand. In this manner, it can be assumed that the level to which the studied distributed interaction events approximated virtual team interaction varied within the sessions. In addition, the ideas' might differ in terms of their creative potential. It can be argued that these limitations could have been overcome by a strict experimental setting. However, I consider the observation of real-life collaboration to be valuable, not least concerning the potential to use the results in practice and also the contribution that resides from addressing the previous theoretical and conceptual findings in real-life interaction.

Finally, an obvious limitation for this study is the implementation of the research as a single case study consisting of fourteen interaction sessions. While the number of interaction sessions and case companies could certainly have been expanded, it is not apparent whether expanding the data sets would have changed the results of this research. In addition, the topics that were the focus of this research are subject to continuation within further research efforts.

6.6 Recommendations for further research

The essays of this dissertation provide, in my consideration, several avenues for future research efforts. In the following, I describe these suggested efforts classified under the main themes of engineering design, artefacts and virtual world research.

First, engineering design is subject to a tendency toward increasingly global and virtual work. This work also involves creative interaction that is increasingly being undertaken in a distributed mode of operation. Therefore, it is important to continue the research of Taylor and Saarinen (1994), Nemiro (2002), and Thatcher and Brown (2010) to discover how ICT tools can support distributed creative collaboration. Noting the potential of already existing but not widely adopted, or emerging, technologies, the possibilities for distributed, creative effort may encounter substantial changes during the next decades. While the changes are partially driven by the development and commercial success of technology, research efforts are central to grounding the technical knowledge behind the technology and figuring out collaboration practices that empower the use of the technology. This research direction would also involve exploring the entire process of creative collaboration in distributed settings, and the collaboration medium's potential to change the process.

In their recent study, Rahman and her co-authors (2013) noticed that when collaborating synchronously, shared visual artefacts support design ideation. More research is, however, needed to establish an understanding of how collaboration environments can actually support distributed design activities and, moreover, distributed knowledge work in general. This would involve, for instance, environment's potential to support resolving conflicts that are characteristics for creative, distributed collaboration. While Sivunen and Nordbäck (2014) noted that in computer-mediated settings, social presence is even more crucial to maintain and evoke the importance and nature of communication; this viewpoint can possibly be expanded to other elements of successful distributed teamwork. In this manner, facilitation practices within the interaction sessions and leadership in the successful adoption and use of collaboration tools are promising venues for research efforts that convey a strong relevance in practice.

In addition, it still remains unclear what kind of artefacts will eventually support distributed knowledge work and how. While this dissertation contributes to this discussion by generating a classification scheme of pictorial, combined and written artefacts as epistemic, semi-structured, and technical representations, future research efforts might expand or otherwise contribute to this work. In this dissertation, the classification scheme contributed towards contrasting different collaboration environment technologies; perhaps it could be applied in other domains as well.

This dissertation contributes to the discussion of epistemic and technical objects initiated by Knorr Cetina (1997, 2001, 2008) and builds largely on Ewenstein and Whyte's (2009) work. This discussion is connected to the active research stream of boundary objects (Star & Griesemer, 1987). As a subject for further research, the open issues in essay III, including the introduced bound-

ary object types, could possibly be of further research interest. In particular, an object's potential to alter from an epistemic boundary object to a technical boundary object, or vice versa, over shorter or longer time spans and the collaboration environment's potential to support this change would be an interesting point of departure.

Finally, it was concluded in essay I that the virtual worlds' potential to prime creative interaction was constituted of eight affordances. While the notion, interlinkedness and even existence of affordances provides a point of departure for research efforts, broader concepts beyond the affordances and their relation to creativity would probably be of interest to the virtual world community.

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