TECHNISCHE UNIVERSITÄT MÜNCHEN
Forschungs- und Lehreinheit XI
Angewandte Informatik / Kooperative Systeme

Situative Creativity

Marc René Frieß

Vollständiger Abdruck der von der Fakultät für Informatik der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Naturwissenschaften (Dr. rer. nat.)

genehmigten Dissertation.

Vorsitzender:		Univ.-Prof. B. Brügge, Ph.D.
Prüfer der Dissertation:	1.	Univ.-Prof. Dr. J. Schlichter
	2.	Univ.-Prof. G. J. Klinker, Ph.D.

Die Dissertation wurde am 06.09.2012 bei der Technischen Universität München eingereicht und durch die Fakultät für Informatik am 30.12.2012 angenommen.

Abstract

Creativity is the starting point of every innovation and is crucial for the success of any company. IT-based creativity support systems have been shown to be promising in view of fostering creative processes. However, state of the art applications still disregard characteristics which are typical for creative situations, such as the need for social, intuitive, and face-to-face interaction. This thesis investigates important requirements and practices via interview techniques and explores a concept for novel ways of IT driven creativity support. Here, collocated settings allow for a rich vocabulary of interaction types between the team members and the IT system. A main focus is the development of a multi-touch IT environment centered around a large tabletop display and enriched by small coupled private displays (smartphones, tablets). A key contribution lies in the evaluation of this environment through several case studies. In this regard, the tabletop environment is compared to traditional IT support.

Kurzfassung

Kreativität liegt jeder Innovation zugrunde und ist daher für den Erfolg von Unternehmen von zentraler Bedeutung. Obwohl man Kreativitätsprozesse durch den Einsatz von Software erfolgversprechend unterstützen kann, werden typische Anforderungen, die für Teamarbeit in Kreativsituationen benötigt werden, durch bestehende IT Systeme noch nicht ausreichend berücksichtigt. So besteht beispielsweise ein Bedarf an sozialer, intuitiver und face-to-face Interaktion. Im Rahmen dieser Dissertation werden gängige Praktiken kreativen Arbeitens mit Hilfe von Interviews untersucht, dadurch Anforderungen abgeleitet und ein Konzept für neuartige Wege der Kreativitätsunterstützung erforscht. Der Fokus liegt dabei auf der Entwicklung einer IT-Umgebung, die aus einem berührungsempfindlichen Tisch-Bildschirm in Kombination mit privaten Mobilgeräten (Smartphones und Tablets) besteht. Im Rahmen der Evaluation werden mehrere Fallstudien aufgezeigt und ein Vergleich mit traditionellen IT-Systemen durchgeführt.

Acknowledgments

This dissertation would not have been possible without the help and support of many people.

I would like to thank first and foremost my advisor, Prof. Dr. Johann Schlichter for giving me the opportunity to join his research group and for thoroughly reviewing my thesis and providing precious feedback. Moreover, I would like to thank him for giving me the freedom and opportunity to work on this interesting topic. I am also grateful to Prof. Gudrun Klinker, Ph.D. for being my second advisor, also providing me valuable feedback to my thesis.
I would like to thank Dr. Florian Forster and Dr. Florian Echtler for building upon the applications and the tabletop device developed in the scope of their doctoral theses. Finally, I would like to thank all our present and former group members for their numerous and valuable feedback and motivation as well as the great working climate what made me especially enjoying my work.
I owe my deepest gratitude to my cousins Andrea Schug Vonk, Claudia Schug Schütz, and Kristine Schug for proofreading the English of my thesis despite their rare free time. Credits also go to my family for their support and encouragement. It is needless to emphasize again, that all this would not have been possible without the support of my parents, who have given me the education opportunity that provided the foundation of this work. Last but not least, my sincere appreciation goes to my girlfriend Noriko for her patience, support, and understanding during the writing of this thesis.

Contents

Chapter 1

Introduction

1.1 Motivation

With the era of knowledge creation, the need for companies to make use of the ideas created by their management and employees is gaining more and more importance. With business environments changing more and more rapidly and the expansion of many economies on a global scale, the need to differentiate from competitors has dramatically increased. Hence, new ways to differentiate from others need to be continuously found [Garfield, 2008]. The resulting high competition on the market has led to an increased importance for innovation. Every innovation process - whether open or closed - is based on creativity at its fuzzy front end as "*all innovation begins with creative ideas*" [Amabile, 1996, p.1154]. Hence, creativity plays a crucial role in innovation. "*Creativity aids a company in differentiating itself from its competitors by helping the company examine its current paradigm and consider ways to improve within this paradigm or to modify the paradigm in fundamentally new ways*" [Garfield, 2008, p.745]. According to research [Amabile, 1996,Sternberg and O'Hare, 1996], creativity can be defined as the development of ideas, outcomes, products, or solutions that are judged as a) original and novel and b) appropriate and potentially useful for a given problem.

Modern research on creativity can be traced back to the 1950s [Farooq et al., 2005] and has since then mainly been addressed by the psychological and social sciences. Since the early 1990s, however, Computer and Information Science and Engineering (CISE) has also started focusing on creativity in the context of (information) technology [Edmonds, 1994]. Because of increasing research on the influence of IT support on creativity, it gained a certain significance in the fields of Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) [Farooq et al., 2005]. One main reason for this is that both disciplines investigate traditionally diverse areas such as computing, psychology, art, music, and design in a more integrated and inter-disciplinary way. The class of information systems which support creativity is commonly known as Creativity Support Systems (CSS). "*Creativity Support Systems are computer-based systems that* *support individual- and group-level problem solving in an effort to enhance creative outcomes*" [Garfield, 2008, p.746]. The use of information technology has shown potential to foster the creative skills of individuals and groups in order to develop more creative solutions [Massetti, 1996, Couger and McIntyre, 1993, MacCrimmon and Wagner, 1994]. Even more, computer support has been shown to mitigate several negative effects within interacting groups [Isaksen, 1998, pp.12-14] through the possibility of parallel (and distributed) input, accounting for contributions, and providing a persistent and reproducible storage of data. This can lead to improved team effectiveness in idea generation sessions [Bostrom and Nagasundaram, 1998, p. 397]. This is also emphasized in [Garfield, 2008, p.748]: "*A CSS can not only enhance both an individual's creativity, but can also enhance the creativity of a group*". However, most of these early studies only addressed the usefulness of computer support for creativity in general, neglecting the specific needs of creative collaboration itself.

This shortcoming is, for example, stated in [Mamykina et al., 2002, p.96]: "*However, recent research has begun to paint a more complicated picture of creativity that highlights the importance of social interactions, mentoring, and collaboration in creative work.* [...] *The importance of analyzing creativity in this more holistic sense is readily apparent when one considers that most creative pursuits in industry involve interdisciplinary teams working together to develop a product that cannot be created by a single individual alone*". Here, especially the interaction between people plays an important role as "*creativity does not happen inside one person's head, but in the interaction between a person's thoughts and a socio-cultural context*" [Csikszentmihalyi, 1997, p.23]. The importance of social interaction as a vital source for creativity is also emphasized by Gerhard Fischer: "*Much human creativity arises from activities that take place in a social context in which interactions with other people and the shared artifacts are important contributors to the process*" [Fischer, 2007, p.692]. Consequently, these social and interaction contexts are of particular importance when supporting creativity with technology as, according to [Fischer, 2005, p.2], "*creativity occurs in the relationship between an individual and society, and between an individual and his or her technical environment*". Facilitating an IT environment to support a group's creativity in a more optimal way can be particularly challenging: different skills have to be coordinated, various creative abilities and collaboration styles have to be taken into account, knowledge and information need to be exchanged and interpreted. Hence, the core requirements for fostering collaborative creative problem solving can be described as **communication**, **coordination**, and **interpretation** [Hilliges et al., 2007]. These requirements are referred to and investigated in later parts of this thesis.

Traditional IT applications relying on personal computers are not specifically tailored to support these requirements. "*Using single-user systems in a collaborative setting leads, in most cases, to a communication breakdown since the user's concentration has to shift away from the group and towards the computer in order to use it*" [Hilliges et al., 2007, p.137]. In contrast to true face-to-face settings where people directly communicate and collaborate, traditional computer mediated communication renders users relatively anonymous. This leads to stereotypical impressions of other users based on language, typographic, and contextual cues [Walther, 1997]. However even if used in a collocated setting, the physical layout of traditional technology (e.g. computer screens in front of each participant) can inhibit the interactions between the parties involved [Rodden et al., 2003]. As a consequence, in such situations, technology is very often absent or shut down because it is considered disruptive to communication and the creative flow [Streitz et al., 1999]. As "*important parts of our professional and personal life still depend on collocated collaboration and face-to-face communication*" [Hilliges et al., 2007, p.137], novel approaches to IT support for such settings are needed. These approaches should, in particular, address a higher user satisfaction and a natural group collaboration by providing new intuitive methods for computer-mediated human-to-human interaction that allow for facial expression, body language and the immediacy of verbal communication. "*The importance of creating an emotional as well as physical environment that encourages creativity should not be underestimated*" [Mamykina et al., 2002, p.99]. As pointed out by Gerhard Fischer, such "*appropriate socio-technical settings, at the same time, have the potential to amplify the outcome of a group of creative people by both augmenting individual creativities and multiplying rather than simply summing up individual creativities*" [Fischer et al., 2005, p.3].

1.2 Research Question

Due to the discussion presented above, it is worth doing more research on novel socio-technical environments in the context of collocated creative collaboration. In this regard, applications on (large) sharable screens which can be controlled simultaneously by multiple users (so called Single Display Groupware (SDG)) have been identified as promising for the creative domain: "*Creative projects often benefit from group activity and input, but the restrictive nature of current systems can limit expression. The potential benefits of using SDG in this domain include being able to work more effectively by working in parallel and eliminate unnecessary turn taking*" [Stewart et al., 1999, p.290]. Novel tangible interfaces which allow for a direct and touch-based interaction combined with a large display size are even more promising, as they enable new forms of creative expression, collaboration, and human-computer interaction: "*The advent of touch computing and relatively large sharable screens combined to produce systems that are not limited to relatively specific and routinized transactions.* [...] *This enables a new kind of computing: the social NUI*[1]*, where people can share experiences in the here and now and use the computer simply as a support mechanism*" [Wigdor and Wixon, 2011, p.39].

While multi-touch technology allows multiple users to directly interact with and collaborate on a large display, Stewart also points out that "*there will* [still] *be collaborative situations in which co-present interaction at a single display will not be as useful as networked synchronous collaboration or asynchronous collaboration*" [Stewart et al., 1999, p.290]. Reasons for this can be quite diverse. First, research on creativity has shown that in early phases of a creative process individual work can be preferable to group work to avoid a tunneling of individual search spaces [Magerkurth and Prante, 2001] or to express ideas more anonymously [Carte et al., 2006]. Second, by working on a public display, personal data

[1] Natural User Interface

cannot be accessed easily and capabilities for more advanced individual work are restricted due to limited space for individual control elements. Coupling small mobile displays (such as smartphones or tablets) to the large public display are one solution to overcome this shortcoming. Using such devices allows, for example, carrying personal data and sharing it to the group. Even more, the private workspace on the coupled displays introduces a certain degree of anonymity and privacy, while preserving the advantages of the face-to-face setting as most of the group work is still performed on the public display. These advantages are also stated by Shoemaker when referring to physical world settings without IT support: "*people are free to reference private notes or make private sketches, while collaborating around a public artifact. At any time, people can choose to make private information public or public information private. This ability to have both public and private information is an aspect that is lacking in existing SDG systems*" [Shoemaker, 2000, p.349].

Based on this prior knowledge, this thesis contributes to the following **research question**: "*What are the peculiarities of creative collaboration and how can they be supported by a socio-technical environment based on a multi-touch tabletop display and coupled mobile devices*".

The practical part of this research (mainly) builds on an existing application developed in the scope of Florian Forster's PhD thesis on "Computer Support of Collaborative Creative Processes" [Forster, 2010], completed in 2010 at the Technische Universität München (TUM). Forster's thesis focused on the question of how to formalize creative processes into a computer model. This model - building on creativity techniques - was then implemented in the context of the so called IdeaStream application. As this application provides a flexible application core which allows for attaching arbitrary types of client devices, it forms an applicable basis for developing a novel IT environment. To evaluate his theoretical process model, Forster implemented a web-based front-end into IdeaStream. Both aspects make IdeaStream ideal for conducting a comparison of different ways of IT support. As a side project of this work, also a more art-related type of creativity is regarded: the collaborative composition of (electronic) music.

To solve the research question presented above, the design science methodology is applied. Within the next section, we show how the research presented in this thesis can be categorized into the seven design-science research guidelines by Hevner et al. [Hevner et al., 2004, p.83].

1.3 Methodology

Recognizing the lack of prior research on tailored support systems for creativity, we decided to use a **design science approach** for solving the research question. According to Hevner et al. "*the design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts*" [Hevner et al., 2004, p.75]. We are guided by the intention to fill a gap of knowledge by designing an IT artifact which addresses the problem domain - and "*to bridge practice to theory rather than theory to practice*" [Holmström et al., 2009, p.65]. Hence, the research objective - exploring how collaborative creativity can be supported by novel means of IT in a more situation-sensitive way - requires an **exploratory research design**. To thereby ensure its scientific value added, Hevner et al. [Hevner et al., 2004] proposed seven guidelines that are related to the steps of our approach. These guidelines and our corresponding activities are summarized in Table 1.1.

Guideline	**Corresponding Activities**
1) Design as an Artifact: "*Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.*"	Creation of a concept and prototypical implementation of a socio-technical environment supporting collaborative creativity, based on a multi-touch tabletop display and coupled mobile devices.
2) Problem Relevance: "*The objective of design-science research is to develop technology-based solutions to important and relevant business problems.*"	Creativity is important for every company for being competitive. According to a recent German study involving 534 participants [iQudo, 2010], only 6.4% of all ideas emerge at the workplace. Hence, fostering creativity by providing a special IT environment which is more sensitive to the needs of creative collaboration is an important as well as relevant business problem.
3) Design Evaluation: "*The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.*"	Evaluation of data (e.g. log-files, tracking-data, video/audio recordings) and user experiences (e.g. interviews, surveys), gathered from experiments and user studies. Additional comparison to other, more traditional ways of being creative.
4) Research Contributions: "*Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.*"	Clear contributions to the research fields of CSCW, HCI and CSS in form of a concept and a design artifact in the sense of a validated Creativity Support System based on a multi-touch tabletop display and coupled mobile devices. A detailed list of contributions can be looked up in Section 1.4.

5) Research Rigor: "*Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.*"	Practical (interviews) and theoretical (related work) approach to elicit requirements; iterative prototype development combined with experiments, user studies, and questionnaires for validation.
6) Design as a Search Process: "*The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.*"	Iterative loops for the elicitation, refinement and validation of requirements and the prototypical instantiation.
7) Communication of Research: "*Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.*"	Continual scientific presentation, publication, and discussion of technological concepts, solutions, and evaluation results in the scope of (technology-oriented and management-oriented) international conferences and journal articles.

Table 1.1: Design science research guidelines [Hevner et al., 2004, p.83] and corresponding research activities

1.4 Contributions

Based on the research methodology presented above, this thesis contributes to different fields of information science. This mainly relates to the research field of Creativity Support Systems (CSS), but also targets the more general research fields of Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW). In detail, this thesis aims to provide the following contributions (structured in chronological order):

C1: Overview of (interdisciplinary) theoretical research on creativity and related work on different IT environments for supporting (collaborative) creativity.

C2: Analysis and categorization of creative situations and IT and non-IT tools for creativity support in a business context.

- **C2.1:** Interviews with creativity experts from ten companies of the German ICT sector.
- **C2.2:** Categorization and characterization of creative situations and related IT and non-IT support tools.

- **C2.3:** Characterization of the creative collaboration situation and implications on a novel way of IT support (referred to as a "situative creativity support").

C3: Concept for a situative creativity support system based on a multi-touch tabletop display and coupled mobile devices.

C4: Practical realization in the context of two application scenarios.

- **C4.1:** Tabletop application supporting collaborative creativity techniques.
- **C4.2:** Extension by a coupled display application for smartphones and tablets.
- **C4.3:** Tabletop application for the collaborative composition of music.

C5: Iterative evaluation activities

- **C5.1:** Preliminary study with the tabletop application of C4.1.
- **C5.2:** Main study with the tabletop application (C4.1) and coupled smartphones as input devices (C4.2).
- **C5.3:** Comparison of C5.2 to a distributed (web-based) application.
- **C5.4:** Comparison of C5.2 to a traditional scenario without IT support.
- **C5.5:** Analysis of collaboration in C5.2.
- **C5.6:** Additional study with the tabletop application (C4.1) and an extended coupled display application based on tablets (C4.2).

1.5 Thesis Structure

Guided by the design science methodology presented above, the section below describes the structure and line of argumentation of this thesis. For this purpose, it summarizes the content of each chapter briefly and shows interrelations between the different chapters.

Chapter 1

The current chapter presents a summary of the motivation and the research question of this thesis and illustrates the research design and the main contributions of this work.

Chapter 2

Chapter 2 gives an overview of the fundamentals of creativity and creativity support. First, the term **creativity** is defined by discussing its history as well as recent **definitions from literature**. Building on these definitions, the related concepts of open innovation and open creativity are explained and the broader **context of this research**, namely the BMBF[2] project "Open-I - Corporate Open Innovation", is explained. In a next step, Section 2.2 introduces one of the most often used views on creativity, the **4P framework of Mel Rhodes** [Rhodes, 1961]. This framework acts as the theoretical basis for the research

[2] Bundesministerium für Bildung und Forschung - Federal Ministry of Education and Research

conducted within this thesis and describes creativity as the interplay of three different dimensions (person, press, process) that lead to a creative product (the fourth dimension). To be more precise, each of these dimension, and especially the creative process and the creative press, is examined in more detail. Concerning the creative process, **creativity techniques** as a practical realization are introduced by showing different procedural categories (and examples) of such techniques. With regard to the creative press, an overview of interdisciplinary approaches to this dimension is given. Section 2.3 concludes this chapter with a classification of electronic support tools for creativity (so called **Creativity Support Systems**) and an examination of different related IT environments.

Chapter 3

To answer the question which **categories of creative situations** typically occur in **practice** and which tools are used to support them, ten **interviews** were conducted with experts (mainly leading project / product managers) from ten companies of the German Information and Communications Technology (ICT) sector. The first section of Chapter 3 describes the applied interview methodology and presents selected statements and related insights from the interviews. On the basis of these insights, a more generalized categorization of creative situations and their characteristics / properties is established. In a second step, the **creative collaboration situation** is examined in more detail by referring to insights gained from the interviews as well as theoretical work on this subject. The section concludes with a definition of a situative IT support for collaborative creativity and a discussion of its implications. Section 3.2 is devoted to a **concept** for a **collocated and collaborative multi-touch** and **multi-display environment** for supporting creativity. First, we examine collaboration characteristics and opportunities for a natural face-to-face collaboration on and around tabletop devices. Next, we regard user interface design guidelines for touch-based input. Finally, we investigate why and how coupled mobile devices (smartphones and tablets) can enhance such an environment. Section 3.3 concludes this chapter with the introduction of the two application scenarios for being implemented in the context of this thesis: collaborative creativity techniques and the collaborative composition of electronic music.

Chapter 4

Chapter 4 gives an overview of the **two developed applications** and their implementations. First, Section 4.1 introduces the implementation of the **first application scenario**, a tabletop-based application supporting **creativity techniques**. As this application is based on IdeaStream, it is named IdeaStream Tabletop Client (ISTC). For this application, the software architecture, the applied user interaction paradigms (e.g. gestures, physics simulation), and the concrete user interface elements (so called widgets) are discussed. Next, an **extension** of the ISTC application by **coupled mobile devices** (smartphones and tablets) is introduced in Section 4.2. Finally, Section 4.3 presents the implementation of the **second application**, an **art-oriented side project** that focuses on the support of the **collaborative and collocated composition of electronic music** on a multi-touch tabletop device.

Chapter 5

Chapter 5 focuses on the **evaluation** of the concept and the implementation of the ISTC application. First, Section 5.1 establishes the **main evaluation goals**. Next, Section 5.2 introduces the **technological infrastructure**, referring to the used tabletop device and a dedicated tracking environment for (mainly) gaining knowledge about the interaction in the physical space around the tabletop device. Section 5.3 then presents a discussion of a **preliminary study** giving insights into shortcomings of a prototype of the ISTC tabletop application. After solving most of these shortcomings and including smartphones as coupled input devices, the **main study** was conducted. Section 5.4 is devoted to this study and first describes the applied **creative process structure** and the **different experiment settings (web, tabletop, no IT support)** that were **compared**. Next, we regard **quantitative data (number and quality of ideas)** and a statistical analysis of a **user survey**. Furthermore, we present an examination of the interaction in the physical space on and around the tabletop device. Finally, Section 5.5 examines an **additional study**, conducted with a more **advanced version** of the **coupled display extension** of ISTC (based on tablets). The chapter concludes with a discussion of the main results in Section 5.6.

Chapter 6

Chapter 6 concludes this thesis by giving a **short summary** of the previous chapters. Additionally, it presents a **critical discussion** of the **main lessons learned** and a **summary** of the **main contributions**. Finally, it proposes improvements and research questions for **future work**.

Chapter 2

Fundamentals of Creativity Support

This chapter introduces the theoretical background and the fundamental concepts that form the basis of this thesis. Section 2.1 examines creativity as a whole by giving a short overview about the history of the term "Creativity" and related definitions from literature. Next, it frames creativity into its broader context, the concepts of innovation and open innovation. Connected to these concepts is the context in which this research took place: the Open-I project. Hence, this project and the related activities such as workshops are briefly described. To gain more detailed insight into creativity, Section 2.2 introduces the most popular framework for describing creativity, namely Mel Rhodes' 4P of creativity [Rhodes, 1961]. This framework describes creativity as the interplay of several dimensions (person, press, process) that lead to a creative product. In a next step, these dimensions and especially the creative process and the creative press are examined closer. The last section of this chapter establishes a classification of and takes a look at IT-based tools and IT environments supporting collaborative creativity (so-called Creativity Support Systems (CSS)). These environments range from traditional distributed applications running on single-user PCs and communicating over networks to dedicated systems for collocated group work. In this regard, also an application which is of particular importance for this thesis is introduced: IdeaStream. The chapter concludes with a discussion of the presented concepts, tools, and IT environments.

2.1 Creativity

2.1.1 Introduction to Creativity

Creativity is a term that is often used in many different contexts. One fact about creativity is that it is a fundamental part of everyone's life, because the world we live in has largely been shaped by (human) creativity. This pervasive nature of creativity is described by the author and filmmaker Robert Fritz [Fritz, 1991, p.5] as follows:

> "*The creative process has had more impact, power, influence, and success than any other process in history. All of the arts, many of the sciences, architecture, popular culture, and the entire technological age we live in exists because of the creative process.*"

Not only in history, but also in the present moment and for affecting future developments, creativity is particularly important. Especially for the economic success of companies, creativity should not be neglected: "*The global economic competition faced by today's organizations makes creativity imperative; the degree to which companies can transform creative ideas into innovative products and services is often the difference between success and failure*" [Puccio, 2006, p.2]. And even for whole societies "*to give a fair chance to potential creativity is a matter of life and death*" [Toynbee, 1964, p.4].

To gain a more precise view on creativity, it is important to grasp the meaning of the term "creativity" more precisely. It originates from the Latin word "creare" and refers to the human potential to construct or invent something new. Although one could imagine that this understanding of creativity is quite intuitive, many different definitions have emerged. In appeal to its Latin origin, creativity is typically seen as the process of bringing into being something that is both **novel** and **useful** (e.g. [Sternberg and O'Hare, 1996, Amabile, 1996]). Novel in this context means to be the first, to be unique, or phrased in operational terms "*to be a statistically infrequent or uncommon idea*" [Puccio, 2006, p.2]. "*To be useful means to solve some problem, resolve some difficulty, or fulfill some desire or wish*" [Puccio, 2006, p.2].

But creativity is much more than just an outcome or product. The creative process is often seen as a mysterious phenomenon, with sudden insights seeming to work at an unconscious and inaccessible level [Schooler and Meicher, 1994]. This magical moment of discovery where an idea comes into consciousness makes creativity seem sudden, without logic, and hard to grasp. Hence, it may seem difficult to study creativity scientifically and systematically. This may be one reason why scientific approaches have analyzed a variety of different perspectives on creativity. One of these perspectives can be found in psychological literature regarding human centered factors which influence creativity. There, evidence was found that elements of personality, affect, cognition, and motivation, for example, can either foster or hamper creativity (e.g. [Csikszentmihalyi, 1997, Amabile, 1996, Feist, 1998]). In another perspective, creativity research addressed contextual and organizational factors influencing creativity [Amabile, 1996, Csikszentmihalyi, 1997, Törnqvist, 2004].

In one of the most common definitions of today, the 4P of creativity, Mel Rhodes [Rhodes, 1961] proposed bringing the different perspectives from research together in order to create a unified framework for describing creativity. According to this framework, creativity can be seen as the interplay of **person**, **process**, and **press**, that lead to a creative **product**. The 4P of creativity quickly became the standard for research on creativity, helping to classify the various efforts in this field. They also act as theoretical basis for this thesis and are therefore regarded in more detail in Section 2.2. But first, the broader context of creativity, namely the concepts of innovation and open innovation, as well as the research project in the context of which this thesis was written, are introduced.

2.1.2 Creativity in (Open) Innovation

Creativity is of particular importance to innovation, which is regarded as one of the crucial success factors in enterprises in an increasingly complex world [Cohen and Levinthal, 1990, Steiner, 2009]. Every innovation process - no matter if it is open or closed - is based on creativity, especially in its rather fuzzy initial stages: "*All innovation begins with creative ideas*" [Amabile et al., 1996, p.1154]. While creativity is seen as the process that leads to the development and the generation of ideas, innovation is the practical implementation of the idea concept [Majaro, 1988, Hauschildt and Sören, 2007]. Hence, an innovation needs to ensure that the commercial and profit goals are met and that the idea concept is mature enough to have an opportunity in a market environment.

Several types of innovation processes have evolved over the past decades. Depending on a company's sourcing strategy for innovations, these strategies can range from internal to external and can involve few or many contributors (cp. Figure 2.1). Formerly, a company's innovation process was mainly rooted in the research and development (R&D) department, where dedicated specialists developed solutions in a more or less closed environment [Chandler, 1990] (**internal closed innovation**). In order to complement this single source of creativity and knowledge through the integration of external know-how, companies increasingly opened their innovation management to collaborate with external partners and customers [Chesbrough, 2003, Reichwald and Piller, 2006].

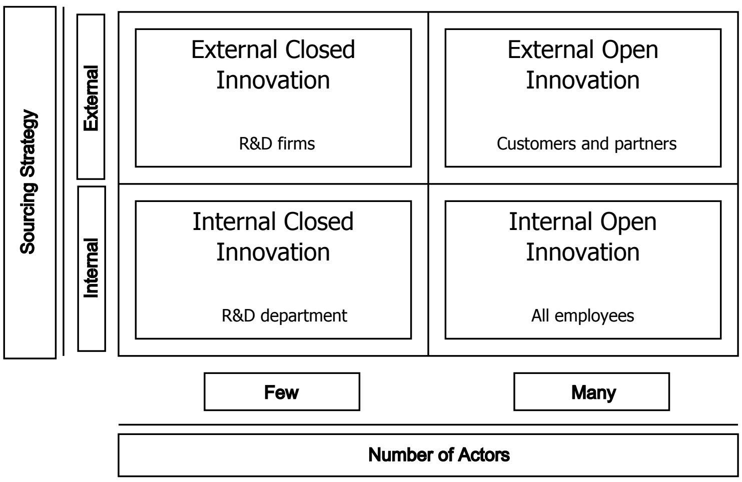

Figure 2.1: Scopes of innovation management [Reinhardt et al., 2010b]

By integrating external specialists or outsourcing the R&D almost completely to specialized firms, the collaboration with (contractual) external research partners widens the scope of a company's innovation management (**external closed innovation**). However, the source of knowledge and capabilities remains within a specific domain.

In times of global competition, with free information flows and shortening product life cycles, the generation and development of ideas and innovations within a single organizational unit or confined knowledge-space is no longer sufficient. Hence, more and more companies utilize open innovation networks in order to use external sources and channels for idea creation and innovation commercialization [Chesbrough, 2003] (**external open innovation**). In this scenario, many more contributors, like customers and company partners, are integrated into the value creation activities (e.g. as lead users) [Reichwald and Piller, 2006].

Another huge potential for innovation is at the interface between the traditional organizational boundaries and the spheres of single actors [Shipton et al., 2006]. Against this background, there exists another major source of potential innovators: the employees of a company. As they are located within the company they share a common vision and motivation. Further, they have different functional backgrounds and thereby can contribute many more perspectives and ideas than just one single department. Attempting to integrate all of them into **internal open innovation** processes implies the need to create adequate conditions and IT support for unfolding their creative potential.

In the new open forms of the innovation process, creativity, analogously called **open creativity** [Steiner, 2009], is becoming even more important than in traditional innovation processes. As in open innovation, in open creativity "*the synergetic interplay between internal and external sources of creativity at the individual and collaborative levels* [...] *needs to be utilized*" [Steiner, 2009, p.1]. As a consequence, open creativity is characterized by a higher process complexity and a higher degree of collaboration than in classical group creativity [Steiner, 2009, p.7].

Closely connected to the interdependence between creativity and innovation is the research project in whose context the research in this thesis was conducted. The next section gives a description of the main goals and research activities of this project.

2.1.3 Context of Research: The Open-I Project

The project "Open-I: Open Innovation im Unternehmen"[1] (reference number: `01FM07054`) has been funded by project grants from the German Federal Ministry of Education and Research (BMBF) and the European Social Fund (ESF). As already included in the name of the project, the related research activities mainly focused on the open innovation phenomenon. More precisely, the project provides initial insights into open innovation within companies (earlier referred to as **internal open innovation**) by taking an interdisciplinary research approach. Based on an analysis of leadership, controlling, and motivational aspects in the context of searching, selecting, and implementing employee-driven innovations as a framework, an interactive innovation management platform that encourages, motivates, and supports employees to actively participate in the innovation process of an organization was designed and implemented. Further information on the Open-I project can be found on the project's web page [Open-I, 2012] or at [Fokusgruppe Management offener Innovationsprozesse, 2012].

[1] English: Open-I - Corporate Open Innovation

One major research question to be answered in the project was how and at which stages creativity in company internal open innovation processes can and should be supported by IT. In this regard, the IdeaStream application that was originally developed in the scope of Florian Forster's PhD-thesis on computer support of collaborative creative processes [Forster, 2010], was integrated into the innovation management platform and the related innovation process structures [Reinhardt et al., 2010b, Reinhardt et al., 2010a, Reinhardt et al., 2010c,Reinhardt et al., 2012]. As already pointed out in the introduction, IdeaStream allows for the collaborative use of creativity techniques (see Section 2.2.3 for a definition and examples of creativity techniques). A detailed description of IdeaStream and the underlying process model can be looked up in Section 2.3.3.

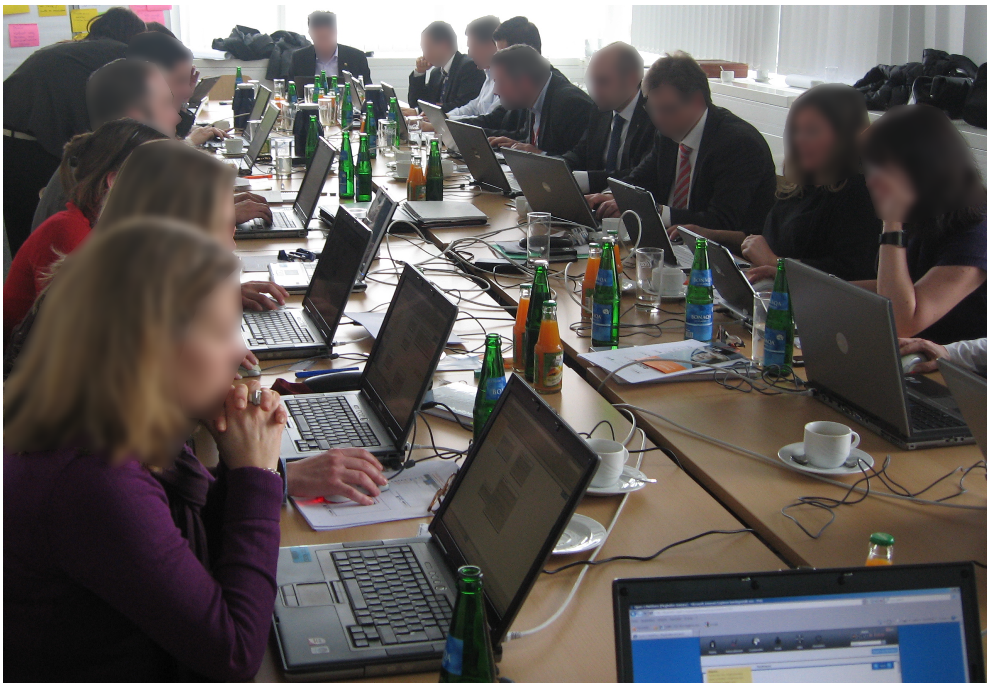

Figure 2.2: IdeaStream workshop in the Open-I project (anonymized)

The IdeaStream application, which initially came up with a web-based front-end, was then field-tested with different company partners in workshops. However, although the web-based front-end of IdeaStream was designed for a mainly distributed use, it was not only used in distributed, but also in collocated workshops. Figure 2.2 shows a photo taken during such a workshop. As can be seen, using laptops in this setting caused that the participants started focusing on their computers and lost the connection to other group members, leading to a break in communication and face-to-face collaboration. Hence, the fact that they were sitting around a tabletop did not play any role in this collaboration as all activity was shifting towards the IT system. In addition to the use of IdeaStream in these workshops, also traditional Brainstorming (based on index cards and a flip chart) was applied. When using these tools, the participants collaborated more actively and more verbal communication took place. This gave the main inspiration and impulse for conducting this thesis: thinking about a more tailored IT support for collocated creative collaboration situations than it is achieved by using a web-based application.

However, further discussion of different approaches of IT environments for supporting creativity (Section 2.3) is necessary to answer this question concretely. Before, the different (interplaying) dimensions of creativity (the 4P framework of Mel Rhodes [Rhodes, 1961]) are examined more closely.

2.2 The 4P of Creativity

In his influential article "An analysis of creativity" from the 1960's [Rhodes, 1961], Mel Rhodes argued that creativity is too complex to be investigated as a single entity. After analyzing the various published definitions of creativity and imagination, he determined that creativity should be regarded as a multifaceted concept, instead of giving a single definition for it. According to Rhodes, creativity can be seen as the interplay of **person**, **process**, and **press**, that lead to a creative **product** (the so-called 4P) [Rhodes, 1961, Fellers and Bostrom, 1993]. This concept is illustrated in Figure 2.3.

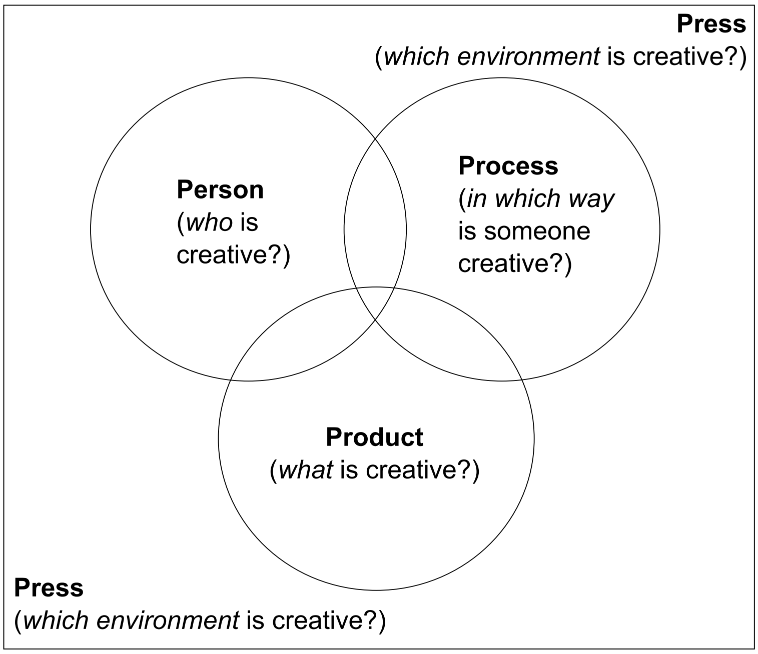

Figure 2.3: Mel Rhodes' framework - The 4P of creativity (adapted from [Couger, 1995, p.5])

- **The creative product:** Which criteria can be applied to judge if an idea or an artifact is creative?
- **The creative person:** Who is creative, and which attributes make some persons more creative than others?

- **The creative process:** What are the activities that lead to creative insights?
- **The creative press:** How does the environment / the context influence the other three dimensions?

The following sections present these four dimensions of creativity in more detail.

2.2.1 The Creative Product

A first question that comes to mind when thinking about creativity is, how can someone know that something is really creative? Taking into account related literature on this topic (e.g. [Scritchfield, 1999]), this "something" can be defined as a product or outcome of whatever kind. These outcomes can be concrete (e.g. images, texts, cars, songs) or abstract (e.g. ideas, concepts, theories). Furthermore, they can be created either collaboratively or by single individuals. Sternberg and Lubart define the creativity of such a product as "*work that is both novel (i.e. original, unexpected) and appropriate (i.e. useful, adaptive concerning task constraints)*" [Sternberg and Lubart, 1999, p.3]. In a similar way, Besemer and O'Quin [Besemer and O'Quin, 1987] describe the creativity of a product by three characteristics:

- **Novelty/Originality - What is the originality or newness of the product?**
  Novel ideas can be particularly desirable because they are important in distinguishing a firm from its competitors [Woodman et al., 1993]. Novelty can be measured by either calculating the frequency with which an idea is expressed within a given set of ideas or by the rating of users based on their personal notions in regard to the given problem [Garfield, 2008].
- **Usefulness/Feasibility - How does the product address the challenge it was created for?**
  The feasibility of an idea in the environment in which it is getting implemented also needs to be judged. For example if there are resource constraints, an idea which is easier to implement would get a higher feasibility than ideas which are harder to implement [Garfield, 2008].
- **Synthesis/Appropriateness - How does the product go beyond just addressing the challenge?**
  Typically, the appropriateness of an idea is assessed by its fit with the organizational goals [Garfield, 2008]. Even if ideas are novel and feasible, they might still be inappropriate.

In addition to these three characteristics, Monica J. Garfield highlights two more criteria for creative products: **Quality** and **Paradigm Relatedness** [Garfield, 2008]. Quality is obvious: no one wants to produce low-quality ideas/products. Judging the quality, however, can be very subjective and should thus be rated by experts [Ruscio and Amabile, 1998]. Paradigm Relatedness refers to a classification of ideas "*in a way that highlights the differences between them, without making a judgment about the extent to which they are creative*" [Garfield, 2008, p.754]. This way, different types of ideas can be equal in their creativity, although different in their expression.

2.2.2 The Creative Person

The cognitive process of being creative starts in the minds of individuals as they formulate the problem and start generating ideas to solve it [Van de Ven, 1986, p.590]. There are lots of approaches to the question which attributes make a person more creative than others. As stated by Puccio, attributes of a **creative person** refer "*to the skills, traits, abilities, and motivation that predispose an individual to be creative*" [Puccio, 2006, p.1].

Guilford regards creativity as an aggregation of four personal character traits [Guilford, 1950]: **Originality** (capability of expressing new ideas), **fluidity** (quantity of answers given to a question), **flexibility** (variety of answers provided) and **elaboration capability** (level of detail, definition, concreteness of the answers). An important finding of Guilford's research activities is that creativity and intelligence are - even though both are cognitive processes - fundamentally different abilities. While a certain minimal degree of intelligence is needed to be creative, a higher IQ value does not correlate with a person's creative performance. Even though different approaches to measure the creativity of a person were proposed (e.g. the Torrance test [Runco et al., 2011]), the significance of creativity tests is heavily disputed [Albert and Runco, 1999]. In addition, the reliability of creativity tests is weak, because people score different values on different days. Creativity seems to be a much less stable attribute than intelligence, which in turn raises the question of how to influence creative performance. These considerations led to increased research efforts in the other dimensions, in particular concerning the creative process and the creative press (cp. Sections 2.2.3 and 2.2.4).

Another problem with Guilford's definition was that he broke down the complex topic of creativity into four individual character traits. This was criticized by other researchers like, for example, Amabile, who noted that the social aspects of creativity should not be disregarded [Amabile, 1983]. In most cases of solving a creative task, people do not work in isolation. Instead they often work with others, as part of formal or informal groups, teams, or organizations [Drazin and Kazanjian, 1999, MacCrimmon and Wagner, 1994]. There are various factors which can have an impact on a team's creative output such as group diversity, conflict, and leadership. A more diverse group may, on the one hand, be more creative as the range of different perspectives on a problem broadens [Burnside et al., 1988]. On the other hand, this may (especially for newly composed groups) decrease the level of creativity as the group members are missing shared (past) experiences. Finally, another problem potentially hampering creativity are conflicts within a group.

In the following, several of the negative effects which can decrease group creativity in collaborating teams are again summarized [Applegate et al., 1986]:

1. **Group pressure**: Fear of judgment by the other group members and power imbalances (e.g. when different hierarchy levels participate) inhibit participation and can lead to unwanted conformity of idea proposals [Isaksen, 1998].
2. **Social loafing**: Social loafing describes the tendency of group members to do less than their potential would allow them to do. It can occur either if a group member feels isolated from the group or if he feels too submerged [Isaksen, 1998].
3. **Production blocking**: In [Diehl and Stroebe, 1991], the authors see production blocking as the dominant factor for efficiency losses in group brainstorming processes. Production blocking refers to the fact, that in verbally interacting groups, only one member can speak at a time, while the others have to listen. Hence, all but one member of the group are blocked and cannot work on their own ideas at this time.

In summary, the composition of a creative team and the manner in which such a team is interacting can play a significant role in a team's ability to produce creative products [Garfield, 2008]. Typically, such teams collaborate in a more or less structured process. The next section focuses on the characteristics of such creative processes.

2.2.3 The Creative Process

As pointed out earlier, this thesis is partially based on the theoretical discussion of Florian Forster's PhD thesis [Forster, 2010]. As Forster's central goal was to analyze the structure of creative processes for establishing a formalization in the style of a computer model, several sections of this chapter are adapted from his work.

The **creative process** concerns itself with how creativity occurs. It involves the mental activities a person or group goes through to reach a creative end [Puccio, 2006]. To gain a more formal definition, these mental activities need to be separated from processes, which are not creative at all. In an interview, Torrance defined creative processes in the following way [Shaughnessy, 1998, p.442]:

> "*I tried to describe creative thinking as the process of sensing difficulties, problems, gaps in information, missing elements, something askew; making guesses and formulating hypotheses about these deficiencies, evaluating and testing these guesses and hypotheses; possibly revising and retesting them; and finally communicating the results. I like this definition because it describes such a natural process.*"

In contrast to this informal definition of creative processes, research on creativity aims to formalize them more precisely in order to gain a better understanding and, as a consequence, to support them more optimally. In literature, mainly from psychological research, models for the creative process can be divided into **descriptive** and **cognitive** models. While descriptive models describe the creative process from an outer perspective, cognitive models regard it from an inner perspective.

Descriptive Models

In descriptive models, the creative process is described as a phase model being determined by a linear sequence of (mainly) cognitive activities. One of the earliest descriptive process models which is also regarded as one of the most famous ones, was introduced in 1926 by Graham Wallas [Wallas, 1926]. Seen from an outer perspective, a creative process (according to Wallas) starts with an initial problem (e.g. in the style of a question) and ends with a set of related solutions (e.g. ideas), which were generated in order to solve this problem. Wallas' model forms the basis for most of the creative thinking training programs conducted nowadays [Torrance and Sternberg, 1988]. Also many current day models of creative problem solving can be traced back to an adaptation of this early model [Aldous, 2007]. Due to its prominence, it is reasonable to describe Wallas' model in more detail:

Wallas suggested that a creative process is built on four sequential stages:

1. **Preparation:** The field in which a solution has to be found needs to be examined in all directions. For this purpose, the creative persons who participate need to be well prepared.
2. **Incubation:** Incubation means thinking about the problem in an unconscious manner. In this regard, Wallas noticed that good ideas often occurred when a period of time was spent away from the problem. Like the preparation, the incubation can last minutes, weeks, even years [Proctor, 2005].
3. **Illumination:** Illumination refers to the emergence (the "click" or "flash") of a new idea. Wallas suggested that resting the mind by doing other activities could help an idea to emerge [Proctor, 2005]. Such ideas can be partial solutions to the problem or the complete solution itself. The illumination stage is often very brief, leading to many insights within a short period of time.
4. **Verification:** In the verification stage, a (mental) validity check of the idea is carried out. It is checked if the ideas which emerged in illumination satisfy the need and the criteria defined in the preparation stage [Proctor, 2005].

As mentioned earlier, many other models emerged after Wallas' model was established. Examples are the models by Amabile [Amabile, 1996], Basadur [Bacot et al., 2000], and Osborne/Parnes [Parnes, 1992]. More detailed information and differences between these models can be referred to in [Forster, 2010].

An interesting observation regarding descriptive models of creativity is, that a general pattern can be found [Forster and Brocco, 2009]: the **sequence of two distinct phases** which are characterized as **divergent**, followed up by **convergent** phases. In divergent phases, answers in the form of ideas are generated and collected in order to answer / solve the initial question / problem. In convergent phases these ideas then get discussed, evaluated, and filtered (e.g. discarded or selected). VanGundy summarized this principle with the following statement: "*In the divergent phase, you just create entries, in the convergent phase you select hits or cluster to hotspots*" [Vangundy, 1992].

These two phases can be traced back to a theory introduced by Guilford [Guilford, 1967]. According to this theory, the combination of two patterns of human thinking, namely the ability to generate multiple solutions to a problem (divergent thinking) and the goal-oriented ability to deduce a single solution to a problem (convergent thinking), is mandatory for generating creative solutions. Nevertheless none of the descriptive models allows for practical conclusions on how to support each of the phases more explicitly (e.g. by IT) [Forster, 2010].

Cognitive Models

In contrast to descriptive models, cognitive models view creative processes from an inner perspective. Hence, this perspective aims to characterize more precisely the cognitive activities that happen during a creative process.

As pointed out by Forster in his PhD thesis [Forster, 2010], one the most representative examples for cognitive models is the Geneplore model by Finke et al. [Finke et al., 1992] (also cp. Figure 2.4), which is described within this section. Other less prominent examples for cognitive models can be found in [Forster, 2010, p.15]. According to the Geneplore model, creative thinking processes are characterized by the combination of two phases: the generation of so-called "preinventive structures" and their exploration and interpretation (*Focus Concept*).

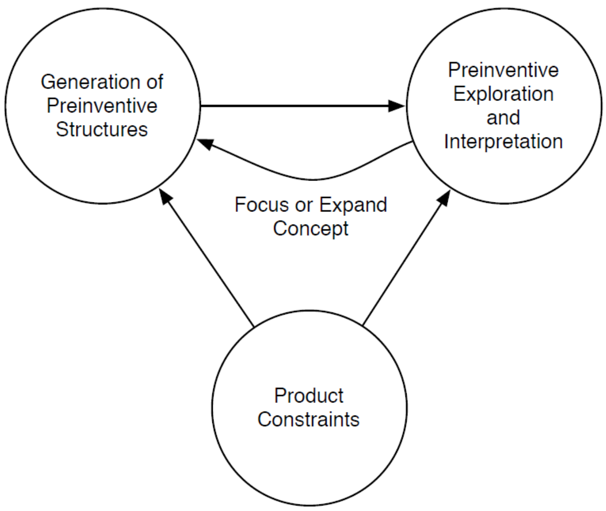

Figure 2.4: Geneplore model [Finke et al., 1992]

The term "preinventive structures" refers to new combinations or shapes that can be constructed from existing elements by forming associations, mental syntheses, and transformations. The model also proposes iterative loops in which results of an exploratory phase get injected into a new generative phase to generate further preinventive structures (*Expand Concept*). So called product constraints need to be taken into account during all phase transitions allowing the model to work for various situations and restrictions.

Kellyn Dunn and Samantha Roppolo give a more practical explanation of the Geneplore model [Dunn and Roppolo, 2010]: "*To gain a better understanding of the Geneplore model, one could draw a parallel to planting flowers. In relation to the model, a package of seeds could represent preinventive structures. In order to grow the flowers successfully, one must consider the product constraints including the flower pot's size and the climate. Pulling from previous gardening experiences and selecting the appropriate soil for the flowers are examples of concepts that would apply to the generative process of the model. Finally, the seed's germination defines the exploratory process. If the flowers fail to grow, one would reevaluate the amount of sunlight the flowers need or adjust the watering schedule. Ultimately, the success of the plant's growth is characterized by how one employs and combines these processes to produce a successful result.*"

Cognitive models give more concrete insight on how the activities that occur during a creative process can be characterized [Forster, 2010]. Nevertheless, cognitive as well as descriptive models do not allow for real insight into practical approaches to support creative processes. Both models only define a framework for creative processes and, because of their abstract nature, cannot be easily adapted into a model suitable e.g. for a computer system [Forster, 2010, p.16]. A more concrete approach used to support creative processes in practice are so-called techniques of creative problem solving (short: creativity techniques), which are addressed in the next section.

A Practical Approach: Creativity Techniques

A practical approach to support creativity, in which divergent and convergent phases appear, is in the use of creativity techniques [Forster, 2010]. Geschka defines creativity techniques as directives for a group or a person, which in their cumulative effect foster and encourage the generation of ideas (translated from German: "*Als Kreativitätstechniken ist ein Satz von Denk- und Verhaltensregeln für eine Gruppe oder ein Individuum zu verstehen, die in ihrer Gesamtwirkung das Entstehen von Ideen begünstigen oder anregen.*" [Geschka, 2006, p.992]). They are typically based on a set of certain rules, activities and constraints that aim at providing a more structured process for creative problem solving as a form of guidance. These rules include so-called heuristic principles such as forming associations, abstractions, analogies, combinations, variations, etc. As already included in Geschka's definition, creativity techniques can be used by individuals as well as groups. Most relevant to this thesis are **group creativity techniques**.

The oldest and probably best-known (group) creativity technique is the Brainstorming technique [Rickars, 1999]. Invented by the advertising executive Alex F. Osborn [Osborn, 1957], the Brainstorming technique is nowadays, according to a study by Fernald and Nickolenko [Fernald and Nickolenko, 1993], applied in 92% of the companies in the United States. Osborn found that in conventional business meetings the creation of new ideas is inhibited. To solve this problem, he proposed rules designed to help stimulate the generation of ideas in such meetings. In this context, he described Brainstorming as "*a conference technique by which a group attempts to find a solution for a specific problem by amassing all the ideas spontaneously by its members*" [Rickars, 1999, p.220]. The rules of Brainstorming are as follows [Osborn, 1957]:

- **Criticism is ruled out:** This includes self criticism as well as criticism of others. A judgment of the ideas should therefore be deferred until a later stage.
- **Freewheeling is welcomed:** The more radical the generated ideas are, the better.
- **Quantity is wanted:** If more ideas get generated, the probability of capturing a good idea and the chance that new ideas emerge from others will also increase.
- **Combinations / improvements of ideas are sought:** The aim is to elaborate on and expand the suggestions and ideas of others, using the ideas of others as inspiration for own ideas. Additionally, the combination of existing ideas can allow for the exploration of new ones.

Osborn showed that by applying these new rules, people's natural inhibitions which prevented them from putting forward ideas they might have considered "wrong" or "stupid" were reduced. Even more, he found out that generating those "silly" ideas could spark off very useful ideas because they changed the way people think. Due to its simplicity, popularity, and success, Brainstorming has been implemented in many IT applications supporting creativity ("Electronic Brainstorming" [Rickars, 1999, p.219]). Some of these IT systems are, amongst others, presented in Section 2.3.

However there exist many other creativity techniques beyond Brainstorming which are more complex in their process structure. The next part of this section gives an overview of different categories (and related examples) in which creativity techniques can be classified.

Closely related to Brainstorming is the 6-3-5 Brainwriting technique which was developed by Bernd Rohrbach in 1968 [Rohrbach, 1969]. In contrast to Brainstorming, where all participants act together synchronously, in this technique, each participant is working on his own. Initially, a sheet of paper is handed out to each participant. This sheet is prepared with 3 columns and 6 rows. Every participant is then asked to write down three ideas in the first row (= one idea in each column). After a certain amount of time (which is chosen according to the difficulty of the problem which needs to be solved) the sheets are passed to the next participant. Now the ideas written down in the phase before are sought to be improved. This step is repeated 5 times, until every participant has worked on each sheet of paper. This process is reflected in the name of the technique: 6 participants, 3 ideas, and 5 iterations.

Brainstorming, Brainwriting 6-3-5 and similar techniques are typically classified as **Techniques of Free Association** [Geschka, 2007]. Another class of creativity techniques are the **Techniques of Structured Association** [Geschka, 2007] in which the creative problem solving process takes place according to given patterns. A popular example is the "Six Thinking Hats" technique invented by Edward de Bono [de Bono, 1985]. It is based on the assumption, that the human brain thinks in several distinct ways which can be used for addressing particular issues of a problem. In this regard, De Bono identified six different states of the brain [de Bono, 1985] (each state has a color assigned to it):

- **Information (White):** Considering purely what information is available → numbers, data, and facts
- **Emotions (Red):** Instinctive gut reaction or statements of emotional feeling (but no justifications)
- **Bad points judgment (Black):** Logic applied to identifying flaws or barriers → dangers, difficulties, problems
- **Good points judgment (Yellow):** Logic applied to identifying benefits, seeking harmony → advantages, benefits, positive aspects
- **Creativity (Green):** Statements of provocation and investigation, seeing where a thought goes → creative thoughts, ideas, alternatives
- **Thinking (Blue):** Thinking about thinking ("meta thinking") → Superior aspects, moderation, and coordination of the other hats, drawing conclusions

The "Six Thinking Hats" technique involves the use of these metaphorical, colored hats in discussions. Each hat allows the group to think more deeply about a problem. Switching to a state is symbolized by the act of putting on such a hat, either literally or metaphorically. All states are taken by a group simultaneously (parallel thinking) and all contributions are "collected" under the respective hat. It is also important to differentiate between the different hats very thoroughly.

A third class of creativity techniques is **Configuration Techniques** [Geschka, 2007]. These aim at generating new solutions / ideas by pulling together already existing partial solutions to a problem. A prominent representative of this class is the Morphological Analysis, specifically invented for solving multi-dimensional, non-quantifiable problems [Ritchey, 1998]. Therefore, a problem is broken down into its essential sub-concepts (dimensions). For each dimension new ideas are generated. Finally, the ideas that were generated for each dimension are combined, forming a solution to the initial problem as a whole.

Confrontation Techniques stimulate creative idea generation by guiding the participants "out of the problem field". For this purpose, they use functional and structural principles from fields extraneous to the problem [Geschka, 2007]. Taking a different point of view can then result in ideas which are, for example, more radical. All variants of this technique conclude with a short Brainstorming phase, where all ideas are finally collected. Interesting examples of confrontation techniques are the "Visual Confrontation" and the "Random Stimuli Technique". While the first one uses images (e.g. photos, sketches, etc.), the latter uses words (e.g. terms, phrases) as confrontational elements. Such terms can be randomly picked from a book, for example. Confrontation techniques are often performed in groups in order to make use of mutual stimulation within the group (e.g. by verbal communication) [Geschka, 2007].

The last category of creativity techniques according to [Geschka, 2007], is **Techniques of Imagination**. These allow the problem solver to bring solutions into the problem solving process which are not really feasible. One example is the "Take a picture of the problem" technique [Vangundy, 1988] in which a problem gets analyzed "like watching it through a camera lens". Different elements of a problem can be focused and thus be viewed through different perspectives. These observations "sharpen" the comprehension of the relationships between the problem elements and therefore allow new solutions to emerge.

As has been shown, many different categories for creativity techniques exist, each including a nearly unlimited amount of variations and types of such techniques. However, not only the way how a creative process is supported can influence creative results. Around such a process, there always exists a creative environment (press). Different views on such creative environments are addressed within the next section.

2.2.4 The Creative Press

"*The term press refers to the relationship between human beings and their environment*" [Rhodes, 1961, p.308]. More precisely, the **creative press** "*refers to the **environment** the person is in, or the product is produced, or the process occurs. It is concerned with the climate and everything that affects the climate where creativity takes place. This is where creativity and creative behavior can flourish or be fatally hindered*" [Scritchfield, 1999]. The effects of the creative press are never stated as an exclusive source for creativity. Consequently, no single definition has emerged from this perspective. Instead, existing definitions for creativity (e.g. from person or process) have been extended by views on the creative environment. Hence, the creative press is always seen in **interdependency** with the other dimensions.

According to VanGundy [Vangundy, 1988], the creative press can be divided into three categories: **internal**, **external**, and **interpersonal relationships**. "*Internal relates to one's personal perceptions of the external climate. The external are the factors, physical and other, that exist all around the person, product or process. Interpersonal relationships with others is self explanatory*" [Scritchfield, 1999]. As the latter include social relationships and other social aspects of creative collaboration, they partially overlap with some views on the creative person. Summarized, the creative press can be seen as an individual's (or group's) physical and psychological surroundings in a broader sense.

Contemporary studies on the creative press primarily focused on the organizational climate / work environment in which creativity occurs (e.g. [Burnside et al., 1988, Amabile et al., 1996, Amabile, 1997, Ekvall, 1996]) and therefore have been gaining increased attention within the business sciences. The majority of those studies primarily examined factors that contribute to creative productivity. In a creativity-induced environment, the successful interaction and the relationship between the variables of person, product, and process can be observed. "*The environment in which an individual finds him/herself actuated the existence of creative behavior and performance radically*" [Antonites, 2003, p.86]. Torrance defined such a creative environment as a "responsive" surrounding that is fueled by curiosity [Torrance, 1995, p.28].

Nieman and Bennet [Niemand and Bennet, 2002] determined barriers to creativity in such an environmental context:

- **Social Environment:** "*The social environment entails all the variables affecting the human being, whether individually or in group format on a social or societal level*" [Antonites, 2003, p.89]. E.g. a lack of understanding and support for new ideas or an autocratic decision-making structure can influence creative behavior in a negative way.
- **Economic Environment:** Missing growth prospects, less financial support or a lack of risk taking can hamper creativity.
- **Physical Environment:** Continuous or isolated distractions (e.g. disruptive sound, climate, and energy) pose a barrier to creativity. Also routine or tasks which are related to each other slow down creative behavior.
- **Cultural Barriers:** The cultural context can influence creative behavior. E.g. in some cultures it is uncommon to ask questions or to question an issue.
- **Perceptual Barriers:** Perceptual blocks are barriers which prevent the ability to perceive things (objects and/or abstract figures) clearly and correctly [Antonites, 2003, p.92]. E.g. a customer may see a potential product different than its developer.

As pointed out by Monica J. Garfield [Garfield, 2008, p.751]: "*The creative press or environment is the context in which creative ideas are produced and explored.* [...] *For an environment to be conducive to creativity, the workplace should be encouraging of creativity (at the organizational, supervisory, and group levels)*". As one particular interesting facet of such a workplace, Garfield highlights computer systems supporting creative processes. These systems bring their own internal (and external) environments and thus affect the way in which teams work. Some computer systems for supporting creativity "*are more restrictive in nature than others, which may cause users to perceive the technical environment in which they are working as restrictive and thus less conducive to the creative process. Furthermore, the fit between the technical environment of the CSS and the organizational environment in which it is used will greatly impact the outcomes of the system use*" [Garfield, 2008, p.752].

Within the last two decades, many different IT environments for creativity support have emerged. Each of these environments involves different characteristics and supports different styles of collaboration. An in-depth look on and a discussion of those environments (and corresponding example applications) is given in Section 2.3. Before, the main definitions for this thesis, derived from the theoretical background discussed so far, are presented.

2.2.5 Definitions for this Thesis

In concluding the discussion of the 4P of creativity, it has to be restated that, like in a chemical reaction, the right qualities of all three dimensions **person**, **press**, and **process** must be present in order to establish **creative products**. Thus, this has to be particularly taken into account when designing an IT system for creativity support. As every dimension of the 4P can be (and has been) viewed and interpreted in numerous ways, there is a need to further frame (and define) the 4P within the scope of this thesis:

- **Creativity:** Creativity is the ability to create creative (or innovative) products. Although this ability is more or less expressed by individual persons, everyone possesses at least a basic ability to be creative.
- **Creative Product:** A creative product is always based on an idea in a broader sense. Hence, it can either be abstract or more concrete and manifest in arbitrary representations. A creative idea should also be novel and useful (at least for the persons involved in its creation and as it relates to the problem domain).
- **Creative Process:** A creative process is the sum of activities which focus on finding creative products. Such a process can be more or less formal and structured. If multiple persons participate in a single process, the process is called **collaborative**.
- **Creative Person:** Persons (and their related skills, motivation, and abilities) that are involved in a collaborative creative process. During this process, the persons are engaged in a **social situation** which influences the creative collaboration. A more detailed view on this social situation and its influence on creativity is given in Section 3.1.3.
- **Creative Press:** In the context of this thesis we define the creative press as the **IT environments** that are used to support creativity. An IT environment consists of the application itself, but also of different kinds of IT devices that are used to interact with the application. External factors of such environments are, for example, physical properties of the used hardware devices such as their display size or shape, but also technological constraints like networking capabilities or the way how a user interacts with the device. Different methods of IT support can influence the motivation and abilities of an individual, the perception of the IT environment (internal factors), as well as the social situation of and the collaboration within a group (interpersonal relationships).

The next section examines different historic and state-of-the-art examples of IT environments supporting creativity from a research (related work) perspective. These systems are commonly referred to as Creativity Support Systems (CSS) and have been studied since the early 1990s by CISE researchers [Farooq et al., 2005]. However, before, a classification of Creativity Support Systems is given.

2.3 Creativity Support Systems

2.3.1 Classification

Creativity Support Systems belong to the more general class of **Information Systems (IS)**. According to Krcmar [Krcmar, 2005, p.25], "*Information Systems are socio-technical systems, which involve human and machine components (subsystems) and which can be used toward the goal of an optimal provision of information and communication according to economic criteria*" (translated from German: "*Bei Informationssystemen handelt es sich um soziotechnische ("Mensch-Maschine"-) Systeme, die menschliche und maschinelle Komponenten (Teilsysteme) umfassen und zum Ziel der optimalen Bereitstellung von Information und Kommunikation nach wirtschaftlichen Kriterien eingesetzt werden*"). As pointed out by Paul Beynon-Davies, such systems exist as "*a natural consequence of the need for humans to communicate and coordinate their activity*" [Beynon-Davies, 2009, p.4]. Information systems may be categorized according to their application domain and the types of supported processes, but also according to the amount of people using the system. For this thesis, information systems supporting structured as well as unstructured creative processes are targeted. These systems are referred to as **Creativity Support Systems (CSS)** and are defined as "*computer-based systems that support individual- and group-level problem solving in an effort to enhance creative outcomes*" [Garfield, 2008, p.746].

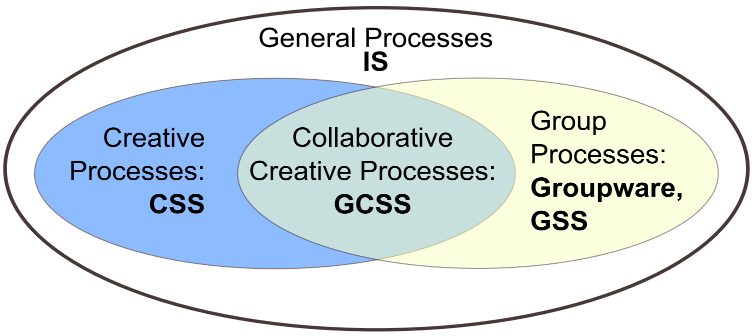

Figure 2.5: Types of processes and support systems (adapted from [Forster, 2010])

Creativity Support Systems have gained more and more importance as "*a growing community of innovative tool designers and user interface visionaries is addressing a greater challenge and moving from the comparatively safe territory of productivity support tools to the more risky frontier of creativity support tools*" [Shneiderman, 2007, p.22]. According to Ben Shneiderman, "*creativity support tools extend users' capability to make discoveries or inventions from early stages of gathering information, hypothesis generation, and initial production, through the later stages of refinement, validation, and dissemination*" [Shneiderman, 2007, p.22]. In this regard, Monica Garfield contends that a CSS "*can enable people to be more creative than they would be without using a system*" [Garfield, 2008, p.748].

As a CSS can be used by single individuals as well as by groups, for the scope of this thesis we want to (mainly) target systems which particularly support the collaboration of several participants. This class of systems is called **Group Support Systems (GSS)** or, in a shorter term, **Groupware**. One prominent definition for GSS is given by Nunamaker et al.: "*GSS are interactive computer-based environments which support concerted and coordinated team effort towards completion of joint tasks*" [Nunamaker et al., 1997, p.165]. The support of collaborative processes by IT-based Information Systems is more commonly known as **Computer Supported Cooperative Work (CSCW)** [Borghoff and Schlichter, 1998]. In contrast to Groupware which refers to the specific implementation of such systems, CSCW refers to the field of research concerning them. In Figure 2.5, the interrelations between the introduced classes of systems are again shown schematically. The main focus for this thesis lies on the intersection of GSS and CSS, namely (collaborative) **Group Creativity Support Systems (GCSS)**. To gain further insight into the environmental characteristics of GCSS, in the following two prominent classifications of Groupware are regarded.

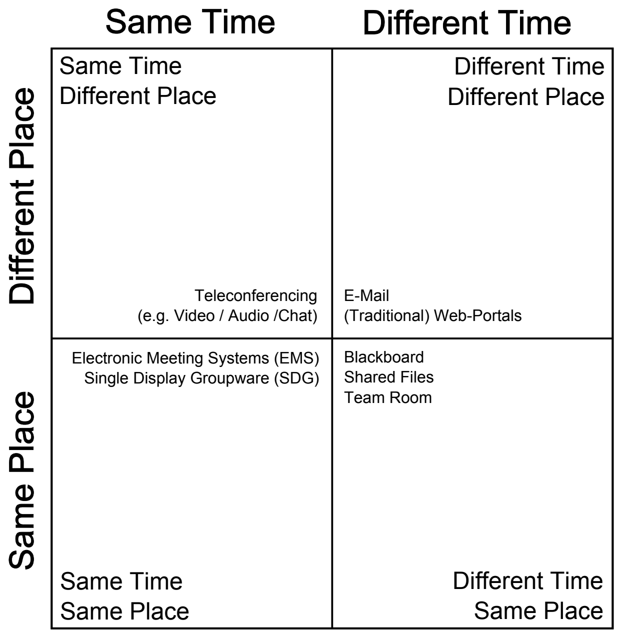

Figure 2.6: Robert Johansen's Four Square Model [Johansen et al., 1991,Gross and Koch, 2007]

The first is the Four Square Model by Robert Johansen [Johansen et al., 1991,Gross and Koch, 2007]. This two-dimensional taxonomy classifies Groupware according to the way how participants are distributed over space and time during the group process. Depending on their respective constellation, different types of electronic collaboration are more or less suited. The different pairs of situations which may occur are (1) Same Time/Same Place, (2) Different Time/Different Place, (3) Same Time/Different Place, and (4) Different Time/Same Place (cp. Figure 2.6). However, as mentioned in [Gross and Koch, 2007], flexible Groupware systems may also cope several of those squares at once.

While Johansen's matrix describes where and when interaction between group members occurs, it does not describe the functional relationships between the group members or between the group members and the IT system. As pointed out in [Gross and Koch, 2007], describing these relationships is important to grasp the environment of an IT application. To solve this issue, Dix et al. proposed the people/artifact framework [Dix et al., 1993] (see Figure 2.7). The directional and bi-directional arcs within Figure 2.7 indicate channels of communication either between participants **(P)** or between a participant and the work artifact. **Direct Communication** refers to the communication with words, which can be, for example, a verbal conversation, a letter, or an email. **Understanding** refers to the nonverbal communication between participants (e.g. by body language). **Feedback** is communication from the artifact to a participant as a result of an action performed on it by some other user in the system. Finally, **Control** is communication from a participant to the artifact (e.g. a command changing a system state). While all those ways of communication share one common goal, the construction of a **common understanding** [Gross and Koch, 2007], Dix et al. state two more different ways of communication: **Feedthrough** and **Deixis**. The first means communication through an artifact (e.g. when a participant gets notified after an artifact got manipulated by another participant). The latter means the communication to the artifact as a result of direct communication between the participants, usually resulting in a change of the system's state.

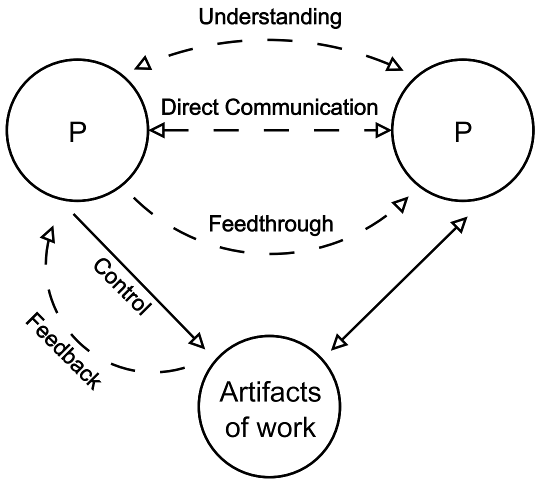

Figure 2.7: People/Artifact Framework (also known as Cooperative Work Framework) [Dix et al., 1993, p.465]

One important aspect of Creativity Support Systems is that the three different interaction modes of **communication**, **coordination**, and **cooperation**, according to which Groupware can also be classified [Sauter et al., 1994], all need to be supported [Hilliges et al., 2007]. This makes it a strong challenge on how to design such a system and how to support the different interaction modes as well as the functional relationships by IT. Other challenges which need to be faced when developing a Creativity Support System lie in the vague requirements for being creative and the unclear measures of success [Shneiderman, 2007]. That may be one reason why various applications and different types of IT environments for creativity support have emerged over the last years and decades. The next sections provide a brief overview on how Creativity Support Systems originated and which different types of IT environments are resembled by prominent state-of-the-art applications.

2.3.2 Electronic Meeting Systems

Early studies on the IT support of creativity focused on special IT environments to support creative processes in the style of meetings. Those so called **Electronic Meeting Systems (EMS)** were designed "*to improve group effectiveness, efficiency, and satisfaction*" [Nunamaker et al., 1991, p.41]. Nunamaker et al. define a meeting as "*any activity where people come together, whether at the same place at the same time, or in different times*" [Nunamaker et al., 1991, p.41]. A categorization of the domain of EMS (on the basis of Robert Johansen's Four Square Model) can be seen in Figure 2.8.

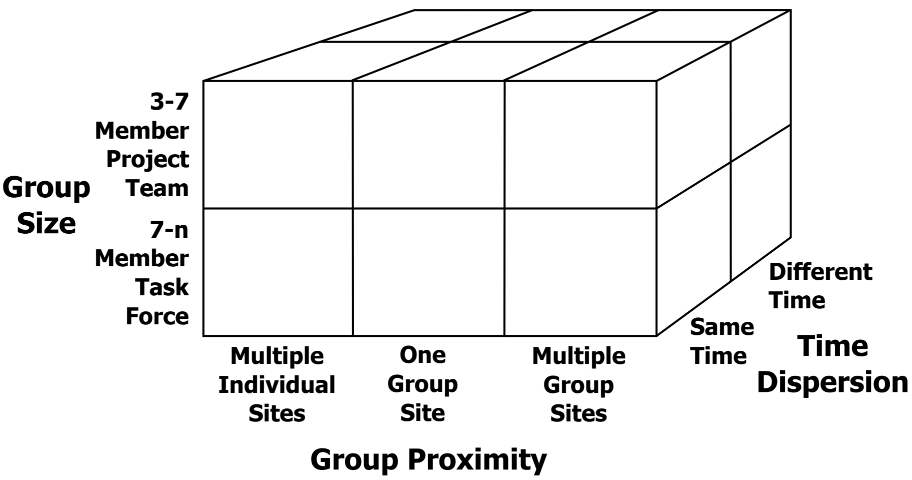

Figure 2.8: EMS Domain [Nunamaker et al., 1991, p.44]

Although Nunamaker's definition of a meeting may refer to a broad variety of different tasks, he also points out that many groups follow a common sequence when using an EMS in practice [Nunamaker et al., 1991, p.43]. This typical process fits into our definition of a creativity-technique based problem solving process. It starts with the generation of ideas in the style of a traditional (electronically supported) Brainstorming (30-45 minutes - divergent phase). Every participant can use his own workstation to enter ideas, while results are shown on a large-screen video display (or a wall projection) at a central, visible spot. Thereby, it is not marked who actually contributed which idea. One example for such an environment (in a same time/same place scenario) is shown in Figure 2.9. As the workstations are all networked, it is also possible that some users join remotely (same time/different place). In a next step of the applied process, the resulting ideas are organized into a list of key issues which then were prioritized by a voting mechanism (convergent phases). In a last step, another idea generation phase is imposed to establish an action plan ("*For each of the top 5-10 ideas, who can do what to accomplish it?*" [Nunamaker et al., 1991, p.44]). The process itself is typically guided by a dedicated meeting leader/facilitator standing beside the public front display.

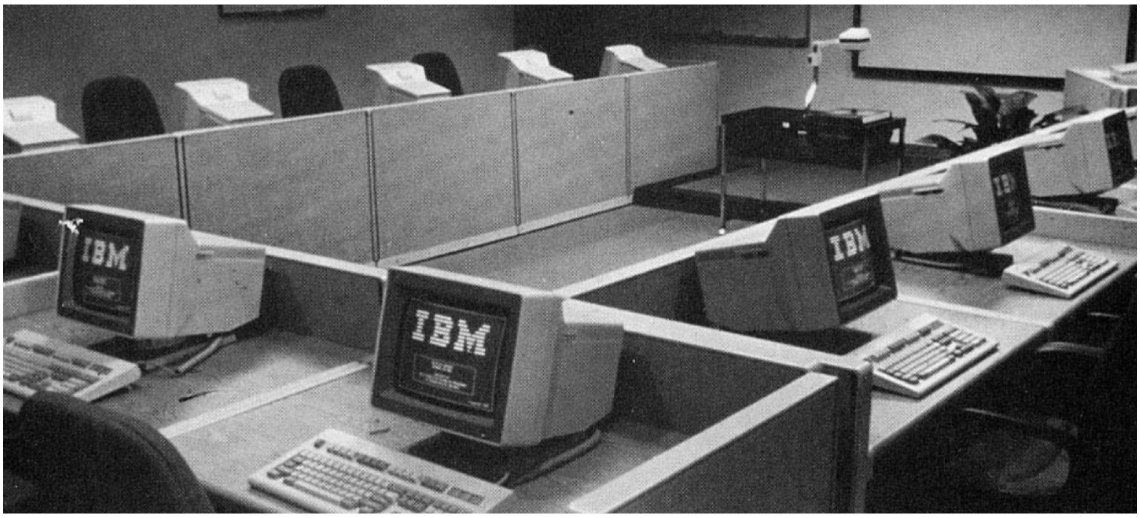

Figure 2.9: Electronic Meeting System at the IBM Decision Support Center, Boulder, Colorado [Nunamaker et al., 1991, p.42]

Nunamaker highlights several advantages of an IT support in the style of an EMS [Nunamaker et al., 1991, pp.43-44]. These, in some parts, can counteract the negative effects on group creativity introduced in Section 2.2.2:

- Simultaneous work of all participants (→ Less production blocking)
- Equal opportunity for participation (→ More anonymity → Less group pressure)
- Discouragement of behavior that can negatively impact meeting productivity (→ Less social loafing)
- Enabling of larger group meetings (→ More information, knowledge, and skills)
- Process support
- Access to external information
- Development of an organizational memory from meeting to meeting (→ Persistent data storage and contribution accounting)

Although research on and the use of such specialized Electronic Meeting Systems was quite popular in “the early days”, lots of technologies have changed the IT environments of today’s world. Within the next sections, some of these state-of-the-art examples are regarded.

2.3.3 Distributed (Web-Based) Applications

Nowadays, a popular way of (distributed) IT support are web-based applications. Since the World Wide Web (WWW) was made public on the 6th of August 1991 [WWW Summary, 2012], the number of websites has increased significantly [Netcraft, 2012]. Hence, it is not surprising that lots of web applications for creativity support have emerged. Within the last years, novel types of such applications showed up allowing for true synchronous collaboration by using technologies such as AJAX. In [Forster, 2008], Florian Forster analyzed popular (and online available) examples of such collaboration tools. More precisely, he regarded Bubbl.us [Bubbl.us, 2012], Google Docs [Google Docs, 2012], Mindmeister [Mindmeister, 2012], Skrbl [Skrbl, 2012], Thinkature [Thinkature, 2011], and ThinkTank 2.0 [ThinkTank 2.0, 2012]. It has to be said that apart from the applications discussed, there exists a broad variety of other collaborative and non-collaborative web-based CSS. Discussing all of these applications would go beyond the scope of this thesis. Hence, Forster’s work was taken as a state-of-the-art overview.

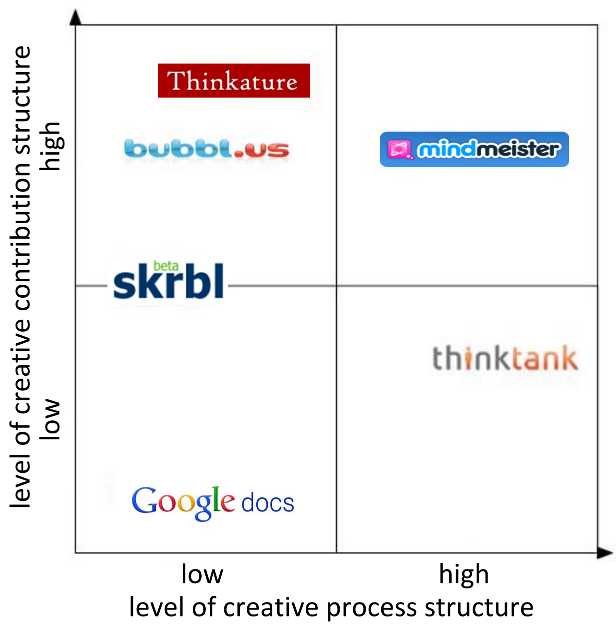

Figure 2.10: Classification matrix for web-based creative problem solving applications [Forster, 2008, p.285]

Forster classified the reviewed applications according to their level of process and contribution structure. The resulting classification matrix is shown in Figure 2.10. Tools with a high level of process structure can support creative processes explicitly or implicitly [Forster, 2008]. Implicitly means that specific functionality of a tool is activated or deactivated according to the principles of the process. Explicitly means that the process guidelines are explained in a direct (e.g. a textual) form. The analysis led to the insight that the level of contribution structure can be raised by several means. While some applications clearly separate contribution entities (e.g. by boxes), others include the possibility to define relations such as hierarchies, dependencies or arrangements between such entities. Others, in turn, also allow for different types of entities such as sketches, images or textual content. Next, Forster used the applications in workshops in a German mechanical engineering firm with groups of four engineers. Referring to the gathered user experiences, Forster points out that a higher level of contribution structure should be preferred, because a too simple idea model could hinder the expression of complex ideas [Adamczyk et al., 2007]. He also found out that less structured additional information such as comments may distract from the actual creative artifact.

Forster highlights that especially for applications involving a high contribution structure, IT support could provide advantages. All contributions are automatically saved and can be (electronically) processed in subsequent steps. This makes "*it easy to identify and separate the participant's ideas during and after the process*" [Forster, 2008, p.286]. In contrast, in tools having a low contribution structure (e.g. Google Docs), the assignment of contributions to participants can be problematic. Regarding the process structure, a low level allows for a flexible adaption to custom demands but also requires the participants to have previous experiences with creative processes so that no explicit guidance by the system is needed. Forster also states that high as well as low levels of process structure may have benefits: "*Tools with a high level of process structure need less coordination efforts in the group, though this usually means to be bound to one specific technique or process. Tools with a lower level of process structure allow a broader set of techniques to be applied, but also* [need] *a higher level of additional coordination in the group or even a dedicated facilitator.*" [Forster, 2008, p.288]. For all evaluated applications, the participants of his study stated that they needed some way to communicate with others. If a tool did not include such a communication channel, the participants felt hindered and isolated.

In his summary Forster remarks, that an application having both, a high process structure as well as a support for a variety of different techniques can be possible. Such an application would combine the advantages of both sides and "*could greatly enhance the creativity support of the applications*" [Forster, 2008, p.288]. For this purpose, Forster developed an own CSS - the IdeaStream application - which is explained in the next section.

IdeaStream

Based on the insights gained from his analysis of web-based CSS, Florian Forster developed an IT application being of particular importance for this thesis: **IdeaStream** [Forster, 2010]. Foundation of this application is a unified process model for creativity based problem solving processes derived from theoretical models (refer to Section 2.2.3), as well as an examination of over 25 different creativity techniques [Forster and Brocco, 2008]. The derived abstract process model can be seen in Figure 2.11.

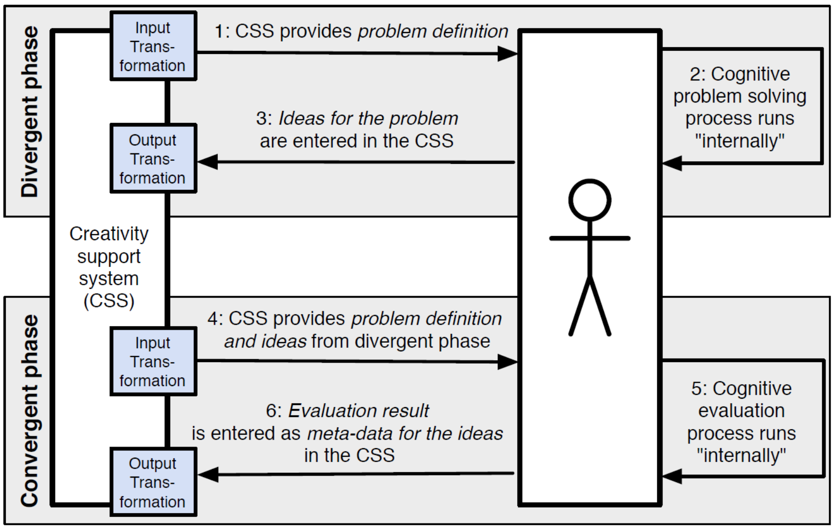

Figure 2.11: Model of the computer-supported creative problem solving process [Forster and Brocco, 2008, p.809]

It suggest that a creative process can be divided into convergent and divergent phases. "*In the divergent phase, the CSS has to provide at least a definition of the problem, and the response by the human is to be interpreted as idea for this problem. During the convergent phase, the CSS has to set the context for the user's evaluation process by displaying both the problem and the ideas from the previous divergent phase. The user's response during this phase has to be interpreted not as ideas, but as data about the ideas (meta-data)*" [Forster and Brocco, 2008, p.809]. Respectively, a creativity technique can be modeled as a sequence of several of such convergent and/or divergent phases. Next, Forster concretized his model "*for being used in the context of a computer system*" [Forster and Brocco, 2009, p.4]. This computer model, which is presented as a class diagram in Figure 2.12, as well as the built on IdeaStream application are of particular interest, as they are used as a basis for the main application developed in the scope of this thesis. Therefore, it is worthwhile to describe both in more detail.

As can be seen in Figure 2.12, divergent and convergent phases are represented by the classes `DivergentPhase` and `ConvergentPhase` which extend from a more general `ProcessPhase` class. The `ProcessPhase` can (* must) contain the following attributes [Forster and Brocco, 2009]:

- `problem (*)`: The problem that should be solved within the current phase, e.g. represented by a textual description.
- `participants (*)`: The persons (the users) that are participating.
- `ideas (*)`: The ideas of the respective process phase. For divergent phases, the set

of ideas is usually initialized empty while for convergent phases, it is initialized with ideas resulting from a preceding divergent phase, so that these ideas can be evaluated. This implicates specific requirements for the representation of an `idea`. For divergent phases ideas are modeled as a flexible construct which can contain (combinations of) sketches, texts or images. For the convergent phases ideas are attributed with meta data such as scores (numerical values), comments (text), or both.

- `timelimit`: Time limits, typically represented by an integer value, store the remaining seconds for a phase. If there is no time limit required, the attribute stays empty.
- `anonymous`: Further information if a phase is being conducted anonymously. Shame or fear of rejection can inhibit the expression of more radical ideas in divergent phases while in convergent phases, group pressure can influence the voting behavior. It has been shown that these negative effects can be avoided by allowing for anonymous contributions [Connolly et al., 1990].

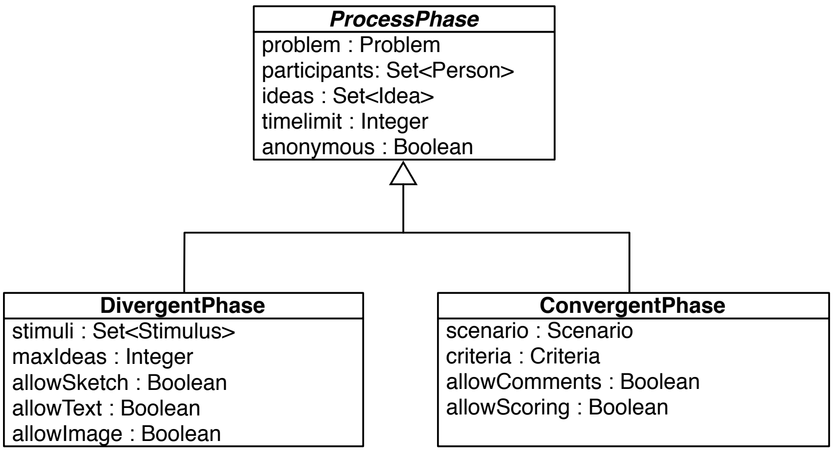

Figure 2.12: Class diagram of a creativity-technique based problem solving process in IdeaStream [Forster and Brocco, 2009, p.618]

Divergent and convergent phases extend from the base `ProcessPhase` class and gain additional attributes:

For divergent phases (`DivergentPhase`) those are `stimuli`, `maxIdeas`, `allowSketch`, `allowText` and `allowImage`. Depending on the creativity technique, a set of related (mental) stimuli has to be presented to the participants. Stimuli are only rarely defined by the creativity technique itself, but are often contributed in previous (divergent) phases (e.g. in the Random Stimuli technique). For this purpose, the `Stimulus` class is modeled similar to ideas and can consist of texts, images or sketches. The `maxIdeas` attribute limits the number of ideas that may be generated. If there is no limit, the value is left empty. The last three attributes (`allowSketch`, `allowText`, and `allowImage`) regulate if the corresponding features are allowed for expressing an idea.

To rate and select ideas in the convergent phases (`ConvergentPhase`), a `scenario` defines a context for the idea evaluation. This context is formulated and judged with respect to a certain `criterion` (e.g. leading to an overall evaluative question "How feasible are the ideas in scenario XYZ ?"). Those criteria can be defined in the technique itself, or be generated by the participants in a preceding (divergent) phase. `Scenario` and `criterion` can also be empty. In this case, the idea is to be evaluated as a whole. As already mentioned earlier, ideas can be evaluated by comments or scores, enabled or disabled by the attributes `allowComments` and `allowScoring`. Finally, if scoring is allowed, an upper limit for a score can be set (ranging from 0 . . . `maxScore`)

In the following figures, instantiations (examples) of Forster's model are shown and explained. Examples for other techniques can be found in [Forster, 2010].

Brainstorming is modeled as a single divergent phase, because one of its main principles is to avoid the evaluation of ideas during the idea generation phase (Section 2.2.3). The Brainstorming rules (e.g. "Wild and unusual ideas are welcome") are included in the supplementary information presented with the problem attribute (#P). In the traditional Brainstorming technique, no further restrictions are made and thus, no other attributes are needed. Variants like the Brainsketching technique would set `allowText` / `allowImage` to false and `allowSketch` to true.

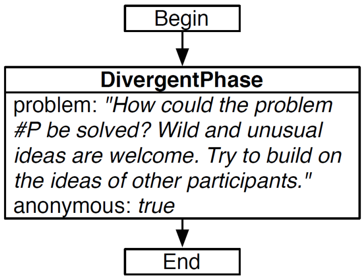

Figure 2.13: Brainstorming [Forster and Brocco, 2009, p.620]

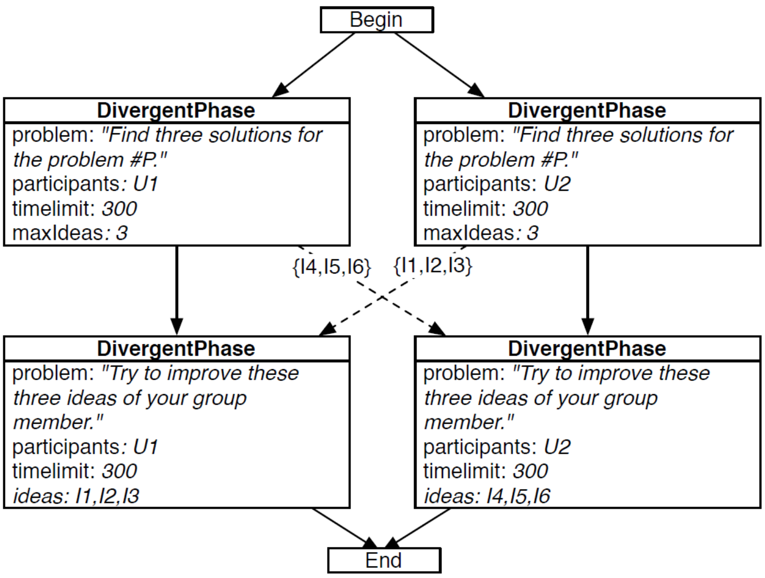

Figure 2.14: Brainwriting 6-3-5 [Forster and Brocco, 2009, p.620]

Another example for creativity techniques is the Brainwriting 6-3-5 technique (Section

2.2.3). Figure 2.14 shows the instantiation of this technique according to Forster's model. `U1`, `U2` in the figure resemble two participants. In a first round (upper two phases), they are asked to find three solutions to the given problem. Each participant has to work separately on his/her ideas, so `U1` and `U2` are in separate phases (`participants` attribute). The technique also imposes a time limit of five minutes (cp. value of 300 seconds for the `timelimit` attribute). An upper limit of three ideas is set within the `maxIdeas` attribute. When the time limit has exceeded, the ideas generated by the participants are exchanged and placed in the `ideas` attributes of the next phases. The participants are now asked to improve the received ideas instead of generating completely new ones.

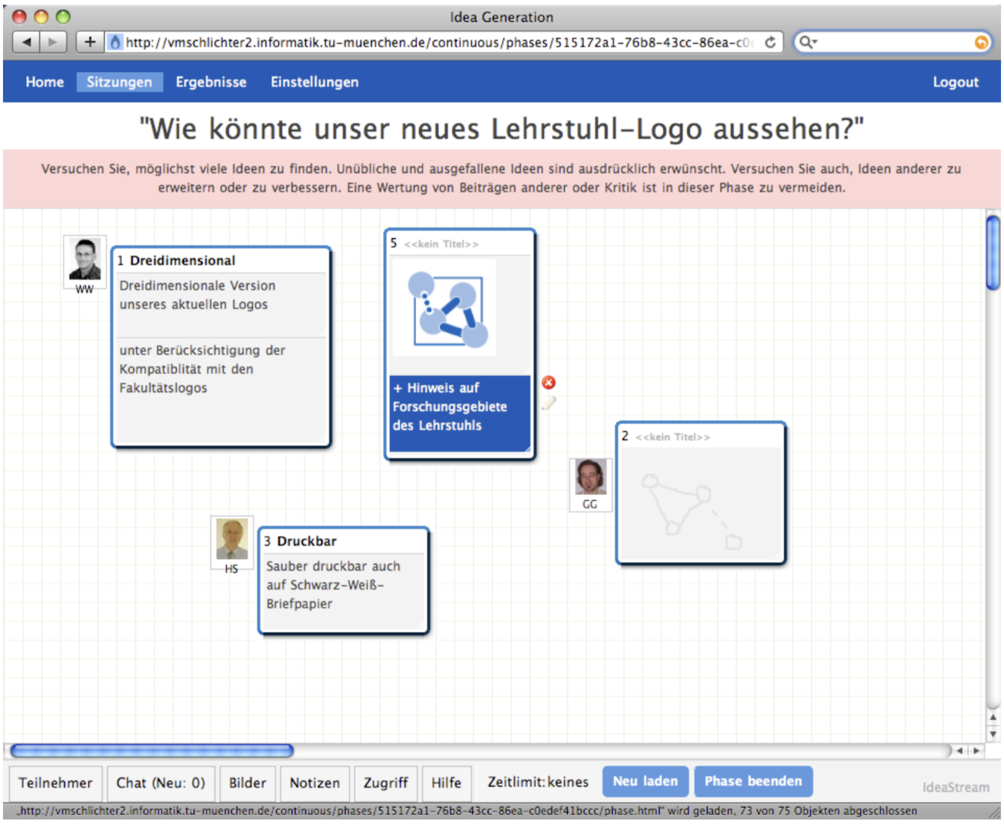

Figure 2.15: IdeaStream web client (divergent phase) [Forster, 2010, p.112]

To validate the process model and to conduct experiments, a web interface was implemented for IdeaStream. In divergent phases (idea generation), the ideas are created and modified on a **virtual whiteboard**. This can be seen in Figure 2.15. The whiteboard allows teams to collaborate (mainly) synchronously via AJAX [Forster, 2010]. This way, all user-actions are synchronized in real-time, so that other users (who are remotely participating) see what is currently happening. For example, when another user is editing an idea, his/her photo is shown for the time being. Ideas on the whiteboard can either be created, modified, moved, copied, or deleted and are publicly accessible to all session participants. An idea is, in analogy to Forster's model, represented by a title and a set of components called aspects that contain pieces of information, which in turn compose the idea. To allow for a certain flexibility, these pieces of information can be texts, uploaded images, or sketches. By clicking on an idea-card, a mode for editing its contents gets activated, allowing a user to either enter text (via keyboard) or to sketch (via pointing the mouse).

Images are uploaded to an area in the toolbar at the bottom of the screen (see Figure 2.15) and can then be dragged to the whiteboard. The toolbar also contains a list of all users that are currently participating in the session, a chat (to communicate with others), an area to write private notes (which can be "pushed" to the whiteboard as new ideas), and a tab showing information about the current session agenda (when clicked). For the moderator, a special user which controls the flow of a session, there exist two more buttons, one for setting access restrictions and one for ending the current phase. Finally, a field is reserved for the time limit, in case it is required by the creativity technique.

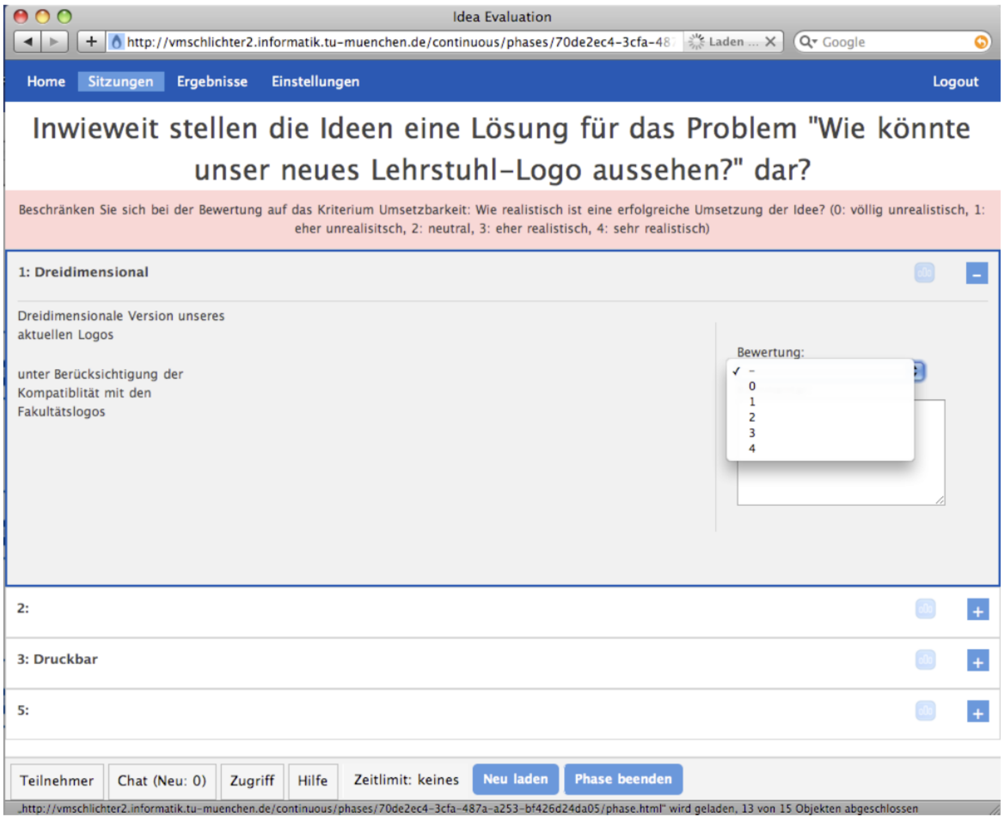

Figure 2.16: IdeaStream web client (convergent phase) [Forster, 2010, p.112]

For convergent phases, the whiteboard is discarded in favor of a list view of all previously generated ideas. Such a list is shown in Figure 2.16. Unfolding a list entry by clicking on the "+"-shaped button allows to review the respective idea and to select a rating score. Furthermore, for some convergent techniques, a field for a textual comment or rating is provided. In contrast to divergent phases, convergent phases are typically not performed collaboratively. Each user is rating the ideas for his own, without knowing anything about the ratings of others. Nevertheless, the chat is still available for mutual coordination.

Figure 2.17: Mobile web client of IdeaStream [Forster, 2010, p.113]

IdeaStream also comes along with a mobile web client developed for smartphones which have a JavaScript capable browser (Figure 2.17). Due to restrictions in screen resolution and size of such devices, a list view of the ideas is used for idea generation (instead of a whiteboard). This list view also works synchronously and can be used in the same session with users working from the whiteboard on traditional PCs. However, this is quite a novelty for mobile devices, as nearly all existing applications (see next section) only work in single-user modes with collaboration only being possible by sharing artifacts asynchronously.

2.3.4 Applications for Smartphones and Tablets

Smartphone applications, so called apps, became popular over the last years with the commercial launch of the Apple iPhone in 2007 [Honan, 2007] and the unveiling of the Android distribution on 5th November 2007 [Open Handset Alliance, 2007]. Closely related to smartphones are touch-based tablets like the iPad.

A first category of creative applications on such devices targets scenarios related to several types of artistic work. First, there are **sketching and image processing** applications like Adobe Ideas [Adobe Ideas, 2012] (Figure 2.18 - Item 1), ZeptoPad [ZeptoPad, 2012] or Autodesk SketchBook Pro [Autodesk SketchBook Pro, 2012] (iPad only). These applications typically present an open space (often also called whiteboard) on which a user can draw sketches. Depending on the application the way to create those sketches can differ. E.g. ZeptoPad uses vector-based graphics which can, for example, be used to draw lines. In contrast, in Adobe Ideas the user paints on the display with his fingers.

Figure 2.18: 1) Adobe Ideas [Adobe Ideas, 2012], 2) SimpleMind Touch [SimpleMind Touch, 2012], 3) Evernote [Evernote, 2012]

Another category of applications which support creativity on mobile devices are **note taking tools**. This use case may be especially important when an idea emerges en route. A prominent example for such an application is Evernote [Evernote, 2012] (Figure 2.18 - Item 3). According to its web page [Evernote, 2012], Evernote "*lets you create notes, snap photos, and record voice memos that you can then access any time from your iPhone, computer, or the web*". A more complex variant of this application class are mind mapping tools such as SimpleMind Touch [SimpleMind Touch, 2012] (Figure 2.18 - Item 2) or Thinking Space [Thinking Space, 2011]. According to Tony Buzan [Buzan and Buzan, 1995], a mind map has four essential characteristics:

- The subject of attention (e.g. the problem to solve) is crystallized in a central image.
- The main themes of the subject radiate from the central image on branches.
- Branches hold a key image/word printed on the associated line - details radiate out.
- The branches form a connected nodal structure.

Hence, mind maps are a graphical method for note taking and structuring content, but not really a creativity technique. Due to their characteristics they help to bring ideas into a certain order (hierarchical or tree branch format) and are often combined with colors or symbols to distinguish those ideas. Many mind map applications can be synchronized with a corresponding desktop or web application. Obviously there also exists a variety of other creativity support tools on modern day smartphones and tablets (e.g. in regard to music performance [Ocarina, 2012, Rectable mobile, 2012]). Regarding all would, as with web-based applications, go beyond the scope of this thesis.

The process and collaboration support in most of the smartphone applications is generally very low. They just provide a sandbox for creative tasks. They also do not provide any means for "true" synchronous collaboration. The smaller screen size may be one reason why smartphone based applications are typically used by single users only. The collaborative part comes into play, when users synchronize their creative artifacts with the web or share them via email. An exception may be the support of communication, either by using the smartphone as a traditional telephone or by using apps which allow for messaging or voice conferencing. However, although applications designed for pure smartphone/tablet use are often very less collaborative, such devices can be a valuable improvement in a completely different scenario: collocated IT environments. How and why is discussed (among others) within the next section.

2.3.5 Single Display Groupware and Multi Display Environments

As mentioned in Section 2.3.2, early Electronic Meeting Systems often combined networked PCs and a central, publicly visible wall projection. Building on these scenarios, a novel type of IT support emerged which is seen as promising for supporting collocated collaboration [Stewart et al., 1999]. Such so called **Single Display Groupware (SDG)** systems are defined as "*computer programs that enable co-present users to collaborate via a shared computer with a single shared display and simultaneous use of multiple input devices*" [Stewart et al., 1999, p.286]. An important difference to Electronic Meeting Systems is that all participants collaborate directly around or in front of a single and shared display. Such a single public display can be, for example, equipped with several keyboards for parallel input. More novel applications use pen or touch based input for interacting directly with the display. Stewart notes, that SDG is potentially useful in the creative domain, "*where users are involved in a creative, expressive, or constructive task such as writing, drawing, artistic expression, programming, and brainstorming*" [Stewart et al., 1999, p.290]. More novel studies propose special types of SDG devices using horizontal and multi-touch capable tabletop displays and therefore allow for direct and concurrent (e.g. pen or touch based) input.

But there exist also cases, where the large SDG display is combined with other devices. Such so called Multi Display Environments exist in different variations. First, there are applications which combine several SDG devices (e.g. tabletop and wall displays) for different types of collaborative activities. Second, in other examples, mobile devices such as smartphones or tablets are used in context of the large display. What is common in all of the second examples is that the single shared display is used as focus point for the group collaboration and cannot be completely substituted by the functionality implemented on the coupled mobile devices. This section focuses on some prominent examples for collaborative (collocated) CSS building on SDG and MDEs.

A first category of applications which in particular showed up on tabletop displays,

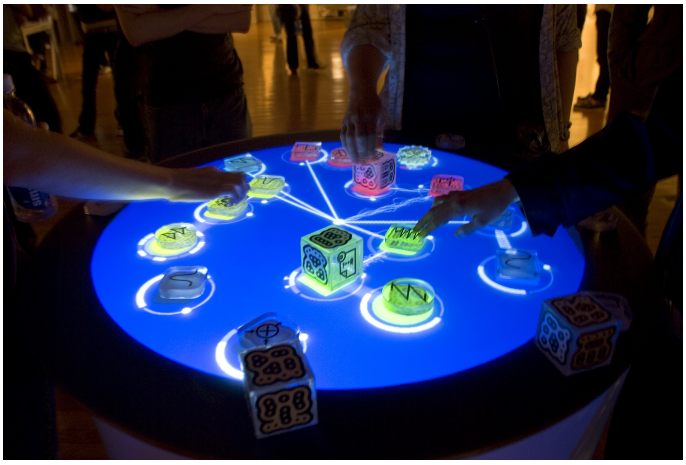

Figure 2.19: The reacTable [Jordà et al., 2006]

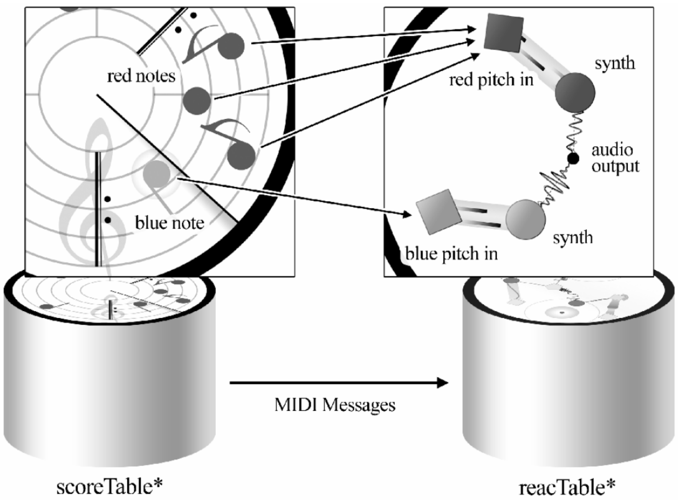

Figure 2.20: scoreTable and reacTable [Jordà and Alonso, 2006]

supports creativity in a more artistic definition. A prominent example to name in this context is the collaborative creation and performance of electronic music with the reacTable [Jordà et al., 2006] (see Figure 2.19). This application even gained popular interest far beyond academic scope (e.g. in live performances) and has also been ported to different types of mobile devices, such as the iPad or the iPhone [Rectable mobile, 2012]. The reacTable is a multi-user instrument portraying a modular synthesizer. Users can add entities for signal processing by placing certain physical objects on the table (so called tangibles) and modify their parameters by physical interaction. Physical interaction in this context means turning or moving such a physical object and interacting with the tabletop surface by using gestures. The signal flow is represented by the topological relationship between objects. However, the objects that the application features are strictly limited to real-time triggering of note events and real-time articulation. There do, however, also exist objects for very basic sequencing. As an extension to the original reacTable, the scoreTable [Jordà and Alonso, 2006] allows for the composition of note events, but as it is intended to accompany reacTable (Figure 2.20), it neglects the sequencing of their articulation. On the scoreTable, tangibles can be positioned in a circular looping stave on which a radar sweep rotates. This sweep triggers the corresponding note each time it passes a note puck. The pitch is controlled by the distance of a tangible to the center of the table, whereas its angular position determines the onset time of the event. There exist several other tangibles, e.g. for setting global parameters such as the tempo or loop points of a phrase. The space on the table can be divided into four areas that are differently colored for four part writing. The scoreTable follows a spatial approach for composition; the positions where objects are placed determine their values and their functionalities. Other research projects on a support of artistic creativity, which shall only be mentioned as further examples, targeted collaborative video editing [Terrenghi et al., 2008] as well as the collaborative selection and post processing of images [Terrenghi et al., 2006].

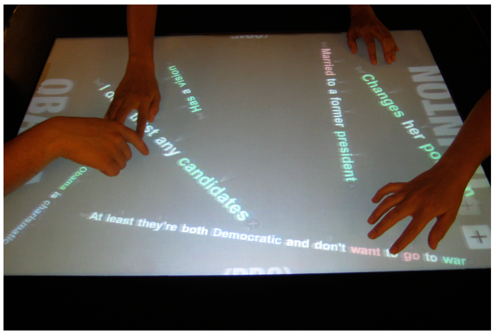

Figure 2.21: The Wordplay application [Hunter and Maes, 2008]

More important is another category of tabletop applications which addresses creativity techniques more directly. The first example, developed by Seth Hunter and Pattie Maes, is a tabletop interface for collaborative Brainstorming and decision making [Hunter and Maes, 2008]. The system includes support for two types of meetings: deciding between a set of alternatives and idea generation. In regard to decision making, the application allows for setting a dynamic background that can be for example a matrix where ideas are positioned in. An idea is represented just as single block of text that can be edited, moved or deleted. Within this setting, the orientation of an idea corresponds to the user who created it and its size reflects the importance of the idea. Input of text is realized via speech recognition and, to compensate errors within the speech recognition, via a scalable multi-touch keyboard. In addition to just generating ideas, the system is connected to a database of semantically related terms which aids in finding additional associated ideas within the same context. This feature gets triggered by doing a "stroke" gesture over already existing ideas. According to the study by Hunter and Maes, a three month long-term evaluation realized by lab demos, museum events, and group internal usage, multi-touch computing seems especially suited to augmenting collaborative discussions within social conversation spaces because of the fluid interaction with the application. Unfortunately, except of the implementation of simple Brainstorming in the style of entering phrases, no approach of supporting other creativity techniques or a higher process structure was given. Furthermore, the single on-screen keyboard as well as the speech recognition lack true multi-user collaboration support.

In another example, an exploratory design study by Geyer et al. [Geyer et al., 2010], a combination of an interactive tabletop device and digital pen and paper technology was

Figure 2.22: Theme access token, digital pen & paper, and zoomable pin board [Geyer et al., 2010, p.261]

evaluated. Fur this purpose, the IT environment was used in full-day creativity workshops conducted with professionals from creative industries. They used a creativity technique similar to de Bonos "Six Thinking Hats" (Section 2.2.3) where each participant is assigned a different role. Additionally, different themes of stimuli (e.g. collections of inspiring images) are provided and the technique is applied on different tasks. Roles as well as tasks are assigned randomly. Several user interface (UI) elements of the resulting application can be seen in Figure 2.22. The main input mechanism works via digital pens that are able to track texts / sketches written on specially marked sheets of paper. The tracked data can then be transmitted via Bluetooth to the tabletop application. The user interface on the tabletop surface is similar to a zoomable pin-board. There, images and idea scribbles can be clustered according to the provided stimuli-themes. Additional color-coded physical tokens are used to access the available topics as well as to switch between two application modes. By placing a token on a topic cluster it gets activated and the included ideas are shown. Each sheet of paper is assigned to a specific cluster by the special markers on it, which are noticed by the digital pens. If no token is placed on the tabletop surface, the application switches to the presentation mode. The participants rated the tool as fun and intuitive and stated that they could see benefits for creativity workshops. The possibility of parallel input, the zoomable pin board, and the increased group awareness were rated as the most positive aspects. However, the participants experienced that the zoom is only useful when one member takes the role of a presenter and the rest of the participants is watching. They also stated that the novelty of the applied technology combination (mainly due to the digital pens) was distracting.

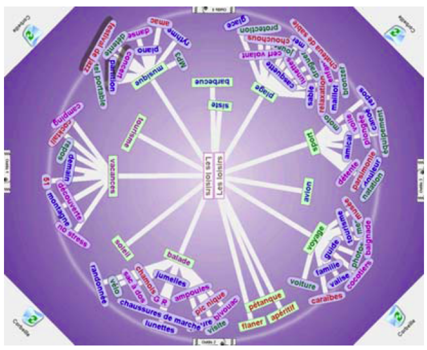

Figure 2.23: Mind map created on a tabletop device [Buisine et al., 2007]

In the next example, Stéphanie Buisine et al. [Buisine et al., 2007] investigated the usability and usefulness of interactive tabletop technology to support group creativity in the style of collaborative mind mapping (see Section 2.3.4 for a description of a mind map). The respective tabletop application is therefore adapted to this interaction scenario. A session starts with a fixed root label in the center of the table, containing the initial field to explore. For different view angles, this label is duplicated and rotated along a symmetry axis (see Figure 2.23). The mind map is then built top-down. A node is created by using a doubletap-and-drop interaction which was judged as natural and easy to perform with direct manipulation. A node's background color represents its level in the hierarchy. Furthermore, nodes can be positioned freely on the tabletop's surface. For entering the label of a node, only text input from a single source was implemented. Although this input was not possible in parallel, Buisine's experiment showed, that a "*tabletop system enabled a better collaboration: while the control condition showed strong leaders and followers, in the tabletop condition the participants collaborated in a better-balanced way*" [Buisine et al., 2007, p.30].

Figure 2.24: Tabletop environment for Brainstorming [Hilliges et al., 2007]

Hilliges et al. [Hilliges et al., 2007] investigated design guidelines for and implications of using a tabletop device in combination with a large wall display for face-to-face group Brainstorming. The developed application and the corresponding setting can be seen in Figure 2.24. Ideas in Hilliges' application are represented in the style of post-its, as they are commonly used in traditional Brainstorming. Text-input is realized via digital pens but without any optical character recognition. In addition to the tabletop device, a wall-display is included that mainly acts as a supplementary information space for the grouping of ideas. That's why the application can already be seen as as one example for Multi Display Environments. In context of their work, Hilliges et al. conducted an experiment involving 30 participants. This was then compared to the same creativity technique without IT support. In the evaluation they found that the quality and number of ideas generated with the tabletop application was similar to the traditional paper-based Brainstorming, while the perceived quality of the results was slightly higher in the IT-supported setting. Furthermore, they found that using a tabletop workspace for creativity support creates a socio-technical environment which positively affects collaborative creative problem solving.

Like in Hilliges' example, large shared displays are not always seen in isolation. However, in most other studies, SDG environments are enriched by smaller mobile devices of varying kind. In the following, only examples related to creativity support shall be described. A more comprehensive examination of these applications beyond the scope of creativity support is made in [Frieß and Kleinhans, 2011].

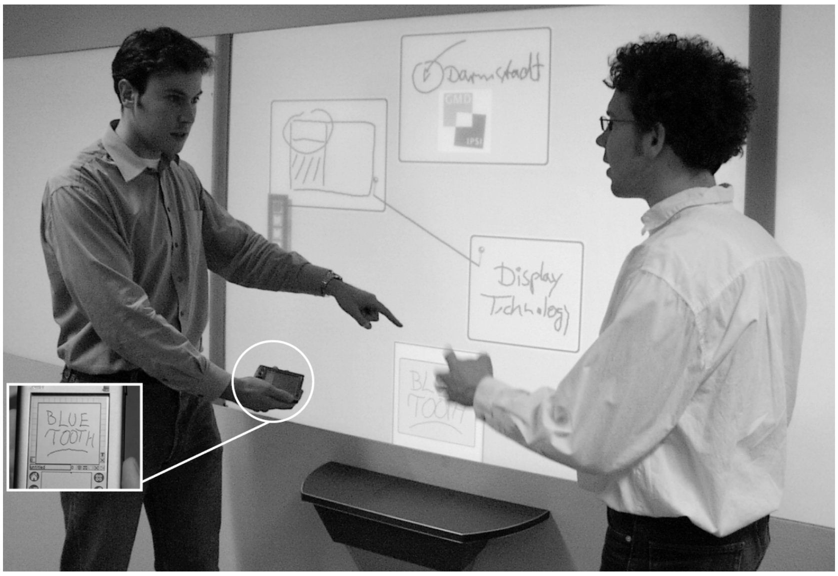

Figure 2.25: Coupled PDAs for Creativity Support [Magerkurth and Prante, 2001]

Magerkurth and Prante regarded the use of PDAs for creativity support [Magerkurth and Prante, 2001]. The PDAs were used as input device for collocated creativity sessions in front of a large virtual wall (see Figure 2.25), but also for individual idea collection outside the (direct) temporal and spatial context of a creativity session (e.g. in a preceding incubation phase). In this regard it was emphasized that ideas can emerge everywhere and every time, especially if someone is not focused directly on solving a problem. The PDA application includes two views, one for creating/editing an idea by drawing sketches, inserting texts, and assigning a title, while in the other, ideas can be clustered on a virtual pin board. Such a cluster can then be transmitted to a larger virtual wall to present the ideas to a broader audience.

Another study closely related to creativity support used a multi-device approach for supporting informal meetings in front of a digital whiteboard [Rekimoto, 1998]. The corresponding IT environment included a handheld computer for each participant which serves as a tool and data entry palette. Data (texts, drawings) which is entered on the tablet can then be transfered to the whiteboard (and vice versa) by a "pick-and-drop" operation: "*A user first taps the pen on an object in the first display, then taps again on another display. During this operation, the pen virtually "holds" the data providing an illusion of manipulating digital data as if it were a physical object*" [Rekimoto, 1998, p.346] (cp. Figure 2.26). As the author points out, the multi-display approach is similar to a specific Brainstorming methodology, namely the KJ-method, in which participants first write ideas on small cards and then spread them to a table for organizing them in the group. In addition to the private input of data, Rekimoto also proposes to use the coupled displays as a way to access existing personal data: "*A user can search for data on his/her own PDA, without disturbing other participants' activities*" [Rekimoto, 1998, p.346]. The author concludes that coupled displays can help to separate personal and public workspaces as "*it is natural to assume that participants might not want to display every piece of information on the whiteboard*" [Rekimoto, 1998, p.346].

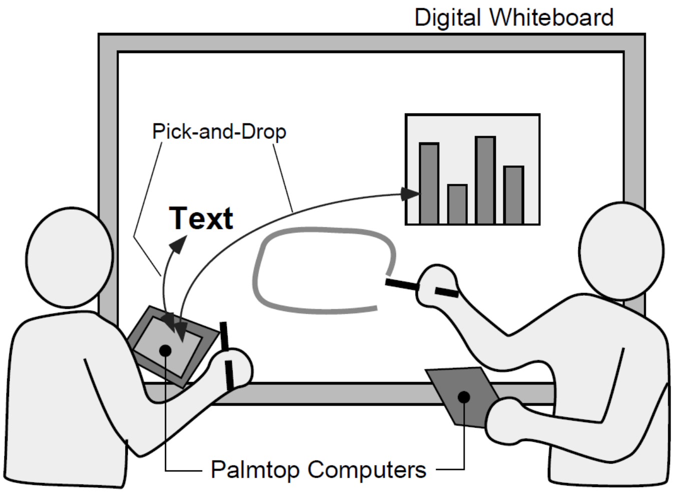

Figure 2.26: Multi-device approach by Rekimoto [Rekimoto, 1998]

Magerkurth and Prante argue that using coupled mobile devices in a SDG scenario can help to combine the advantages of pure SDG systems on the one and distributed systems on the other side, leading to more optimal results in a creative process [Magerkurth and Prante, 2001]. The lack of private workspaces in pure SDG settings is also referred to by Shoemaker: "*In SDG systems, [...] users are gathered around a shared display, and all information is by default public. Every user has the same view of the same screen, and has an automatic awareness of everything other users see. This is one of the main benefits of SDG environments, but it is not always desirable. In physical world settings, people are free to reference private notes or make private sketches, while collaborating around a public artifact. At any time, people can choose to make private information public or public information private. This ability to have both public and private information is an aspect that is lacking in existing SDG systems.*" [Shoemaker, 2000, p.349].

Regarding the applications presented in this section the following critical issues can be raised. Many systems use **outdated technology**. For example, in most of the regarded examples the input on the large tabletop or wall displays / projections is realized without the possibility of true parallel work (e.g. due to a single shared keyboard as input device). Furthermore, they lack novel and direct ways of interacting with the shared display (such as directly touching its surface). Outdated technology also shows up in the coupled display scenarios. Nearly all of the regarded studies use old PDA or tablet PC devices, mainly being controlled by a pen. Studies being conducted with novel smartphones and tablets hardly exist. Another problem is the comparatively low complexity of the implemented applications and the isolated way in which they are used. As already discussed in the context of web-based applications, most systems miss a **more complex process structure** resulting in simple application scenarios and less user guidance. Most examples can only be seen as a demonstration of technology and a proof of concept. While mobile applications are often synchronized with a web-based counterpart (e.g. Evernote [Evernote, 2012]), the collocated SDG applications typically stand for their own, missing any **interoperability** with other IT environments except, in the very few cases of MDEs, with PDAs that are typically used to interact with and to support the SDG device. Although many studies argue that SDG is good for collaboration, only in one study [Hilliges et al., 2007] a comparison to other creative environments (a paper-based method) was made. The missing interoperability to other (different) approaches of IT that are building on the same application model prevents a true **comparability** of a SDG application to e.g. a distributed scenario. Hence, the comparability of the applied studies is questionable. A reason may be that the applications developed so far were all implemented just for experimenting with the new technology of SDG devices on a basic level.

2.4 Summary

Within this chapter, the fundamentals of creativity and creativity support were discussed. Starting with giving a definition of the term "creativity", the 4P framework of Mel Rhodes [Rhodes, 1961] was introduced. Based on this framework, an in depth examination of its four dimensions product, person, process, and press was made. In a next step, IT systems supporting creativity (so called Creativity Support Systems) were categorized into the more general classes of information systems and Groupware. In this regard, we discussed models aiming at environmental characteristics of Groupware, namely Robert Johansen's Four Square Model and the People/Artifact (Cooperative Work) Framework. Furthermore, a brief overview on first approaches on dedicated IT environments for creativity support (Electronic Meeting Systems) was given. Finally, state-of-the-art examples of (distributed) web-based applications, smartphone (and tablet) apps, as well as dedicated environments for collocated creativity support (Single Display Groupware, Multi Display Environments) were presented and discussed. By regarding those environments and the scenarios they are designed for, one can see that they can be easily clustered according to Johansen's model. While web-based applications are mainly used in "different place / [same time | different time]" situations, smartphone applications are typically used in a "different place / different time" setting (except for their use for communication). The last category of IT environments focused on collocated ("same place / same time") situations.

However, this chapter only targeted a scientific perspective on creativity and on creativity support based on information technology. To gain an impression on what types of creative situations occur in practice (in companies) and which properties are to be supported in such situations, experiences and best practices from professional life need to be regarded. This is subject to the next chapter.

Chapter 3

Situative Creativity

It is our first goal within this chapter to investigate how creativity can be supported by IT in ways which address the needs of the creative situation itself. We focus on typical creative situations which occur in practice. For that purpose, we conducted interviews with ten creativity experts from companies of the German ICT sector. After presenting the applied interview methodology, we discuss selected interview statements and derive insights into typical creative situations and their characteristics. The full list of the cited interview statements can be found in Appendix A. In addition to the sole characterization of creative situations, we also investigate (in the interviews) which types of IT and non-IT tools are currently used to support creative tasks and processes. The second part of this chapter takes a more detailed look on the characteristics of the creative collaboration situation and the social aspects involved. Therefore, we refer to lessons learned from the interviews as well as related scientific work. Based on this examination, we discuss properties to be supported by a Creativity Support System and define our understanding of a situative creativity support. Finally, we point out in detail, why a tabletop-based application, combined with touch-based input and enriched by coupled mobile devices, provides promising basis for such a situative creativity support. In this regard, we also discuss how such an application should be designed. The third section concludes this chapter by describing the two application scenarios that are addressed by the implementations presented in Chapter 4: collaborative creativity techniques and the collaborative composition of (electronic) music. While the first is typical for being applied in companies, the second represents a more artistic form of creativity.

3.1 Status Quo of Creativity in Germany's ICT Sector

In order to find out more about creative situations being typical in today's business life, we conducted interviews with ten experts from German companies active in the ICT sector. Within this section we present the applied interview methodology, selected interview statements, the main derived situation categories, their characteristics, as well as problems and chances concerning an IT support. Furthermore, we take a more detailed look at the creative collaboration situation which needs to be supported by IT. On this basis, we establish a definition of and guidelines for a situative creativity support. The interview results, as well as parts of the analysis, have been published in two journal articles [Brocco et al., 2011, Frieß et al., 2012c].

3.1.1 Interview Methodology

To determine the different types and characteristics of typical creative situations (and related IT and non-IT support tools) in today's companies, we applied an inductive category building [Bortz and Döring, 2006] based on interviews. These interviews were conducted within a time-span of approximately one year. As a focus group for the interviews, we selected ten companies active in the (German) ICT sector. Half of these companies are also active on a global scale. At the time of the interviews, the number of employees in the interviewed companies ranged from 100 (smallest) up to 180.000 people (largest). The reasons why companies from the ICT sector were chosen are simple. First, an economic sector which explicitly demands for a high degree of creativity had to be selected. Due to the high and fast moving competition, the ICT sector is of particular interest. Second, we wanted to target companies with a high probability of using IT tools when being creative in a team. This made IT-affine companies, which are used to apply software in their daily work processes, even more promising for our purpose. The companies were chosen by accessing research projects (with focus on the open innovation phenomenon), but also by making use of private contact networks. The interviewees who were selected this way, are mainly decision makers from an upper hierarchy level (company founders, leading project, product and innovation managers). Due to their positions and functions, their domain of expertise explicitly includes knowledge on creative processes and settings in their company.

After initial questions concerning meta information about the interviewees themselves (e.g. their name, position, age, qualification, etc.) and the company they work in (e.g. number of employees, founding date, geographical distribution, etc.), we started introducing our topic and our view on creativity by explaining the 4P framework of Mel Rhodes (see Section 2.2). During this introduction, we also emphasized that the creative problems we are referring to can be quite diverse, ranging from finding ideas for new products over company internal improvements to simple daily problems like "*Which place should we go to for our company outing?*". Based on this broad definition of a creative problem, we aimed at identifying creative activities in the interviewed companies. For each of these activities, we then looped through a semi-structured interview guideline [Bortz and Döring, 2006, p.239] to further frame and characterize the corresponding situations and scenarios. Semi-structured refers to the way how the interview was conducted: There are no preformulated questions and no sequential order of the interview topics in semi-structured interviews [Mayring, 2002, p.66]. Hence, the guideline was mainly used to not forget about relevant aspects. Because of that, the main questions of this guideline which are shown in Figure 3.1, are only used as a form of guidance and were not always asked literally. This way we left it open to the interviewees to talk freely about everything they considered important to the topic. If some point in the guideline was not completely covered by an interviewee, the interviewer interfered and asked more specifically about that aspect. This is in accordance with guidelines for conducting semi-structured interviews [Kromrey, 2000, p.364].

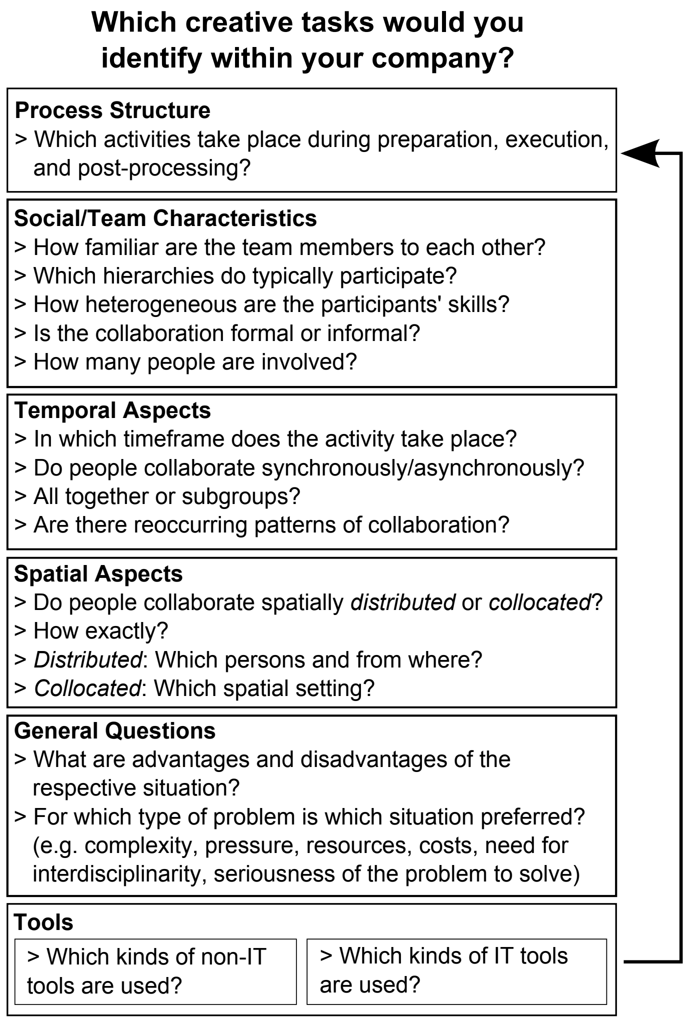

Figure 3.1: Interview guideline

The applied interview guideline in Figure 3.1 is built-up as follows. First, we asked questions concerning the process structure of the identified creative activities. Therefore the process was divided into the steps of preparation, execution, and post-processing. Next, we were interested in the team characteristics and social situation of the involved group members. For example, we asked how good the team members know each other and how familiar they are. The questions about these two dimensions of the 4P framework (process and person) were taken into account because, as pointed out in Section 2.2.4, creative situations are influenced by the creative press which has to be seen in **interdependency** with the creative process and the creative person.

In a next step, and in accordance to Johansen's four square model (see Section 2.3.1), we asked about the temporal and spatial settings in which the creative activities take place. One goal of this examination was to frame the creative situations more precisely by e.g. finding out if the teams act synchronously or not and in which kind of spatial configuration. In this regard we also investigated which types IT and non-IT tools were used as support mechanism and due to which reasons the spatial/temporal setting was chosen. Consequently, we also wanted to know under which circumstances the interviewees would favor which type of setting. In this context, especially the advantages and disadvantages concerning the group collaboration as well as the social situation were of interest.

Each interview took approximately 1 to 1.5 hours and was audio recorded. For a further post processing, we transcribed these audio-recordings and annotated them by assigning the statements to matching elements of the interview guideline. To support these steps, the software MAXQDA [MAXQDA, 2012] was used. We then consolidated the resulting material to gain a more generalized view on creative situations and their main characteristics. For this purpose, the transcribed statements were paraphrased so that decorations, repetitions, and colloquial language were removed. Finally, the paraphrased statements were further generalized and a category system concerning the different types of creative situations and their influence factors was formed.

In the next section we discuss concrete insights into the typical creative situations given by the interviewees. As all of the interviews were conducted in German, only (simplified and partially paraphrased) English translations of some of the original statements are quoted directly, while others are referenced by keys provided in round brackets. The keys can be looked up in Appendix A where the interview statements can be found in their original German version.

3.1.2 Interview Statements

To get a grasp on possible creative situations, we asked the interviewees about specific creative processes and activities that take place in their companies. The **process structure** of the identified creative activities was stated in most cases as highly informal (e.g. `stmt1`, `stmt33`): "*There is no standard approach, no standard process, no standard set of activities*" (`stmt1`). This is reasoned because these activities (and their respective settings) "*heavily depend on the concrete problem and the number of people involved in solving it, and if these people are spatially distributed or not*" (`stmt2`). Often, not even a formal process structure is pre-defined: "*You let the people run on their own a little bit, so that they have the chance to look in all directions without any restriction*" (`stmt3`). While the creative problems to be solved were stated as varying and diverse, the activities involved were described as communication intense, spontaneous, and challenging to manage. An example is taken from `stmt31`: "*There is much discussion activity taking place*". More structured forms of creative processes were identified in project workshops (e.g. done in the scope of kickoff meetings and project reviews) and regular meetings. Workshops typically last from "*half a day to two days*" (`stmt6`, `stmt53`) while meetings can last from a "*quarter of an* *hour to 2 - 3 hours*" (`stmt30`). In these situations, the creative process is conducted face-to-face and in teams which typically involve about "a handful" of participants (`stmt35`). The process is then often structured in idea generation activities which are followed by an evaluation of the results, similar to the divergent and convergent phases discussed in Section 2.2.3. For the idea generation, different established types of creativity techniques such as the Brainstorming technique were used (e.g. `stmt53`). One company also named the "Six Thinking Hats" technique as well as different customized techniques involving textual or image-based stimuli (`stmt32`). In order to give workshops a more structured process flow and to enforce the constraints of certain creativity techniques, they are often moderated by a dedicated facilitator. The interviewees also agreed that a more complex process (e.g. involving several participants and/or steps) always needs management and moderation: "*I could imagine a process consisting of several steps, e.g. that a group of two people is working today, the other tomorrow. But such a process needs to be managed*" (`stmt20`). Here, it was stated that an IT application, which takes over the functionality of such a moderator, would be a benefit, e.g. for trying out new creativity techniques (`stmt44`). Overall, the interview partners were satisfied with the creative processes being conducted in their companies. Interestingly, they did not have the problem that their employees generate too few ideas. In contrast, they considered the lack of resources for elaborating and implementing the ideas as the real bottleneck in their innovation process: "*We actually have too many ideas, we even cannot elaborate all of them*" (`stmt58`).

Closely connected to the creative process itself is the **documentation** of its **course of action** as well as its **results** (the creative products). Only three of the interviewees mentioned that there are any (digital) documentation activities. For that purpose, they typically write down ideas via text processing applications, take photos or directly enter the ideas into an idea database (`stmt34`, `stmt54`, `stmt57`, `stmt63`). A documentation is then only made for the resulting (final) creative artifacts but not for each action performed or each fragment which is contributed. However, even the interviewees who did not perform any documentation activities stated that a documentation is, in fact, needed because of several reasons. First, a lack of documentation can lead to unproductive repetitions of creative processes: "*We tend to reinvent the wheel from time to time. The problem that we are solving was possibly solved by someone else in our company before. This costs us time and money.*" (`stmt4`). Second, the documentation of the whole course of action (e.g. "who contributed an idea at which point of time") was noted as important, because the information about the person who actually contributed an idea often gets lost: "*If an idea is really good, it is very likely that someone else claims it as his own idea. It is fact that ideas get stolen.* [...] *After a meeting someone who is higher in the hierarchy takes the best ideas and the real idea contributer takes a back seat*" (`stmt18`). A last reason why an electronic documentation of results is important, is to gain the possibility to export them to a broad range of different formats. This can be helpful, for example, to automatically process them in third party applications such as MindManager [Mindjet, 2012], Office, and image processing tools (e.g. `stmt19`, `stmt45`) or to share them with a broader audience e.g. by sending an email (`stmt56`).

Following the characterization of the creative processes, we elicited the **team char-**

acteristics that play a role in creative situations. First, two main scenarios were found among the interviewed companies: Ideas are generated and evaluated either in *groups of persons* (i.e. teams), or by *oneself*. As pointed out earlier, to this thesis it is mainly important to regard the first scenario, collaborative creative processes where ideas are generated in a team. Here, different competencies (e.g. participants from different business domains) were mentioned as one criterion that matters for inviting people to a creativity session (e.g. `stmt52`, `stmt59`). The main reason for establishing such heterogeneous teams, which emerged from the interviews, is the expectation that solving complex creative problems explicitly demands for **participants** from **different fields of expertise**. The reason is that complex creative problems require more knowledge than any single person can possess and that this knowledge is often distributed among stakeholders from **different perspectives and backgrounds**. For this purpose, sometimes even external experts are included in a creative process (`stmt59`). In a similar way, the hierarchy structure of the persons involved was in most cases also stated as heterogeneous (e.g. `stmt5`, `stmt55`), because employees of different hierarchy levels bring in different perspectives and novel ideas as well: "*A new colleague that is coming from university perhaps has novel ideas and makes things hum*" (`stmt61`). Despite these differences in hierarchy levels, the social interaction was stated in most cases as informal and familiar (e.g. `stmt55`). However, it was pointed out that sometimes there can be **conflicts in creative teams**: "*I remember a situation where I knew he* [a colleague] *is very uncomfortable to discuss with. Nevertheless I invited him since I knew he could significantly contribute to the solution of this problem*" (`stmt62`).

	Collocated, Synchronous	**Distributed, Synchronous**	**Distributed, Asynchronous**
Communication Richness	• **Verbal:** Full and direct verbal communication (also between subgroups) • **Non-verbal**: Facial expression, mimic, gestures, emotions as well as object mediated communication (e.g. giving an index card to someone else) • **Speed**: Direct / fast (no delays)	• **Verbal:** Audio/video conferencing (only one direction at the same time: one-to-all, no formation of subgroups possible) and chat (subgroups possible) • **Non-verbal**: Limited possibilities for facial expression, mimic, and gestures (provided by video conferencing) • **Speed**: Electronically mediated, signal delays, signal breaks, slower speed when text needs to be typed in	• **Verbal:** Emails and contributions / discussions on web pages • **Non-verbal**: - • **Speed**: Electronically mediated, slow but typically involving larger amounts of text/information, less time critical

Examples of IT and non IT Tools	Whiteboards, flip charts, cards, wall projections (edited from a single computer), networked (web) applications, note taking, and text processing software, tablet computers	Instant messaging and conferencing tools (i.e. chat, screen-sharing, telephone, video conferencing), synchronous web applications (i.e. Google Docs)	Email, different types of web platforms (e.g. communities, idea management systems, etc.), note-taking via smartphones or traditional notepads
Chances	• Fast (and direct) communication, coordination, and interpretation • Informal conversations and mutual (creative) stimulation • More fun (e.g. due to "real" group collaboration) • Better group awareness and perception • Building of social ties / relationships • More creative results	• Fast integration of external participants • Collaboration over large distances and from different places • Mainly used for communication, no "real" creative collaboration support (except some cases in which collaborative web tools were used)	• Integration of many participants (even up to several hundreds) • Real-time collaboration over large distances and time zones • Good for sharing, evaluating, and thinking about creative results • Mobile use possible (e.g. taking notes directly when ideas incubate)
Constraints	• Documentation and transfer of activities and results problematic • Traditional IT is either non-collaborative (lacks of parallel input channels) or distracting from group process (using personal PCs) • Moderation needed • Coordination activity needed to get participants together at the same time / same place	• Time delays and instable connections possible • Limited media richness to transmit non-verbal communication • "Unnatural" to the human being → exhausting! • Less acceptance of synchronous collaboration tools beyond communication support → People need the "real" for being creative	• "True" collaboration difficult → Needs synchronicity • Mainly performed as a single-user activity • Less motivation for more complex and time consuming applications

Table 3.1: Creative situations derived from the interviews

Concerning the **spatial and temporal settings** in which the diverse creative teams collaborate, **three main types** were identified. Primarily, the interviews showed that there is a need for **collocated (same time/same place)** as well as **distributed ([same time|different time]/different place)** participation in a creative process. A summary of the most important characteristics of these situations is discussed in the following paragraphs. An overview can be found in Table 3.1.

As already pointed out earlier, **collocated creative situations** typically take place in the style of scheduled workshops or meetings. In addition, if all actors are at the same place, they also often instantiate collocated creative situations unplanned: "*If I can see that my colleague is not occupied or stressed, I just walk over to his place and ask him if he wants to join*" (`stmt10`). Collocated situations are typically **supported** by **non-IT tools** such as whiteboards (often combined with index cards) (`stmt31`), but also by **single-user software** such as text processing, note taking or mind mapping applications (e.g. Word, Excel, Powerpoint, MindManager etc.). These tools are then projected to a wall to make them visible to all participants (`stmt36`). However, when used this way, these applications only allow for one input channel at a time: "*People cannot work in parallel on the workspace. All participants are looking at the projection, but only one of them is able to type*" (`stmt11`). As a consequence, they are not able to **contribute in parallel** and a **partitioning of the group into subgroups** is hampered (`stmt35`), for example, because the focus of all participants is directed to the projection. Another approach to IT support in a collocated setting, which was stated by one interviewee, is using a collaborative web application (Google Docs [Google Docs, 2012]) by multiple participants from their own laptops (`stmt48`). However, although this scenario allows for working in parallel, using laptops in collocated settings can distract from the actual task and the group process: "*Everyone did his personal office work instead of participating*" (`stmt12`). A last example of how to use IT in a collocated creative setting was to support information retrieval: one company was using tablets (the iPad) to quickly access information and content from the World Wide Web when coming together for a Brainstorming (`stmt22`).

In contrast to collocated settings, **communication** and **collaboration technology** provides the possibility to collaborate in **situations**, where the actors are **spatially distributed**. This typically happens when spatially fragmented actors, such as employees from other headquarters / departments, freelancers, customers or partners need to be integrated into the same creative task. The most common way to solve creative problems in such a setting together, is interacting asynchronously by writing emails, using web-based systems, or apps on mobile devices. One reason why asynchronicity is needed are the different availabilities of the participants during a longer creative process (e.g. due to different time zones or working hours). These often make asynchronous collaboration necessary (`stmt23`, `stmt37`, `stmt38`, `stmt46`). Especially mobile handhelds and smartphones are popular as they allow for an electronic collection of creative artifacts in many situations of life where no other (more bulky) IT support is around: "*When I was lying in my bed a lot of ideas came into my mind. Then I took my iPhone and wrote two emails to myself*" (`stmt13`). The effect that an idea suddenly flashes up when being outside the daily routine at work, was also stated by another interviewee: "*When I am on my bike or driving my car and I am thinking on something completely different, suddenly ideas are emerging*" (`stmt25`).

While the distributed tools that were described above are mainly designed for an asynchronous usage, IT support also allows to collaborate in a **distributed** setting **synchronously (same time / different place)**. Most popular, in this regard, are tools which solely support the communication between different persons. Examples for such tools, as they are used in the interviewed companies, are instant messaging, chat, and audio / video conferencing applications and environments (e.g. `stmt51`, `stmt47`, `stmt65`). Some of our interviewees even used instant messaging not only in a setting where the participants were spatially distributed, but also in open-plan offices in a collocated setting. The reason was that they consider instant messaging as a more private communication channel (than talking verbally) which helps to not disturb others in the same room (`stmt47`). In addition to tools which only support communication, the interviewees stated to be using virtual collaboration spaces including digital whiteboards, document pools, screen-sharing tools, and real-time collaboration software such as GoogleDocs (`stmt48`) or Adobe Connect Professional (`stmt39`). With these tools, sometimes (simple) group creativity techniques are applied: "*We use creativity techniques in spatially distributed settings, but without any direct IT support for the creative process. They are conducted synchronously, because we then achieve results faster*" (`stmt40`). Due to the advantages of using distributed IT tools, such as a digital and automatic documentation (`stmt39`) and the fact that **more people** can be brought together **faster** and with **lesser coordination** and **traveling costs** (`stmt64`), these tools are often and commonly used in every day work life: "*We are using the virtual space disproportionately often.* [...] *Within a project, about 40% of our communication with the customer is taking place virtually*" (`stmt39`). One interviewed company even carried the use of a distributed synchronous collaboration tool to extremes: "*We also have tools especially suited for meetings in which several hundreds of people participate and ask questions or comment on topics*" (`stmt17`).

Sometimes, different spatial and temporal settings are combined into a **hybrid creative process**: "*First we made a distributed electronic Brainstorming. Then we met in the meeting room to develop and improve our gathered ideas. We did not think in one way, the combination made it. We enjoyed the distributed virtual Brainstorming, because we are from different departments and we were able to compare notes with each other. But we also need the real, we need to look into each other's eyes to improve the team spirit*" (`stmt21`). One interviewee even proposed to allow some participants to join a collocated creativity session remotely: "*I prefer collaborating in a collocated setting, but sometimes, this is simply not possible for each participant. Then, I prefer the combination of a (distributed) virtual conference and a group of people being in the same room*" (`stmt43`).

When asking the interview partners more detailed about the **concrete ways how** they **collaborate** with *distributed tools*, important insights into creative collaboration were gained. Despite the advantages discussed above, such as reducing costs and time for traveling, a more realistic and faster interaction than working asynchronously, and an automatic documentation of creative artifacts, there are still problems which **hamper the acceptance** and the **use** of distributed synchronous collaboration tools in creative work. **Delays in signal transmission** are one important factor that is responsible for this missing acceptance and can still occur even in high end video conferencing systems: "*Latency is a big problem with video conferencing applications. If there is an involved discussion going on and I am saying something, then the others hear me about 1.5 seconds later. Then I already interrupted them and they stop talking and the whole discussion is halted*" (`stmt66`). These communication breaks were stated as **exhausting** and, as a consequence, audio and video conferencing as a **way of communication** which appears **unnatural** to humans: "*It is not the same as being collocated, it is more exhausting*" (stmt14). "*This may result from the fact, that human beings are not made for this kind of collaboration* [...] *They do not have the concentration and discipline for virtual meetings*" (stmt15). Another reason for this mental exhaustion is that the **vocabulary of social behavioral cues** such as facial expression, mimic, and gestures is **limited**: "*You cannot transport mimic, gestures, and a certain atmosphere via a netmeeting. They are only possible when being in the same room*" (stmt8). This is backed by a statement that even in a video conference, people can easily get out of reach: "*One participant may sit in the back where you don't see and hear him anymore*" (stmt14). This also leads to the problem to **partition** the **group into subgroups** or to talk to another participant directly. Hence, **informal conversations** are hardly possible: "*Within a video conference you will not start an informal conversation, simply because it is too exhausting and has a fixed deadline*" (stmt16).

In summary, all interviewees agreed that coming together in a collocated setting, even despite the benefits of today's communication technology, is still needed for truly being creative. This is supported by interview statements which highlight that being collocated is preferred when addressing important problems and topics (e.g. stmt7, stmt9, stmt24, stmt26, stmt50): "*If you know that it is an important topic, you want to communicate directly and face-to-face*" (stmt7). Moreover, bringing together the participants in a collocated setting was also stated as important when a problem demands for a high degree of creativity: "*If I really need to solve problems which demand for a large amount of creativity, I would prefer to do that in a collocated setting*" (stmt9). A central benefit of collocated face-to-face situations is that they allow for a rich vocabulary of social interaction: "*Being collocated is important because you can respond to others in a better way. Without personal meetings, where you can look into each others eyes, nothing will work*" (stmt51). Thus it is not surprising, that even companies who are active world-wide, regularly bring together their creative teams at the same place: "*We see the rest of the team every half year personally. This is a very productive time. If you are in a collocated setting, you can discuss all the things you did not understand in the last half year face-to-face*" (stmt69). This is especially important in the beginning of projects: "*We prefer a collocated setting when the participants don't know each other, to meet each other in real life, and to build natural relationships. I've tried such things via netmeetings, but my experiences are not too good*" (stmt67). Beyond the building of natural (social) relationships, a high quality of face-to-face interaction can foster the building of a common team spirit: "*We enjoyed the virtual Brainstorming, but we also needed the "real". When we look into each others' eyes, the spirit is simply better*" (stmt68). As a direct consequence, also the motivation of each team member is increased: "*You have to work in a team to be creative, because otherwise you are not motivated enough. You need to get stimulated by others*" (stmt20). Even though some aspects of collocated situations may seem unproductive in a first view, for example if some participants "fool around", even this fooling around was stated as an important stimulus leading to a larger number of creative and more radical ideas (stmt24).

Despite these advantages, the interviewees also mentioned problems that can hamper the expression of ideas in collocated creative collaboration situations. These relate to the problem of group pressure which was introduced in Section 2.2.2. "*Certain ideas are expressed in one-on-one interviews only. A main reason is the fear of voicing a controversial idea in the large group.*" (`stmt29`). In the context of this problem, one could think that the more anonymous style of interaction, as it is provided by distributed tools, could be suited better for more shy people and encourage them to express their ideas more actively. However, two interviewees named reasons why this assumption can be wrong. For example, shy people can also have inhibitions to express their ideas verbally (e.g. via telephone (`stmt49`)) or written: "*There are always persons who have difficulties with typing or spelling words* [...] *Distributed communication via written text is very time consuming, involves misunderstandings, and makes it hard for a person to overcome one's inhibitions*" (`stmt42`).

In summary, across all interviews it emerged that one of the most important factors for being creative in a team is a high quality of collaboration, mainly determined by the need for social, fluid, and rich channels of interaction as they are only possible in collocated face-to-face situations. This quality is even stated more important than the generation of a large number of ideas. To determine the properties which are relevant for achieving a high quality of team collaboration in more detail, the examination in the next subsection not only founds on insights gained from the interviews, but also builds upon prior knowledge gained from related research. Based on this examination, we define our view of a situative creativity support and discuss how an IT environment for such a support could be designed.

3.1.3 The Creative Collaboration Situation and a Situative Creativity Support

When people come together to be creative, they are always engaged in a **social situation**. For example, different persons bring in their different attitudes and varying moods, as well as their existing social relationships. Concrete definitions for the term social situation can be found in socio-psychological literature. Eysenck, Arnold, and Meili define the concept of a "social situation" as "*a general term for the field of reference (stimuli, objects, fellow men, groups, values, etc.)* [...] *of a person acting in society* [...] *The social situation may be defined by three categories of the data and the manner in which they are linked: (a) the actual data which influences the acting person, (b) the attitudes which are brought into play at the time of the act, and (c) the degree of ego involvement or awareness of the actual data and attributes on the part of acting person*" [Arnold et al., 1972, p.1008]. A similar definition is given in [Groh et al., 2010, p.1]: "*The general social context of a person located in space and time at a point* $(x;t)$ *encompasses all characteristics of relations to other persons that are relevant to the current situation of that person. "Situation" encapsulates the current state of affairs of that person (their goals, their running tasks etc.). "Current" characterizes some small space-time region* $X \times T$ *with* $(x;t) \in X \times T$ *with immediate relevance to this situation. Higher abstraction level social context elements include e.g. characteristics of other persons present in the current situation, or strengths and semantics of social relations among these persons. Lower abstraction level social contexts* *include discourse patterns, social signals such as gestures and facial expressions during communication etc.*".

In this regard, the interviews showed that the quality of (social) interaction can shape a creative (social) situation in a positive way (e.g. motivation of participants, building of a team spirit, mutual stimulation, less misunderstandings, etc.). This is backed by psychological research such as the work of Mihaly Csikszentmihalyi [Csikszentmihalyi and Sawyer, 1995, Csikszentmihalyi, 1997], in which the importance of social discourse, team interaction, and collaboration as a vital source for creativity is emphasized. **Social interaction** is the process in which people act toward or respond to others [Rummel, 1975] - which can be done by sending (and receiving) social signals either verbally, physically (by mimic, gestures, facial expression), or emotionally. Although this means that the parties involved must be **aware** of **each other**, it does not mean that they need to be directly in sight of each other [Rummel, 1975]. E.g. writing an email to somebody can also be accounted as one way of social interaction. Hence, social interaction is not defined by a physical relation or behavior, or by physical distance, but it is a matter of a mutual subjective orientation towards each other [Rummel, 1975]. Nevertheless, the possible degree and the resulting quality of a social interaction is dependent on the respective situation and also on the tools that are used. E.g. when a group is working face-to-face (collocated), the group members can see each other and interact with each other more directly and quickly and are able to sense non-verbal and emotional signals on a broader scale.

For describing the quality and the success of team interactions in innovative projects, to which also creative projects can be accounted for (see Section 2.1.2), Högl et al. proposed the Teamwork Quality Framework (TWQ) [Hoegl and Gemuenden, 2001]. In this framework, six facets were specified (see Figure 3.2) that are taken as a basis for discussing important properties to support in a creative collaboration situation. As these facets overlap with the insights gained from the interview analysis, we discuss them against this background.

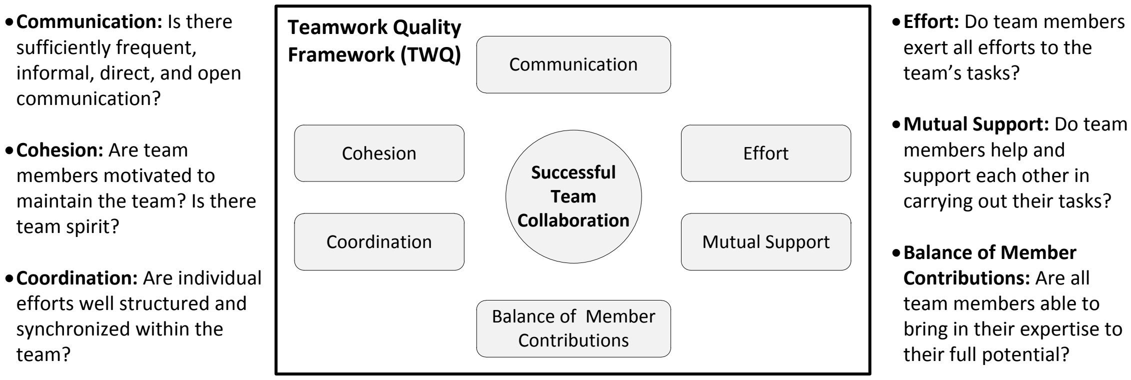

Figure 3.2: Teamwork Quality Framework [Hoegl and Gemuenden, 2001]

The first facet, which was also stated as important by the interviewees, is **communication**. By definition, "*communication is the process by which people convey meanings to each other by using symbols. Communication entails (1) the encoding of a person's percep-*

tions, thoughts, and feelings into language and other symbols, (2) the transmission of these symbols or language, and (3) the decoding of the transmission by another person. [...] *Communication can be verbal, nonverbal, or written.*" [Toseland and Rivas, 2005, p.65-66]. As pointed out in the interviews, non-verbal communication can additionally take place via facial expressions and gestures and even help to transmit certain emotional information, e.g. when having eye contact to another person [Vinciarelli et al., 2008]. According to the interviews, there also seems to be an inner need to communicate in creative group settings in general. The quality of such communication activity can be described by its frequency, openness, structure, and the degree of information exchange [Hoegl and Gemuenden, 2001]. Hence, one reason why collocated face-to-face settings are preferred for being creative becomes clear: More channels of communication are more "open". With a high richness of communication and a fast, undelayed communication speed, information can be shared easily between the participants, enabling them to create novel and to improve existing creative artifacts. Furthermore, possible conflicts and misunderstandings can be resolved before they actually emerge. Another reason why a high quality communication is required for creative processes is the inclusion of participants from different perspectives and backgrounds. Here, people may have an information need with respect to the given problem that they can express via verbal and non-verbal communication.

The second facet in the framework is **coordination** - "*the degree of common understanding regarding the interrelatedness and current status of individual contributions*" [Hoegl and Gemuenden, 2001, p.437]. Coordination is especially important as, according to the interviews, not all members of a creative team are always engaged in the same subtask. Hence, it should be possible to partition a team into subgroups so that different subtasks can be solved in parallel. As a consequence, at a specific point in time, some people may work on their own (e.g. entering data), while others work together to achieve a common goal (e.g. painting on the same image). This steady flux of the group's configuration is called **task coupling** [Tang et al., 2006] and requires the possibility of interacting in parallel. In literature, three main types of task coupling are divided [Wigdor and Wixon, 2011]. In **highly coupled tasks** multiple users help each other performing a specific task. In **lightly coupled tasks** different users perform different tasks to find individual solutions for the same problem (the "divide and conquer" principle). Finally, in **uncoupled tasks** users are working on the same workspace but are engaged in completely different and independent tasks. Coupling is also dependent on the situation in which creativity occurs and the process / task semantics (e.g. creativity techniques) that are applied. Especially in collocated scenarios the social situation (e.g. the social relations) between different actors influence their need or desire to work closely or independently of one another. While in one setting a more anonymous participation (= a low degree of coupling) may be preferred (e.g. if there are conflicts in a team), in another setting a more intense social interaction may be an advantage.
A key component for successful coordination is **group awareness**, the understanding of the activities of others which provides a context for own activities [Dourish and Bellotti, 1992]. Gutwin et al. categorize group awareness into **awareness** of the **task environment** and awareness of the **social environment** [Gutwin and Greenberg, 1995]. The first is required for individual persons to coordinate and complete their part of a group

task. A high degree of task related group awareness is achieved through a good **visibility of action** and allows to realize what other participants are doing and how their actions affect shared artifacts. Thus it helps to control a collaborative process, to coordinate group activity, and to integrate individuals into the group process. This, in turn, can help to reduce the problem of social loafing (Section 2.2.2). A high level of group awareness about the social environment helps to **stick to social norms and conventions**, which require to be aware of others in the group. Thus, with a high level of social awareness misunderstandings and conflicts are further reduced. Finally, supporting group awareness in a better way can help to free up mental resources for the creative task. This knowledge is gained as an inverse conclusion of the interview statement that using distributed tools for collaboration is (mentally) exhausting due to the restricted channels for communication and coordination.

Communication, coordination, and group awareness are closely connected to the third facet of Högl's framework: **mutual support**. It is important that when collaborating in a group setting, the participants are able work together instead of acting as competitors. Hence, they should be able to grant assistance to each other when needed and work together on creative artifacts instead of trying to outdo each other [Hoegl and Gemuenden, 2001]. Otherwise, distrust and frustration may come up due to the missing feeling of being part of the group. This was also pointed out in the interviews: Situations with a high degree of (social) interaction are responsible for socio-emotional processes such as group building, group well-being, mutual trust, and a better team spirit. As a result (and as it was stated in the interviews) team members develop a higher degree of motivation, experience more fun, stimulate each other and, as a consequence, get into a creative flow more easily. As a result, they are also more likely to accomplish their task and to work with other team members with **effort** (the fourth facet). Effort in regard to team collaboration means, for example, workload sharing and prioritizing the team's task over other obligations.

Although our interviewees as well as research on creativity (e.g. [Osborn, 1957]) highlight the importance of communication and a high level of social interaction when being creative, several studies [Taylor et al., 1958, Isaksen, 1998, Delbecq and de Ven, 1971] also made the finding that at least for Brainstorming, nominal groups are more effective (in both quantity and quality of ideas) than groups where the participants are allowed to communicate. In nominal groups, participants work separately from each other and, at the end, their ideas are merged. The reasons for that are diverse: people fear an evaluation of controversial or more radical ideas by the group and many situations do not allow for parallel input or cause some participants to be mentally absent (e.g. doing their daily work instead of participating). A theoretical discussion of the three main responsible factors, group pressure, social loafing, and production blocking, has been given in Section 2.2.2. This problem is addressed in Högl's framework by the fifth facet: **balance of members contributions**. Especially in cross-functional teams as they are typical for solving problems which demand for a high level of creativity, it is important that all team members can bring in all their views and ideas equally. As a side note, also for evaluating creative artifacts it can be essential to balance member contributions. E.g. in [Delbecq and de Ven, 1971, Connolly et al., 1990] it is argued that in convergent phases, where ideas are evaluated, an independent, individual, and more anonymous judgment is of importance.

Despite these potential problems that can occur when creative work is performed as a real group process, a variety of more novel research articles suggests that for the users involved, a high quality of interaction may be preferable to a higher number of ideas: "*Users may not be primarily concerned with the number of ideas generated when planning a brainstorming session, but rather may equally desire group well-being and member support*" [Dennis and Reinicke, 2004, p.1]. Hence, interaction quality can be seen as another important success criterion of creative processes and CSS. This is also emphasized in a statement given by Otmar Hilliges: "*The number and quality of ideas is not the only value to be assessed* [. . .] *the face-to-face situation of manual brainstorming has qualities which, in the long run, might even outweigh pure productivity measurements, namely the positive social aspects of team building, group awareness, and a shared sense of achievement.*" [Hilliges et al., 2007, p.138]. These insights are in accordance with our interview results. None of our interviewees stated the quantity and quality of their generated ideas as critical issue; some even stated they actually have too many ideas. In contrast to that, the quality of group collaboration was stated as important by all of the interviewees.

As a direct consequence of a good group collaboration which is mainly determined by supporting the first five facets, the sixth facet of Högl's framework is improved: group **cohesion**. In general, cohesiveness is defined as "*the resultant of all forces acting on all the members to remain in the group*" [Cartwright, 1968, p.91]. As listed in our interviews, group cohesion expresses itself in a variety of ways. Everyone in the group experienced feelings of joy, well-being, and even fun, when they worked as a group. Furthermore, group members were more satisfied than when they worked alone. For group cohesion it is of particular importance that the group members have the ability to socialize and to develop social relationships. Due to the missing social interaction that is not possible in nominal group work, but also a problem in distributed (synchronous) work. With creativity being the starting point of every innovative project (see Section 2.1.2), a high level of team cohesion gained from the initial creative collaboration can be fundamental, even for the success of the whole innovation project. This is also pointed out by Högl. According to him, a good teamwork quality can improve the effectiveness, efficiency, and work satisfaction of the group as well as of each individual.

Implications on an IT Support

When thinking about an IT support for collaborative creative processes, all these facets have to be kept in mind to achieve and to support a high standard of teamwork quality. As pointed out in the interviews and in the related work section (Section 2.3), state-of-the-art IT applications already cover distributed synchronous and asynchronous collaboration within the scope of the technological and situational possibilities. While communication is often supported by audio and video conferencing systems and applications of different kinds (e.g. Skype), web applications have taken a main role within collaboration tools. Mobile devices, however, are used to support this collaboration when no other IT support is around.

In these areas, a broad range of scientific as well as commercial products already exist (see Sections 2.3.3 and 2.3.4). E.g. in the studies by Florian Forster [Forster, 2010], the impact of a distributed web-based IT application on creativity support was investigated. The scenario which is interesting for further research is supporting a collocated face-to-face situation by novel means of IT. In the context of the discussion above, it is not surprising that here, electronic systems have not yet displaced or even successfully complemented traditional (non-IT) group creativity techniques. Even the benefits of electronic Brainstorming applications in regard to a higher number of ideas, the documentation of the creative process and the contributions, and a persistent storage of data, are only gained at the expense of the satisfaction of the participants with the IT system and the overall group process. Although traditional IT applications which are designed for a mainly distributed and single-person use do at least provide some ways of social interaction, they tend "*to be more task oriented and the leanness of the electronic media typically lessens the richness of the social interactions*" [Dennis and Reinicke, 2004, p.7]. Traditional (distributed) Groupware systems cannot transmit the social behavioral cues that are necessary for an awareness about the social environment [Gutwin and Greenberg, 1995]. Even when setting aside extra time on the agenda to create opportunities for socializing, this socializing is perceived different than the one that emerges from working on a joint creative task in a team. Against this background, a novel approach to IT support which is tailored to explicitly support the properties of collocated creative collaboration situations (e.g. communication, coordination, group awareness, different levels of coupling, mutual support, balancing of member contributions, etc.) needs to be thought of. We refer to such an IT support as a **Situative Creativity Support**.

For supporting creative collaboration with IT successfully, one more thing has to be taken into account: the user interaction with the IT system and the related computational artifacts. Here, the majority of our interviewees stated that an **intuitive handling** of the application is important. An example statement taken from the interviews undermines this need: "*People fear technology, if they can not handle an IT application, they will not use it and, instead, prefer to write down their ideas on a sheet of paper*" (`stmt27`). Most approaches to IT-based creativity support that are used so far, focus on the network as the shared medium. Each participant's interactions are then channeled through that medium via individual PCs leading to a loss of the perception of the outer environment (e.g. as observed in the Open-I workshops, Figure 2.2 (page 15)). In contrast to these applications, a situative creativity support needs to be embedded into the **same physical space** in which the **face-to-face collaboration takes place**. This way, most interaction paradigms that occur during traditional collocated collaboration can be preserved and utilized. First approaches to IT environments that support face-to-face interaction in such an "embedded" way have been examined in Section 2.3.5. However, they still lack more complex application scenarios, novel means of technology, comparability, do not provide a reasoning why specific technology was used, etc. (as already discussed in the end of Section 2.3.5).

Evaluating a situative Creativity Support System and comparing it to other IT and non-

IT supported creative settings can be a challenging task. While for traditional (distributed) IT applications the success is so far measured according to the quantity and quality of the ideas that have been generated, we expect a situative IT support to lead to different results. On a short time scale, as it is the case in an experiment, it is our expectation that the users **perceive** the **group process** and the **application** as **more positive, productive, pleasurable**, and **fun** when using a situative CSS. As a consequence, **group cohesion** will **increase** so that team members are more likely to work in the same team again. This is also pointed out in [Magerkurth and Prante, 2001]: Getting a feeling about the performance of the group can increase the acceptance of the generated ideas and the satisfaction of the users. All these factors can, on the long run, decide about the success and the efficiency of whole innovation projects as pointed out earlier. In summary, a situative IT environment then contributes to a workplace that encourages creative behavior as discussed in the context of the creative press (Section 2.2.4). While such long term benefits can only be measured over a longer time scale and with an application being productively used in a business context, it is our hypothesis that the short term effects of a situative CSS can be measured in an experimental setting. Such an experiment is presented in Chapter 5. Here, a situative approach to IT-based creativity support is compared to two traditional settings: one being conducted with a (distributed) web-based CSS (IdeaStream - see Section 2.3.3) and the other without any IT support.

3.2 A Concept for a Collocated IT Environment for a Situative Creativity Support

Supporting a collocated creative collaboration situation with IT can be a complex and challenging task. Diverse aspects like different collaboration styles, dynamically and steadily changing group configurations, different social relationship / structures, as well as different types of processes have to be taken into account. Depending on the concrete group configuration, an IT application has to mediate between different extremes of group collaboration paradigms. In this section we propose and discuss a concept of a novel way of IT support for collocated creative situations. We mainly address three fields. First, a **public workspace** is needed on which the group can share and work on artifacts. As a second field, we regard the **interaction** of the users **with the IT system** itself. Here, an intuitive use should be guaranteed, allowing the participants to interact simultaneously, so that e.g. the problem of production blocking is avoided. Finally, the third field targets an extension of the previously described concept by **private workspaces**, e.g. to separate individual from group activity. For that purpose, so called coupled mobile devices (smartphones, tablets) can help to mediate between different social settings in collocated situations (e.g. when more anonymity is required) and help to avoid shortcomings such as production blocking, group pressure, and technological limitations of a central and shared public workspace. Furthermore, they allow to bring in several more features which are of relevance to individual users, but not for the whole group. However, when private and public workspaces are combined into the same IT environment, problems and critical issues arise that have to be taken into account. These are also discussed.

3.2.1 The Public (Tabletop) Workspace

A central requirement of a situative CSS is to provide a public workspace on which all participants can share artifacts and collaborate with other team members. Such a public workspace needs to support different group configurations in their collaboration and, as consequence, to dynamically adapt to different degrees of coupling. In traditional IT applications such a public workspace is accessed by every user via his own PC and via network. However, as pointed out above, this setting would result in a reduced awareness of group activity and limit the range of spatial and real world expression and interaction. As we intend to support a high degree of group awareness and true face-to-face interaction, the second option, a workspace that is shared by all group members on a single, large IT device is more promising. In the examples presented in the related work section (Section 2.3.5) it was reported that for this purpose typically vertical or horizontal displays or projections are used. As also pointed out earlier, this class of Groupware is summarized under the term Single Display Groupware. In this section we present and justify design decisions of how to support the properties of a situative creativity support by a collaborative application running on a large single horizontal display.

Interaction in the Physical Space Around a Tabletop Display

There are several reasons which argue against wall projections or vertical displays for supporting group collaboration. As pointed out in the interviews, such projections are typically focused by the whole group and, thus, impose limitations on group interaction and creative productivity. True parallel work is hardly possible (due to production blocking) and face-to-face collaboration is hindered: people are looking at the projection instead at each other and, in most cases, only one of them is typing in content. This behavior is also stated by research on that topic: Rogers and Rodden [Rodden et al., 2003] found out that groups tend to nominate one participant for writing on a whiteboard and then line up before it. Moreover, the physical constraints of a whiteboard mean that standing in front blocks the view and physical access for others. Hence, only about one or two persons can simultaneously have physical access to the whiteboard even when working in parallel. When sitting or standing around a horizontal table-like working surface, roles are more flexible. The participants can take different positions, are able to look into each others eyes, and are able to use a broad vocabulary of gestures for communication. Even more they can interact with others directly via the tabletop surface broadening the available interaction space. A notable feature of working on a tabletop display was determined in [Ha et al., 2006]: the ease with which users communicate actions and intentions. For this purpose, they used many gestures and interaction types which they would also use when sitting or standing around a traditional table (e.g. pointing on an object or transferring it to another user to signal the intention to talk about its contents). A more detailed examination of possible ways of interaction that can take place directly via a tabletop surface and the implications on an IT support are given later in this section.

Before, a closer look is taken at another advantage of using a tabletop setting for group collaboration: the role of the **physical space around it**. Here, people are able to transfer everyday knowledge of how to interact with both the physical world and with other people to the tabletop display environment [Ha et al., 2006]. As the focus of the users lies in the center of the collaboration area and thus provides a **non-fragmented visibility** between the participants, they can directly **look at each other** and **communicate face-to-face verbally**, via **gestures**, or **eye contact**. Even more, when interacting around a tabletop display, different **body orientations** can be intuitively used as a non-verbal means of signaling the will to interact with someone else. The orientation of a person relates to the direction or angle in/at which someone is facing other persons or objects and is, in our view, represented by the shoulder-line. Using the shoulder-line orientation as well as the physical position of a person can give important clues if this person is in a social situation with others [Groh et al., 2010]. "*For example, facing in the opposite direction with respect to others is a clear sign of non-inclusion.* [...] *The second criterion is face-to-face vs. parallel body orientation and concerns mainly people involved in conversations. Face-to-face interactions are in general more active and engaging* [...]*, while people sitting parallel to each other tend to be either buddies or less mutually interested*" [Vinciarelli et al., 2008, p.8].

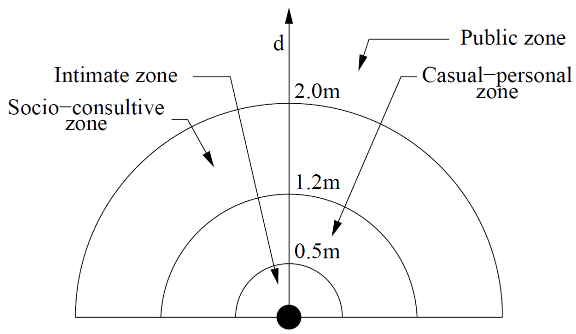

Figure 3.3: Interpersonal distances (d stands for distance) [Vinciarelli et al., 2008, p.13]

Another example of how the physical space between different persons can be used for social interaction is derived from an area of study introduced by Edward T. Hall called **proxemics**. Proxemics is the study of set measurable **distances between people as they interact**. According to [Hall, 1963], the social distance between people is reliably correlated with their physical distance and can be divided into four different concentric zones around a person (see Figure 3.3): the intimate zone (up to 0.5m interpersonal distance), the casual-personal zone (0.5m - 1.2m), the socio-consultive zone (1.2m - 2.0m) and the public zone (>2.0m). Normally, people have the tendency to avoid the intimate zone of others. "*Group members may temporarily be permitted to interact within a person's "intimate" space, but interaction at this distance for prolonged periods will often feel socially awkward*" [Scott et al., 2003, p.12]. The casual-personal zone is the typical distance people favor towards friends or colleagues (people they are familiar with). This zone is about an "arm's length", in which people generally feel comfortable working since this preserves their personal space [Hall, 1963]. Since these distances are mainly dependent on the social relationships people have with respect to each other, psychological characteristics can also play a role: extrovert people, for example, tend to prefer an arrangement that minimizes interpersonal distances, while introvert ones do the opposite. As a consequence, the physical space allows people to dynamically take different positions towards others.

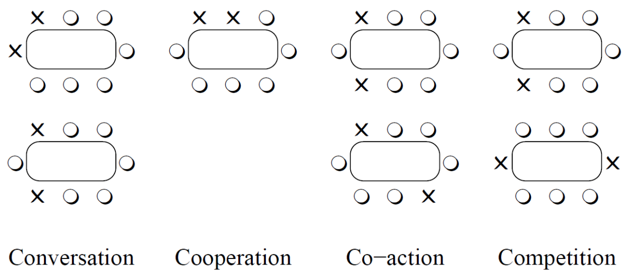

Figure 3.4: Preferred positions (around a table) for different kinds of social interactions [Vinciarelli et al., 2008, p.13]

Even the physical properties of the tabletop display itself can support different ways of collaboration. E.g. when taking **positions around a table** (the so called “seating arrangement”), people tend to position themselves depending on the social interactions necessary to perform a specific task [Knapp and Hall, 1972, Richmond and McCroskey, 1995]. Examples for such seating arrangements and related collaboration activities are shown in Figure 3.4. Circles denote empty positions while the “x” indicates that a place is taken. Another reason for taking a specific position in a seating arrangement is the personality or hierarchy level of a person: dominant and higher status individuals tend to seat themselves at the shorter side of rectangular tables, or in the middle of the longer sides. The reason is that both positions ensure high visibility and provide easier control of the information flow [Lott and Sommer, 1967]. Finally, also the size or the shape of a table can influence seating positions [Scott et al., 2003]. Although various types of shapes are imaginable, the simplest and most common shapes are circular or rectangular. In this regard, e.g. a study on seating preferences in a school library showed that round tables are avoided because it was more difficult to partition the space on their surface than compared to square or rectangular tables [Thompson, 1973].

Summarized, in a setting with a wall projection, where all participants are lined up in front, the differentiation of user positions would not be possible in such a fine grained way as it is possible when using a tabletop workspace. In one of the experiments presented in the evaluation chapter (Chapter 5), measuring the position as well as the orientation was used as one way to determine if and how close people interact with each other in the physical space, while using one of the situative CSS that are presented in Chapter 4. As can be seen, using a horizontal display allows people to intuitively apply social norms and to adapt to different collaboration styles. Consequently one central requirement is to be able to move freely around the tabletop display. This, in turn, also determines how the application (running on the display) needs to be designed. This is subject to the next subsection in which we regard a concept for the public workspace on a tabletop display.

A Concept for a Public Workspace on a Tabletop Display

As a result of any kind of creative process, creative artifacts emerge. As pointed out in Section 2.2.1, these creative products can be quite diverse and depend on the domain in which people are creative. In analogy to the real world, also in an IT application each creative artifact is represented by a virtual object. In the context of traditional web-based CSS, we already pointed out that a higher level of contribution structure should be preferred (Section 2.3.3). In regard to the collaboration of several participants, this has even more advantages. Here, a more **fine grained and modular structure** of the virtual objects allows for a better collaboration. For example, it helps to divide the involved problem-solving activities into several steps. In this way, two users are able to work together on the same virtual object (without interfering with each other) so that a high level of **coupling** and **mutual support** is gained. The importance of allowing for different levels of coupling is also emphasized in [Wigdor and Wixon, 2011] as it decides, if social interactions can be supported successfully.

When designing a tabletop-based IT application, another emerging question is, how the placement of these virtual objects on the tabletop's surface should be realized. Based on the discussion above (free movement of the users around the device) the positioning of the creative artifacts should not be fixed. This way the positions can be adjusted to the position of a user in the physical space around the device (e.g. if he moves to another side or if he wants to view an artifact generated by another user standing on the opposite side of the table). As a consequence, it needs to be possible to move and rotate creative artifacts freely on the tabletop surface. This is also in accordance with the People/Artifact Framework [Dix et al., 1993]: placing objects freely allows for different ways of "feedthrough" communication (the communication through an artifact, see Section 2.3.1). This way, even the digital creative artifacts can be used to support social interaction. An example from the "real world" would be handing over a card to another person which can be interpreted as an intuitive act of communication.

A free object positioning also lets the users smoothly decide how to partition the space on the display. This partitioning is called **territoriality**. Territoriality, in the meaning of the placement of (virtual) objects on a tabletop workspace, helps to **mediate and coordinate (social) interactions** intuitively. As an example, a study on tabletop collaboration involving traditional media showed that users often maintain different areas on a tabletop workspace in order to mediate their interactions with the task objects and with the group [Tang, 1991]. For example, if no area is explicitly reserved for a person, social norms automatically assure that the area in the front of that person is reserved for individual actions such as changing the content of an object. These areas are more commonly known as **personal territories**. A study by Scott et al. on tabletop collaboration [Scott et al., 2004] showed that at most 13% of all performed individual actions take place in other collaborators' personal territories. The remaining space on a tabletop surface which is not occupied by the personal territories is generally considered available for all group members (**group territories**). Group territories are used to share resources with other group members, e.g. for discussion, arrangement, or combination. Hence, the interaction

with objects in the group territories involves more communication and negotiation activity than the interaction with those in the personal territories. The third type, the **storage territories**, originate for example from stacking resources on piles and can emerge on multiple locations on the tabletop surface (overlaying personal and group territories). It was revealed in [Scott et al., 2004] that the location of each storage pile can influence who is utilizing the resources. If a pile is in a more central area, people share the resources. Otherwise, if it is close to someone's personal zone, this user is starting to be responsible for the distribution of the resources.
A typical scenario for territoriality is that when a participant needs to access an item contained in a storage or in someone else's personal territory, he/she would usually ask that person to pass him the item. Hence, personal territories do not imply an isolated work such as using a personal computer, because awareness about the artifacts in the territories is always guaranteed. Moreover territoriality helps to comply with social norms (e.g. to coordinate ownership) and to coordinate intentions. Hence, transferring an object from one territory to another (e.g. by a slide) signals communication and coordination activity [Nacenta et al., 2007]. It also has to be mentioned that the borders of private and public territories should be fuzzy so that they do not pose concrete barriers to the interaction. As territoriality is familiar to humans from real world interaction, its use further helps to minimize cognitive load and thus frees mental resources for being creative.

Another way how a free positioning of virtual objects can aid people in interacting with each other is closely connected to territoriality: **changing the orientation of an object**. Rotating an object on a shared workspace adopts three main functionalities: *comprehension*, *coordination*, and *communication* [Kruger et al., 2003]. A main reason for rotating items on a tabletop surface is to improve their readability, to move them to a position which is best to complete a task, or to regard it from alternative perspectives (→ **comprehension**). This is not only performed for a person's own purpose, but also to help others, e.g. by rotating an object to a specific user in order to explain something. The orientation of items is also used when establishing (personal or group) territories and to communicate ownership or accessibility (→ **coordination**). Thus it plays a mediating role in the coordination of actions between individuals. As an example, in personal territories virtual objects are typically oriented in direction of the corresponding user. This obviously makes these objects less usable by others, as other users cannot read their content comfortably (at least when the content is textual). Consequently, the orientation of items can influence how objects are shared, as they are more likely to be picked up and used if they are oriented towards a user. Finally, changing the orientation of an object can be used for **non-verbal communication** between individuals. "*Orientation plays a mediating role in communication between individuals in a collaborative setting. In particular, orientation is used as an intentional communicative act and is independent from other patterns of communication*" [Kruger et al., 2003, p.374]. Changing the orientation of an object to another person signals that the object, the person's talk, and any accompanying gestures are being directed towards that particular person for communicative purposes. An orientation at an angle which allows two users to read the contents of that object, usually results in discussion or close collaboration activity. Rotating an object to the group results in the same as above, except that the whole group is targeted instead of a single person. Changing the orientation of an object to oneself signals that there is no intention for communication, as the person is doing his/her own personal work.

Territoriality and object positions help to intuitively communicate intentions to other users and to simplify communication, coordination, and interpretation activities on tabletop workspaces. Thereby it can be again argued in favor of tabletop workspaces (and against wall projections) for supporting group collaboration. As a further consequence, it is our goal to support **free participant positions** in the **physical space** and **free object positions** in our **application**. In order to support different types of coupling, the creative artifacts themselves should be composed of **high level and modular contribution structures**. Only if more than one user is able work on the same creative artifact at the same time, highly coupled tasks are possible. However, not every element of an IT application is related to and relevant for all group members. E.g. there is a need for tools which allow for entering data or which support other activities that are only done by a single person at a time (e.g. searching for data or reading information texts). Due to some reasons, these artifacts can be problematic on a public and shared tabletop workspace. A more detailed discussion about that issue is given in Section 3.2.3. Before, another main question to be solved is, in which way multiple users can (and should) interact with a large shared display so that a pleasureful and intuitive interaction with the IT system is achieved. In contrast to many of the previously introduced applications in the related work section (Section 2.3.5), we decided to build upon a novel way of interaction: multi-touch technology. In the following section we discuss how and why this type of application control can be seen as advantageous for creative collaboration and how an application and a related user interface should be designed to support this control paradigm.

3.2.2 Controlling the Application: Touch-based Natural User Interfaces

Studies have shown that **controlling an application by several users at the same time** has some clear advantages over a shared, centralized control by a single person. Although centralized controls enforce a more active group awareness (only one user is controlling the application and all others have to watch his actions), this benefit is gained at the expense of not allowing for simultaneous actions. This demands that the users have to alternate and sequentialize their actions, potentially leading to disruptions in their creative flow. For example, in [Morris et al., 2006] it was found out that parallel control is the preferred method of control regarding the group performance and the users' personal preference. This is also in accordance to the conclusions drawn from the interviews, which highlight the importance of dynamic coupling, parallel interaction and, as a consequence, the reduction of production blocking. This insight is further supported by the research of Scott et al. [Scott et al., 2003], emphasizing the need for parallel input and control of the application to support **group awareness and group articulation**. Allowing for parallel interaction also implies a more **democratic group interaction** (balance of member contributions), because non-verbal contributions are possible for all group members, as the right to control artifacts is distributed. In this way, individual users are not prioritized and thresholds for the collaboration are lowered as particularly self-assured individuals cannot gain full control over the application or the group task in favor of shy ones [Eden et al., 2002]. In summary, being bound to a centralized (non-parallel) input setting is not desirable for a situative CSS.

Concerning the concrete control of an application, it needs to be said that interfaces between humans and computers have run through a long evolution since information technology emerged in the last century. The most important terms to name in this context are the Command Line Interface (CLI), where a user only interacts by typing textual commands and the Graphical User Interface (GUI), typically based on the desktop principle and relying on WIMP[1] user interface elements. While the first uses abstract commands which are applied to an object, in a GUI environment the representation of objects directly reflects their mode of operation and the commands they represent. In this context, Ben Shneiderman coined the term direct manipulation [Shneiderman, 1983], meaning that each action a user performs on an object exerts a directly visible effect. At the time the term was defined, this was mainly achieved by using mice and joysticks to directly manipulate digital artifacts in WIMP desktop environments. This evolution of user interfaces has enabled more people to do more things with computers and broadened the diversity of the computer business [Wigdor and Wixon, 2011]. A main reason is that barriers for novice users were reduced while, at the same time, the functionality of the user interface was increased. When regarding large shared displays, it is clear that the CLI principle cannot be applied reasonably. Using a WIMP-based user interface could theoretically be possible, but would require several parallel input devices such as computer mice and keyboards. The related work regarded in Section 2.3.5 alternatively used digital pens - at this time a state-of-the-art method to directly interact with a display. However, even in these examples, the need of a specific tool (the digital pen) was imposed.

A more novel approach are so called **Natural User Interfaces** (NUI) which are seen as the next logical step in the evolution of user interfaces [Wigdor and Wixon, 2011]. By using the body to control the digital space around us, these interfaces "*promise to reduce barriers to computing still further, while simultaneously increasing the power of the user, and enabling computing to access still further niches of use*" [Wigdor and Wixon, 2011, p.5]. The term **natural** in this regard refers to the way how users **interact with** and **feel about** using an application. While in traditional computer interfaces the use of at least one artificial control device had to be learned, for example, when pointing a mouse cursor on a specific spot, Natural User Interfaces support more advanced and intuitive methods of direct manipulation based on the control of an application by gestures. The two main types of Natural User Interfaces can be categorized into **touch-based** and **free-form input**, as either direct physical contact has to be established with the device presenting the user interface, or it can be operated freely without direct physical contact (e.g. by using gloves, special controllers, real-time video processing). Most interesting for our scenario of creative collaboration is the first category. For example, a study [Ha et al., 2006] showed that direct touch-based input devices foster the support of natural, fluid gestures and the coordination through a greater awareness of intention and action. "*Direct, multi-touch devices hold the promise as a natural input modality*", as they "*better leverage spatial memory* [...] *and*

[1] Windows Icons Menus Pointer

show the promise of easily wielded high-bandwidth input from the user" [Wigdor and Wixon, 2011, p.10]. By directly manipulating an object by performing a (touch-based) gesture on it, human skills for (physical) object manipulation gained from a life-long interaction with the physical environment can be exploited [Klügel et al., 2011].

That's why tabletop devices based on multi-touch technology particularly feature characteristics that support an intuitive collaboration. From a more general point of view, they provide the means for parallel input directly via the display so that in principle multiple users can control an application by concurrently using the same type of input method. As a side note, there are also **socio-psychological factors** that **evolve** from the concurrent **physical interaction on the surface** of a touch-screen. One example is accidentally touching the hands of other users while performing an action, which is generally regarded as unpleasant. In a similar way, the input via touching the surface implies that social norms weigh more strict. As an example, territoriality becomes more important when each action can be directly noticed (or even felt as pointed out above). Two other problems are also related to the interaction via the same physical space. First, some areas on far sides or in the center of a table can be difficult to reach for a user. Second, when arms or hands are used above the tabletop surface, they obscure the display for other users.

When designing multi-touch user interfaces, a variety of different aspects has to be taken into account. One is to provide a **seamless** user experience. As pointed out in [Wigdor and Wixon, 2011, p.43], seamless experiences "*are those in which users are cognitively and emotionally immersed so that they embrace these new experiences and rapidly progress to skilled practice*". To provide such an experience, an application needs to ensure that the interaction with its artifacts is sufficiently close to the real world. This can be taken care of, for example, by **mimicking the behavior of real-world objects**. When a user is interacting with such an object, a direct functional connection between the action and the object needs to be provided. This is the main benefit of touch-based NUIs regarding direct manipulation. For example, when a user is trying to drag a virtual object, this object should move along with his finger. In this regard it is important to rebuild the physical reality as good as possible to not break the illusion of reality. This also means to simulate a realistic physical behavior of virtual objects, such as proposed in [Wilson et al., 2008]. Beyond that, the use of IT allows to extend digital objects by virtual-world capabilities to make them **super real** [Wigdor and Wixon, 2011]. Thus, even something which is impossible in the real world becomes intuitively real. An example for such a "super real" feature would be a two-finger zoom gesture, allowing to enlarge an image.

For multi-touch displays, gestures can be generally divided into two groups determined by the number of touch points on the surface: **single-point** and **multi-point gestures**. In most cases the device cannot differentiate between these raw touch points in terms of their performers or a potential correlation. Even multi-point gestures are to the device single point gestures which are pulled together in their later processing. For this purpose, most applications use their temporal order and their area of origin. In this way, e.g. the previously mentioned two finger zoom gesture becomes possible. This also mitigates another problem with using gestures: **ambiguity**. Ambiguity occurs when similar steps are used for different gestures, for example, when dragging an object to the left reflects a different functionality as when dragging it to the right. Here, both gestures depend on the "one finger down" gesture. It is called ambiguous because at this stage, the system does not know if a drag to the left or to the right will follow. As pointed out in [Wigdor and Wixon, 2011], ambiguity can lead to a higher error rate when interacting with an application. By introducing multi-finger gestures, this problem can be avoided because the vocabulary of possible non-ambiguous gestures is increased. E.g. moving one finger with an object exerts a drag gesture, while using two fingers triggers the zoom gesture.

As a consequence of the discussion above, a user interface should be directly and entirely designed for a touch-based input. Therefore it needs not necessarily copy paradigms and principles of traditional UIs (such as WIMP). But of course, many of the prevalent design concepts of a WIMP-based user interface can be transformed to be operated by simple touch input (e.g. a slider or a button). While in a traditional WIMP user interface, a user has the ability to precisely (pixel-wise) control an application (e.g. by a mouse cursor), touching a finger on a touch sensitive surface covers a much larger area which, in consequence, also raises some critical issues for the design of a touch-based user interface. One problematic effect is called the "fat finger" problem [Wigdor and Wixon, 2011, p.73]. Depending on the way how the touch is recognized, it may not necessarily hit the respective element that the user tries to touch. According to [Wigdor and Wixon, 2011], nearly all currently existing touch platforms (including the iPhone and Microsoft Surface [Microsoft Surface, 2012]) use only a single point within this area to do their hit testing. If that problem occurs, it often cannot be recognized by the user performing the touch (because his finger is in the way). As a solution, the elements a user is interacting with generally need to be **designed large enough** to avoid the "fat finger" problem to happen. According to the research of Wigdor and Wixon [Wigdor and Wixon, 2011], the minimum target size to hit reliably on a large touch screen is 1.6cm, while for smaller touch screens such as on a smartphone it is around 0.9cm.

To further improve the user experience regarding this problem, an application should provide **direct and immediate feedback** to every touch, even if it is not directed onto a virtual object. An example would be a small shadow which is drawn when a finger touches the display's surface, similar to the "contact visualizer" proposed in [Wigdor and Wixon, 2011, p.87]. This way a user is always aware if he hit the right spot or only touched close beside and gets a feeling that the system is responding and working correctly. It should also be mentioned that some transitions when modifying an object's state may require additional visualization aids (e.g. a fade-out animation when an object is removed) to grant the participants a sufficient period of time to recognize what has happened (group awareness). For non-responsive content, visual cues should be integrated (e.g. a deactivated control element should be grayed out).

3.2.3 Private Workspaces on Mobile Devices

As pointed out in Section 3.2.1, a public workspace based on a tabletop display directly and indirectly supports group collaboration in an effective and more natural way than traditional IT. However, even in a true group process, there are always periods in time when one participant is working on his own, e.g. when entering and editing data. Similarly, there are also corresponding elements on the user interface which are relevant to this specific user only. More complex single-user tasks also need more space on the screen as, for example, the elements a user is interacting with increase in size to present more functionality. As a consequence, the public space on the display decreases while the private territories of each user increase. Additionally, depending on the social situation a group is in, also an interaction which is completely in public can raise problematic issues. One responsible effect that has been discussed before is group pressure, the fear of an evaluation (of creative artifacts) by other group members. This fear can hamper the commitment of radical and controversial ideas and restrict an active participation in case of reserved persons. Furthermore, it can also influence the evaluation of creative artifacts in convergent phases. E.g. a participant may rate the idea of a colleague better than he would have, when there would have been more anonymity.

To overcome these shortcomings, a way needs to be thought of which allows a user to disengage from the group activity for short time intervals, but without completely loosing the connection to the overall group process. Such a solution needs to bring together private workspaces and SDG environments without loosing an expressive, face-to-face, and quality-rich group collaboration. Considering that, "real world" scenarios can be regarded. Here, people collaborate around a public artifact (e.g. a whiteboard) and, at the same time, write or sketch their contributions on index cards, which are then pinned to the whiteboard. Thereby, the decision to make their private information public or public information private is left to them at any time [Shoemaker, 2000]. When looking at an IT support, the functionality of providing private workspaces can be taken over by mobile devices such as smartphones or tablets, in the following referred to as **coupled displays**. In contrast to traditional PCs which impose a physical barrier between different users - even when used in a collocated scenario - these devices are lightweight and used in a way "*just as an oil painter effectively uses a palette in his/her hand*" [Rekimoto, 1998, p.344]. Similar to the setting with the index card, one can use a coupled display to anonymously create or modify a (digital) creative artifact and then synchronize it with the public tabletop workspace. Although this process is not 100% anonymous, as all participants still see each other face-to-face, at least it provides a higher degree of privacy than working directly on the public workspace. Furthermore, it helps to keep the public workspace clean of single-user interface elements so that the focus stays on the public artifacts and the interaction with these artifacts. Moreover, accessing these interface elements on the public display would disturb the group interaction as arms and hands overlay the screen and occlude the public territories.

Coupled displays allow for supporting a variety of functionalities, processes, and work styles which are typically bound to single-user systems only. While several projects on coupled displays in Multi Display Environments have been already regarded in Section 2.3.5, a more comprehensive analysis of the related work (and the supported functionalities) has been conducted in the scope of [Frieß and Kleinhans, 2011]. In the following, we briefly summarize in which ways coupled displays can be useful in the context of a situative CSS based on a tabletop display. Furthermore, we discuss which problems can evolve from their use in general and thus have to be kept in mind when designing a coupled display application in the context of Single Display Groupware.

Current mobile devices which are running e.g. on iOS or Android offer a **wide set of built-in functionalities** as well as advanced APIs that allow for a fast development of touch-based applications. They provide, for example, integrated and exchangeable on-screen keyboards for entering and modifying text as well as related functionality for placing the cursor or copying / selecting text. Furthermore, the increased level of privacy provided by coupled displays allows for private communication channels in collocated face-to-face settings. Here, people normally cannot talk to each other in private. Even whispering is not possible due to the direct presence of other group members. By using coupled displays, such a **private communication channel** can be provided, e.g. by a chat feature. Using coupled displays for entering data allows for more fine-grained modes of input than currently available tabletop displays allow for. One aspect in this regard is the precision of the display itself. Modern mobile devices often use capacitive screens to track touches. In contrast, the tabletop devices which were available for the research conducted within this thesis only used infrared cameras for tracking touch points. This technology provides a less precise touch tracking than capacitative screens as they are used for smartphones and tablets [Schöning et al., 2008]. For example, touch-based drawings on small objects on the screen as well as using a virtual onscreen keyboard for entering text were hardly possible (refer to the discussion in Section 5.3 for more information).

Another functionality which can be taken over by coupled displays in collocated situations is **information retrieval**. When collaborating around a public (tabletop) display, the participants typically cannot access private data, because the application is running on a dedicated PC (connected to the tabletop screen) where such data is not available. A coupled mobile device (for example their private smartphone) can solve this problem, as it provides **access to private documents** such as photos, notes, or other files created within third party applications. Nowadays, these files are typically accessed via cloud-based file hosting services such as Dropbox [Dropbox, 2012] and are automatically synchronized with their personal PCs. Furthermore, coupled displays can be used to **access search functionality**, e.g. provided by a Creativity Support System itself (internal content) or by APIs of search engines (external content). Google, for example, offers an image search API [Google Image Search API, 2012] via web services.

In addition to solely aiding the work on creative artifacts in collocated scenarios, private workspaces on mobile devices can also broaden the range of possible creative scenarios beyond a collocated face-to-face setting. By providing a decoupled "offline" state, mobile devices can be used outside the context of the public tabletop display to collect creative artifacts, similar to the applications presented in Section 2.3.4. The need of such a functionality was mentioned in the interviews and is named in literature by the term incubation phase (Section 2.2.3). Moreover, there are also specific creativity techniques which base on the **individual collection of creative artifacts** in a distributed / asynchronous manner (such as the KJ-method (Section 2.3.5)) or which impose the need of single-user phases (such as the Brainwriting 6-3-5 technique (Section 2.2.3)).

Despite the benefits discussed above, using small private devices in conjunction with a large group workspace also encompasses **problems and difficulties**. As a main question, it has to be decided which actions and which information should remain in the public space (= on the tabletop) and which could be transferred to the private space (= the coupled displays). Hence, two main sub-questions arise: how much functionality may be transferred without shifting the focus of collaboration away from the public display (and the group) and how "invasive" should the actions conducted in private be [Frieß and Kleinhans, 2011]? The answer to the first question was already argued in the context of using traditional IT for collocated creative collaboration: working solely on private devices is seen as disruptive to the creative flow and the group interaction in face-to-face settings, as people start **isolating** themselves. The **invasiveness** of actions relates to another problem. Normally, on a public tabletop workspace social norms implicitly regulate the group process to some extent. On the private workspaces the situation is different. E.g. allowing a person to delete the creative artifacts generated by another person in private (= anonymously) could irritate or even anger the owner of these artifacts. As a consequence, such a (private) delete feature would be considered as too invasive.

The resulting conclusion is rather obvious. Actions with a high invasive potential should be limited to be only accessible via the shared public space. In this regard, also the transmission of data from and to the public workspace has to be taken into account. Here, a certain degree of group awareness and a transparent, intuitive user interaction has to be preserved. Hence, each virtual object that is already present on the tabletop should be selected in public for editing it (more anonymously) on the coupled display. This way, the users still have to adhere to social norms such as negotiating with the owner of a creative artifact before modifying it. The same applies for creating new artifacts, with one exception: In case the coupled display is equipped with an offline mode as mentioned above, it needs to be also possible to directly create creative artifacts on the coupled display itself. These artifacts then have to be transferred to the tabletop, which can be realized, for example, by pressing a "transfer" button on the coupled display, or, as in one example from the related work in Section 2.3.5, by a pen-based "pick-and-drop" operation. While in the latter approach the user decides where to place the artifact on the tabletop, in the first approach it should spawn at a spot where currently no other user is active (typically in the center). In this way, the activity of others is not disturbed. Depending on the situation and the desired degree of anonymity, the creator can then choose to drag the artifact to his private territory (on the tabletop) to signal his ownership.

A last mentionable problem of coupled displays are media discontinuities which arise from using different workspaces and different types of devices hand in hand. In order to provide the same view on creative artifacts on different devices and to facilitate their exchange, the data objects should be logically structured and visually represented in the same standardized way. Moreover, with multiple coupled displays in use, the problem arises that the same creative artifact can be accessed via several of such devices. Hence, a **synchronization mechanism** needs to be thought of. E.g. when one user is editing content, this content needs to be locked for all other users who are trying to access the same artifact. For this, the tabletop device needs to act as a central coordinator, to which the lock state is sent and which then distributes this lock state back to all other (connected) coupled displays. The same applies when the edit operation is finished. For the synchronization especially the **performance of the application** (and the **data transmission**) has to be kept in mind to provide a preferably seamless experience and to avoid conflicts resulting from the real-time interaction (e.g. if two users are trying to access the same resource at the same time). Hence, only data elements which are needed on both sides should be transferred so that delays and an unnecessary overhead of data is avoided.

In summary, when integrating new functionality into a coupled display application, the question "*What influence does this feature have on the collaboration with and the work of other users?*" has to be kept in mind carefully. As a consequence, invasiveness needs to be seen as an important classifier for almost all features to be included in a coupled display application. But as pointed out in the discussion above, to distinguish between high and low invasive actions can be a challenging task.

Based on the conceptual thoughts discussed so far, the following section establishes two concrete application scenarios for an implementation. While the first targets the scenario of collaborative creativity techniques in a tabletop environment, the second focuses on the collaborative composition of music.

3.3 Application Scenarios

According to the design-science methodology presented in Section 1.3, a viable software artifact needs to be constructed to investigate on the concepts presented above. While the previous sections regarded special IT devices for implementing a situative Creativity Support System and the design and the interaction choices for a related user interface, this section focuses on two concrete application scenarios.

3.3.1 Collaborative Creativity Techniques

The **first** (and primary) **application scenario** is the collaborative use of creativity techniques. It was considered because of several reasons. First, creativity techniques are commonly used in companies as pointed out earlier in the context of the interviews (Section 3.1.2) and as stated in [Fernald and Nickolenko, 1993]. Second, they are fairly easy to learn, even for **novice users**, because they are typically based on a set of simple rules and constraints. Third, it has been shown scientifically that by using creativity techniques, the generation of ideas is fostered and encouraged (Section 2.2.3). Finally, with the IdeaStream application (Section 2.3.3) available, we had an ideal starting point for an implementation of this application scenario. IdeaStream allows for arbitrary devices to be attached to its application core via its web service architecture and already includes a web-based front-end. Hence, it also provides an ideal platform for performing a comparison of a novel "situative" and a more traditional web-based IT support.

As pointed out in the interviews, using creativity techniques typically involves about a handful of participants, a dedicated moderator, and is especially popular in the scope of creativity workshops, conducted e.g. in the beginning of projects. Such workshops commonly take place in collocated settings, but are also supported by using IT to collaborate in distributed settings. In case of IT support, the moderator can be substituted by an automatic moderation, as it is the case in IdeaStream [Forster, 2010]. However, in practice the moderator is typically maintained to manage and control the process and the restrictions of a creativity technique and to distribute its results to all participants (e.g. via email as mentioned in the interviews). The problems to be solved are commonly represented as a concrete textual question. For example, in our experiments (Chapter 5), we presented the following problem statements to student participants: "*For which purposes could student fees be used?*" and "*How could we improve the food supply at the campus?*". The creative products that emerge when solving such a problem are usually represented in the form of textual or image-based ideas. In scenarios without IT, these artifacts are often written or sketched on index cards and/or flip charts.

Figure 3.5 shows a typical process flow when conducting a creativity session (as it is specified by IdeaStream). In our scenario, the participants first come together at a tabletop device. This device can be placed in a meeting room, but also in other meeting spaces such as a coffee corner or a dedicated "creativity room" to provide a more informal and stimulating physical surrounding.

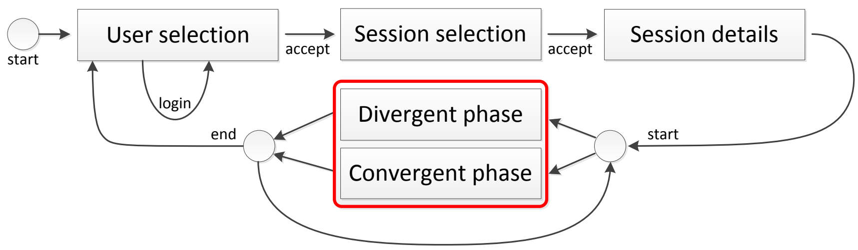

Figure 3.5: IdeaStream application flowchart

Initially, all users have to log in to the application (**precondition 1**) and, in a next step, to select a creativity session. Such a session is created by the session leader via the web front-end and relates to an entered textual problem description (**precondition 2**) and a specific creative process structure, determined by the selected creativity technique (**precondition 3**). This description and the upcoming process flow of the selected creativity technique are then displayed in a separate step - the "Session details" view. From there, the session leader starts the session and the **main creative process** (our primary application scenario) begins. This is marked by the red box in Figure 3.5 and needs to be explained in more detail.

As defined by the process model of IdeaStream, the participants run through one or more divergent and convergent phases that, in their entirety, form a creativity-technique based problem solving process (Section 2.3.3). A detailed derivation of this process model can be found in [Forster, 2010]. Regarding the different creativity techniques that are possible in IdeaStream, the scenario at the tabletop only allows for collaborative techniques in which the participants are working on the same shared workspace. Thus, for example the Brainwriting 6-3-5 technique is not possible, as it requires individual workspaces for each participant. In **divergent phases**, the participants have the opportunity to create, modify, or delete ideas and their particular aspects (texts, images, sketches). Moreover, aspects can be moved to other ideas. All these operations need to be possible by multiple users simultaneously, with one exception. With aspects being an atomic entity, they can only be edited by one participant at a time. Hence, when an operation on an aspect is initiated, a lock state has to be set. This lock is released, as soon the operation is finished. In **convergent phases**, the participants need to be provided with a possibility to review previously generated ideas and to select a rating based on an arbitrary rating scale. Additionally, depending on the creativity technique, in both types of phases restrictions like a time-limit can be provided and need to be enforced (see Section 2.3.3 for more details). As the result of a creativity-technique based session, a final set of ideas (optionally) tagged with ratings as meta-data is gained (**postcondition 1**). Furthermore, an accounting of contributions and actions to the participants needs to be made (**postcondition 2**). For our purposes, this is needed for an evaluation of the application. But, as pointed out in the interviews, it would be also important in a business context.

In the application scenario described above, using coupled displays can take over different functionalities as proposed and discussed in Chapter 3.2.3. Before these functionalities can be provided, first the coupled display has to be connected to the tabletop (e.g. via WiFi). Next, each participant needs to log in at his own device. This should also automatically authenticate the user for the tabletop application (replaces **precondition 1**). Similar to a real world setting, the first purpose for which coupled displays could be used in the context of this application scenario is the (private) input of data such as entering text, drawing a sketch, or adding an image. Furthermore, coupled displays allow to access (and carry) personal data and to search for external (e.g. images or other documents) or internal (an idea database provided by IdeaStream) content. In the convergent phases, the coupled displays can provide a more private way to rate and review the generated ideas. In this regard, the use of coupled displays allows the participants, for example, to take their device and sit down on a chair while rating the ideas or entering content. As the concrete way how the functionalities for the coupled displays are realized is dependent on the implementation of the tabletop application, a more detailed description is given later in Section 4.2.

Finally, creating a tabletop environment for IdeaStream implies that several **quality requirements** have to be taken into account. The first is a **fluid usage of the application**. This means that response times during network communication need to be kept short (in a range of milliseconds). Furthermore, **multiple users** need to be able to work **simultaneously (in parallel)** and in **real time** at the tabletop device. This affects another requirement that comes in conjunction with using the IdeaStream application as a basis: **interoperability** with other IdeaStream clients. Most importantly, a **synchronization mechanism** between different clients needs to be thought of. As pointed out above, for example when an aspect is edited, a lock is set on this aspect. This lock state then needs to be propagated to other clients to avoid conflicts in terms of another client trying to access the same resource. Another example for supporting interoperability with other clients would be to provide a communication channel to communicate with users who are participating remotely (e.g. via web).

3.3.2 Collaborative Composition of (Electronic) Music

The **second application scenario** targets another, more artistic type of creativity. More specifically, we examine how the electronic, solely IT-based composition and performance of electronic music can be supported in real time with a collaborative application on a tabletop device. In the context of this work it needs to be stated that "electronic composition" means that musical elements are solely manipulated with computers and "electronic music" are all sounds which are synthesized by a computer as well. The use of electronic devices in music composition, performance and perception since the middle of the last century has led to electronic music being part of today's popular culture. At the same time, new forms of music composition were introduced to a larger group of people, thereby gradually popularizing IT-supported music composition.

Although several approaches to distributed (asynchronous as well as synchronous) collaborative music composition already exist (e.g. the "Ohm Studio" [Studio, 2012]), novel devices such as multi-touch tabletop displays can open this process into a true collaborative one, bridging between single-user style music composition tools and collocated collaborative music improvisation. In the traditional separation between composition and performance, human performers interpret music notation; in this way the principal perceptual dimensions such as pitch, rhythm and timbre are realized. That is where traditional composition diverges from electronic composition; as the intermediate step of interpretation by the performer is omitted, it burdens the composer(s) with these aspects. In this way, the composition itself incorporates the musical structure and performance [Klügel et al., 2011]. This application scenario particularly demands for social exchange as it can be observed in collocated improvisational settings such as a Jazz session, which made it promising for our purpose. In these settings, musicians communicate face-to-face by immediately and synchronously exchanging and creating novel musical artifacts. Thereby visibility of action, but also nonverbal communication by body language and eye contact become important, as delays of several milliseconds are musically not acceptable and group coordination is also fostered non-acoustically.

Section 2.3.5 already presented the most popular tabletop application for musical expression: the reacTable/scoreTable [Jordà et al., 2006,Jordà and Alonso, 2006]. In contrast to this application which mainly targets the performance of electronic music, the composition of music is typically more process-oriented. As this scenario explicitly demands for **expert users**, it is challenging to be supported by a collaborative tool. A key aspect for composition is to establish a notational system to **express musical events** (the main creative artifacts). These events are typically bundled to **sequences** which are again assigned to specific **instruments**. The unity of all sequences then forms the complete compositional structure. The challenge with that is that a group of participants (like in the previous application scenario typically two to six persons) need to be able to independently, but also collaboratively compose on parts of the same piece of music. Traditional music permits various organizational principles, both hierarchical and non-hierarchical making the communication of musical ideas a knowledge representation problem. In a collaborative setting, it is essential to support organizational principles that are diverse and accessible at the same time in terms of gaining holistic insight into the compositional structure and its modification. Hence, it is a challenge to create a musically **expressive set of notational symbols** whose meaning and effect is plain to all participants. Another requirement for the notation is that it must support **concurrent and simultaneous** collaboration, allowing for different ways of **coupling** to be possible. However, these properties are conceptually difficult to realize for a shared tabletop workspace when using the traditional representation of a score. This is mainly caused by its rigid structure in view of a collaborative context. Hence, a new approach needs to be thought of which has thus to allow for the creation of **meta- and intermediate arrangements** of a composition - a conceptual unification of creating arbitrary musical sketches (separate arrangements) that can coexist and be **gradually shaped into a final composition**.

The concrete realization of this approach and the description of the final application (and its user interface) is subject to Section 4.3. Although we did not go as far as including a coupled display extension to this application, prospects of how these devices could be usefully integrated are also discussed.

3.4 Summary

In the first part, this chapter presented an analysis of interviews, conducted with ten experts on creativity within companies. After introducing the applied interview methodology and the semi-structured interview guideline, we discussed concrete interview statements and established a categorization of typical creative situations and their main characteristics. Next, we took a closer look at the creative collaboration situation and related factors that need to be taken into account for achieving a high quality interaction. On the basis of this examination, we elaborated why collocated situations are most advantageous for a novel "situative" approach to IT support for creativity. In a second step, we explained why large multi-touch tabletop displays are especially tailored for such a support, as they provide an ideal basis for supporting social interaction and group collaboration. Furthermore, we argued why touch-based input facilitates a natural collaboration experience on such devices and described design guidelines for a corresponding user interface. Finally, we introduced coupled displays into that concept by showing chances and challenges of combining these devices with the public tabletop workspace. This chapter concluded by presenting two concrete application scenarios for an implementation of the previously introduced concept.

Chapter 4

Implementation

This chapter presents the implementation of the two main applications developed in the scope of this thesis. Section 4.1 describes the software architecture, the used interaction paradigms, and the design of the user interface of the application concerning the first use case - collaborative creativity techniques on a tabletop display. Section 4.2 then presents an extension of this application by coupled mobile devices (iPhones and iPads). In this connection, we discuss how these devices communicate with the tabletop application (→ the server module) and introduce the software architecture of the coupled display application. Furthermore, we describe its user interface and the supported functionalities. Section 4.3 concludes this chapter by presenting the implementation of the second use case, a tabletop application for collaboratively composing electronic music. In this regard, we describe the implemented compositional structures (sequences and synthesizers) and the collaborative tabletop user interface.

4.1 ISTC: Collaborative Creativity Techniques on a Tabletop Device

This section describes the concrete realization of the application implemented for supporting the first use case (refer Section 3.3.1) - **collaborative creativity techniques on a tabletop display**. The implementation of this use case was first only realized as a tabletop application (Sections 4.1.1 and 4.1.2) and then, in a second step, complemented by a coupled display extension, implemented for smartphones and tablets (Section 4.2). Contributions to the implementation of this application were made in the context of two student projects [Kleinhans, 2009, Kleinhans, 2011]. The concept behind and the implementation and evaluation of the application have been published in two demonstration videos [Frieß et al., 2009, Frieß and Klügel, 2011], as well as two conference submissions [Frieß et al., 2010a, Frieß and Kleinhans, 2011], and three journal articles [Frieß et al., 2012a, Frieß et al., 2012b, Frieß et al., 2012c].

4.1.1 Architecture of ISTC

To simplify and shorten the development of the prototype, we mainly made use of two third party applications. Figure 4.1 shows the interfaces to these applications. The first is IdeaStream, which provides an appropriate process model (based on creativity techniques, see Section 2.3.3) for our use case. Furthermore, IdeaStream takes care of the storage of the respective creative products (ideas) and manages the logging of all actions a user performs. In principle, a tabletop application acts as a client to IdeaStream, whereas we decided to name our application IdeaStream Tabletop Client (ISTC). The second is the cross-platform, cross-device multi-touch framework libTISCH [libTISCH, 2012]. This framework is used for synchronously identifying multiple gestures performed on an (arbitrary) touch-sensitive display and thus allows for the simultaneous collaboration within a group of persons [Echtler and Klinker, 2008]. libTISCH is based on a layer architecture [Echtler and Klinker, 2008, p.464] that covers functionality to detect raw touch points, but also to interpret these touch points as gestures. Hence, there was no need to implement algorithms for gesture recognition by ourselves. In analogy to the implementation of libTISCH, also the ISTC application is implemented in C++. This programming language was chosen as it provides a good balance between performance, cross-platform availability, and graphical capabilities.

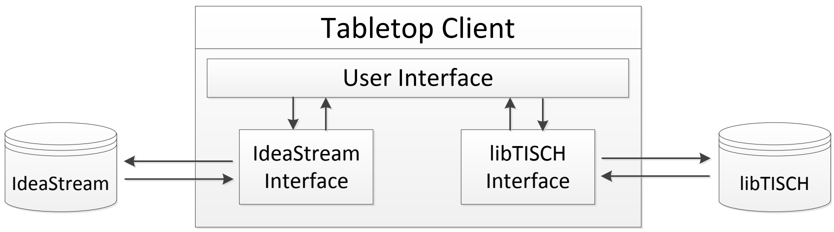

Figure 4.1: Interfaces to IdeaStream and libTISCH

In the following, we first regard the **integration of IdeaStream**, which influenced the **data model** of and the **data flow** implemented in ISTC. After describing mandatory modifications to IdeaStream itself, both are described in the context of the main software architecture of the IdeaStream Tabletop Client. Finally, Section 4.1.2 gives an overview of the implementation of the **user interface**.

Modifications to IdeaStream

IdeaStream is already equipped with a client independent architecture that allows for different devices to be attached to its core. This architecture is shown in Figure 4.2 [Forster, 2010]. The term server relates to the core IdeaStream application, which can be accessed remotely as described by the client-server model. Thus, in later parts of the chapter, we refer to IdeaStream as **IdeaStream server**. The numbered arrows indicate a typical data flow as it occurs when the IdeaStream server is accessed from an arbitrary client (e.g. a tabletop device).

Initially, a client makes a request to the service layer of the IdeaStream server (**arrow 1**). An example of such a request could be a query to retrieve information about the current `ProcessPhase` in which a user is participating. Within a request, unique identification numbers (`IDs`) are transmitted to the service layer. These enable the responsible component to process the request accordingly. As a result, the user performing the request can be identified (e.g. for security reasons or for logging) or (in the example) the desired `ProcessPhase` can be determined. When a request arrives at the service layer of IdeaStream, the relevant components of the data access layer are called (**arrow 2**), which again query the database (**arrow 3**). The reply of the database is then returned to the data access layer (**arrow 4**), where the logical objects are instantiated (**arrow 5**). These are then passed to the service layer (**arrow 6**). Here, in our example, a suitable object method is called on the `Process`, which returns a concrete process phase as an object of the type `ProcessPhase`. This object is then returned to the client (**arrow 7**). The received data (the `ProcessPhase` information) is then processed by the client and visualized according to its user interface.

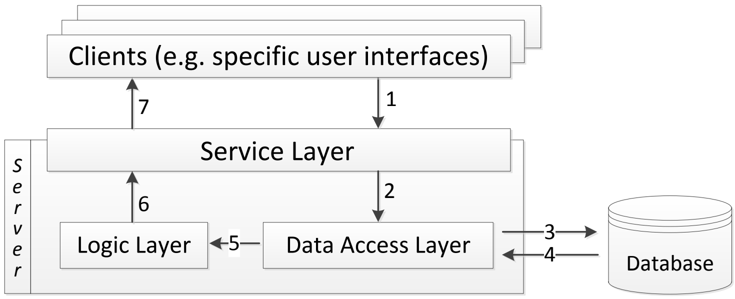

Figure 4.2: Data flow in IdeaStream (adapted from [Forster, 2010, p.89])

For accessing the service layer implementation of IdeaStream we utilized the Hessian protocol [Hessian Binary Web Service Protocol, Version 3.0.13, 2012], which is a lightweight binary web service protocol that builds upon HTTP. Because Hessian relies on its own custom binary format instead of XML for object serialization, the average message length is shorter and objects can be serialized/deserialized faster on both the client and server system [Campo, 2006]. In addition to its good performance, implementations exist for almost any common programming language. Both make it a good and suitable choice for our purposes.

However, one problem that occurred was the fact that the objects used by IdeaStream are quite capacious, including lots of dependencies with other objects. Because of these dependencies, all referenced objects - even those which are not needed - are transmitted. This, in turn, leads to a large amount of data to be transferred and, as a consequence, to a certain delay in data transmission. Even though the Hessian protocol has a feature called references that ensures that every object is only sent once in every request, the amount of data transferred and the delay in data transmission would become simply too large, as the number of referenced objects increases more and more over time (when the application is actively used). To solve that problem, so called Data Transfer Objects (DTO) were introduced to and implemented in IdeaStream. These objects remove the complex reference structures of the real data objects and encapsulate only the information which is needed by a client. A second issue emerged from the unidirectional communication with the service layer of IdeaStream, which causes a problem in the case multiple clients are used in parallel (e.g. web and tabletop). This happens, for example, when an idea is created or modified via one of these clients. This modification then has to be passed immediately to all other connected clients that are e.g. accessing the same session. In theory, these could continuously poll the IdeaStream server for updates. However, this would result in heavy and unnecessary load of the server. As a solution, we implemented custom listener objects to the service layer of IdeaStream, which react to such events. These listeners also make use of remote calls via a Hessian web service implementation, but in the other direction: to a remote service layer which is part of the ISTC application. Hence, in case of an event, the ISTC application and all other possible clients are notified directly by the IdeaStream server via a push mechanism. This allows for changes to be processed faster so that a truly synchronous use is possible.

Data Model of and Data Flow in ISTC

The data model used for ISTC closely resembles a simplified version of the data model used in IdeaStream, basically introduced in Section 2.3.3. As an example, an idea is composed of an arbitrary combination of aspects, similar to IdeaStream. A complete overview of the data objects is provided in Figure 4.3 (data objects). Due to the more simple implementation of the Data Transfer Objects, divergent and convergent phases are both represented by the `ProcessPhase` class and are only distinguished by a flag attribute. Similarly, all types of aspects (images, sketches, and text) are merged into a single class called `Aspect`. In addition, Figure 4.3 gives an overview of the other implemented classes (and their relationships) that were needed for the interoperability with IdeaStream. All corresponding functionality resides in its own namespace, consequently named "`ideastream`". The `ideastream::Interface` class is responsible for the communication to the IdeaStream server. For that purpose, it makes use of two components of the Hessian protocol implementation for C++: `hessian::Proxy` and `hessian::Server`. While the first provides the capability to call remote web service procedures (the service layer of IdeaStream), the latter basically acts as a web server accepting incoming Hessian requests from IdeaStream. All requests to, and also all calls from IdeaStream are passed through these classes, and are then dispatched to one of the concrete `Service` instances. Similar to the service layer implementation in IdeaStream, a `Service` is responsible for handling all functionality that belongs a specific area and serves as both a web service client and server at the same time. Hence, it makes requests to IdeaStream and processes incoming calls from IdeaStream. These are then dispatched to the component of the application that is controlling the user interface by using `Listeners`. Arbitrary classes can implement the methods of such a listener, and register themselves with the respective `Service` to receive event notifications.

As the communication with the IdeaStream server is taking part over a network, in

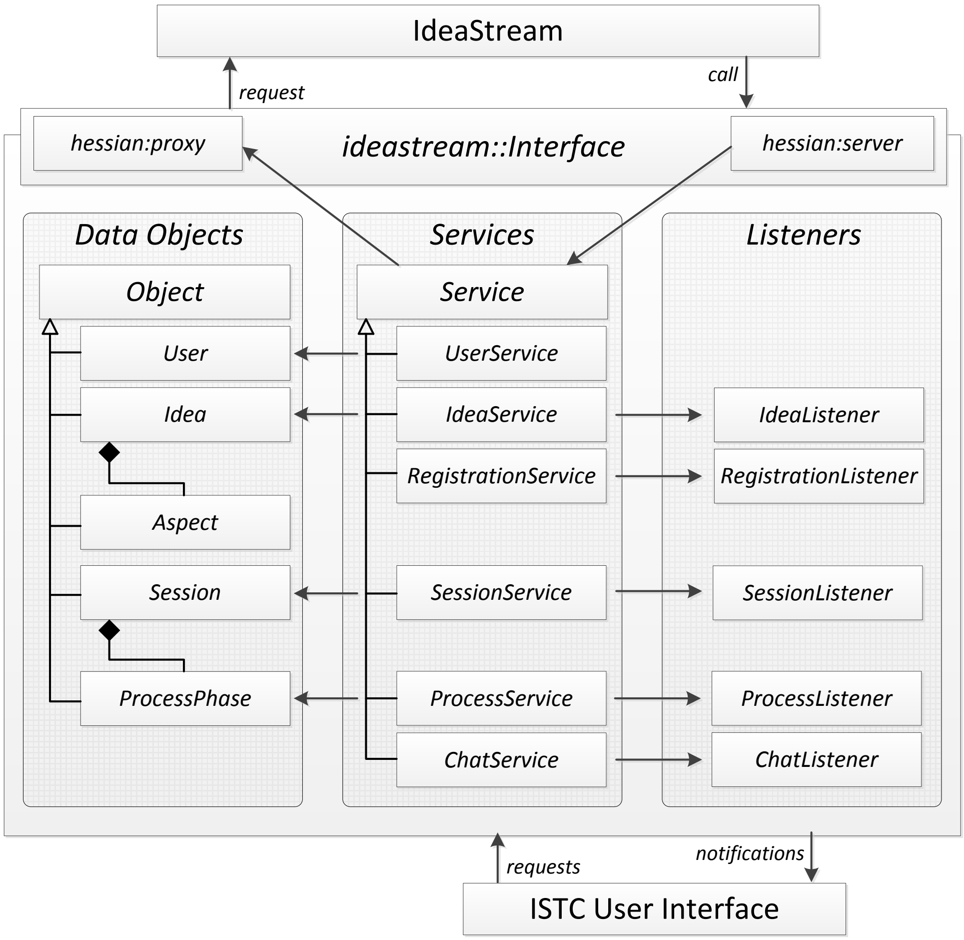

Figure 4.3: Architectural overview of the IdeaStream Tabletop Client

some cases delays in the transmission of data are to be expected. To cope with that issue, multiple threads are used. While the **dispatcher thread** is responsible for sending web service requests to IdeaStream, the **server thread** generates the local web services that accept incoming calls from IdeaStream. Both are responsible for sending/receiving data and for the serialization/deserialization of parameters and results. The results of requests are then processed in the application's **main thread** and dispatched to the object that initially triggered the request. In cases where the timespan between sending a request to IdeaStream and receiving its result gets too long, the proxy pattern is applied. For example, when the `getUser`-method in the `UserService` of the ISTC application is called, it immediately returns an empty `User` object. Then, a web service request is made to the corresponding `UserService` instance in IdeaStream and the `User` object is filled with data as soon as this request has finished. In case a user does not exist, the proxy object is marked as invalid. By using proxy objects, the ISTC application can immediately pass a result to other classes or methods before the data is actually available. This simplifies the application flow and increases the speed of the application. Fortunately, the situation is easier for incoming calls from IdeaStream. In the context of the ISTC application, all of these calls are just notifications to the tabletop client and do not require return values. Otherwise, the IdeaStream server would have to wait for the call to finish.

At this stage, the last missing part of the diagram shown in Figure 4.3 is the **user interface** of the IdeaStream Tabletop Client. With this term we mainly refer to the implementation of the diverse user interface elements and the functionality that was needed to interact with them. For this interaction, the touch recognition framework libTISCH was used and a realistic physics simulation added.

4.1.2 The ISTC User Interface

This section focuses on the ISTC user interface. First the **integration of libTISCH** is described. The second part of the section introduces the applied **physics engine** based on Simple Rigid Body Dynamics. Finally, the software **architecture** of the UI elements (the so called **widgets**) and their **concrete graphical representation** is examined.

As pointed out earlier, we used the multi-touch framework libTISCH to identify gestures performed on a touch-sensitive tabletop display. This display has to be connected to the computer which is running the ISTC application. All functionality in ISTC that is related to the integration of libTISCH is bundled within the namespace "`tisch`". Figure 4.4 shows the relationships between the main classes in this namespace. The central class is `tisch::Interface`, which manages the socket-based UDP connection to the background service of libTISCH. This service, the so called gesture demon (`gestured`), handles the touch and gesture recognition. For this purpose, it needs to be provided with information about regions on the screen that respond to touches (so called zones - defined by the outline of a polygon) and a list of gestures to be matched.

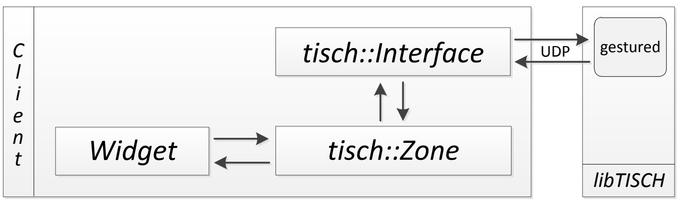

Figure 4.4: Integration of libTISCH

All UI elements in the ISTC application with which a user is able to interact, extend from the `Widget` class. The different concrete types of these so called **widgets** are introduced later in this section. Every time a new `Widget` is instantiated, also an instance of the `tisch::Zone` class is created and registered within the `tisch:Interface`. `tisch:Zone` is responsible for holding information about the areas on a widget that are responsive to gestures (the zones) and the list of gestures that can be applied onto them. In analogy to the integration of IdeaStream, `tisch::Zone` uses the `tisch::Interface` class to send this information to `gestured` which, in turn, dispatches all incoming touch events back to `tisch::Zone` (also via `tisch::Interface`). The `tisch::Zone` instance now ensures that the respective `Widget` is updated and visual feedback is provided to the user. For example, depending on the performed gesture, it updates its position, angle, or size.

Guided by the goal to make the interaction with the application even more realistic, a physics engine was added to the ISTC application. This engine was found in a completely different area of informatics: game development.

Physics: Simple Rigid Body Dynamics

In traditional desktop environments based on the WIMP input principle, there is typically no need for a simulation of physics. Hence, most of the developments and concepts in terms of simulating physical effects can be found in the fields of game development and simulations. The physical effects that are to be simulated for this application are pushing / flipping an object over the tabletop surface. To do so, typically one or more forces (touches) are applied onto this object. It then start to move into a specific direction and, depending on where the force (the touch) was applied, to rotate. To simulate these effects, a comparatively simple approach called "simple rigid body dynamics" was used. The ideas behind this approach are based on a series of articles by Chris Hecker [Hecker, 1996,Hecker, 1997a,Hecker, 1997b]. At the time these articles were published (1996), most commercial games were built upon a principle called **kinematics**, the study of movement over time [Hecker, 1996, p.14]. Kinematics does not deal with the reasons that are causing a movement behavior and, instead, just deals with the actual movement itself. Another term which comes up in this context is **dynamics**. Dynamics is the study of forces and masses that cause the kinematic quantities to change as time progresses [Hecker, 1996, p.14]. The difference between the two concepts is illustrated in an example:

> "*How far a baseball travels in 10 seconds if it's traveling 50 kilometers per hour in a straight line is a kinematics problem; how far a baseball travels in the earth's gravitational field if I smack it with a bat is a dynamics problem*" [Hecker, 1996, p.14]

As pointed out by Hecker, the term "rigid body" refers to a **constraint** placed upon the objects to be simulated: a rigid body **never changes** its **shape** during the simulation. In the context of this application, two additional constraints are used. First, **only rectangular** rigid **bodies** (the widgets) are to be simulated. This way, the physics equations can be further simplified. Second, instead of giving different widgets different masses, we decided to set the **default mass** for all widgets to a **value of 1**. Third, the physics simulation of our application only needs to take into account a **two dimensional space** (the tabletop surface), so that z-coordinates can be seen as constant (widgets move in a two dimensional space, z-coordinates are only used to position them on top of each other, to bring them to the front, etc.).

It may be surprising that an important aspect of rigid body dynamics is that interacting with (e.g. pushing) an object does not directly affect its position: "*you actually can't* *directly move an object by pushing on it*" [Hecker, 1996, p.14]. What does affect an object's movement is its acceleration. Equation 4.1 shows the relation between an object's position ($\mathbf{r}$), velocity ($\mathbf{v}$), and acceleration ($\mathbf{a}$). A dot means differentiated with respect to time and a double dot means twice differentiated. Vice versa, integrating the acceleration over time gives the velocity of an object, and integrating the acceleration twice gives its position.

$$\frac{d^2\mathbf{r}}{dt^2} = \ddot{\mathbf{r}} = \frac{d\dot{\mathbf{r}}}{dt} = \frac{d\mathbf{v}}{dt} = \dot{\mathbf{v}} = \mathbf{a} \tag{4.1}$$

Based on this equation, it needs to be explained how the interaction with an object influences its acceleration. When interacting with an object, typically a force is applied at a specific point (of the object). According to Newton's law, a force ($\mathbf{F}$) is in relation to the derivative of the mass times the velocity. The **mass times the velocity** is called the **linear momentum** and denoted by $\mathbf{p}$. Because mass is considered constant (at the involves speeds) it drops out of the derivative so that Newton's $\mathbf{F} = m\mathbf{a}$ is gained. For single point masses, this would provide everything that is needed to calculate how a given force influences the acceleration. However, for more complex shapes another simplification is used to simulate rigid body dynamics: the concept of the **Center of Mass (CM)**. In the case of rectangular shapes, the center of mass ($\mathbf{r}^{CM}$) is trivially the center of the rectangle. Fortunately, all that is needed to calculate the acceleration of a rectangular object is to calculate the acceleration for this point. If multiple forces are applied, these can simply be summed up to one vector of total force ($\mathbf{F}^T$) before beginning the calculation. The $\boldsymbol{M}$ in the following equation refers to the total mass of the body (in our case equal to 1). A more detailed derivation can be referenced in [Hecker, 1996, p.16].

$$\mathbf{F}^T = \dot{\mathbf{p}}^T = \frac{d\mathbf{p}^T}{dt} = \frac{d(M\mathbf{v}^{CM})}{dt} = M\dot{\mathbf{v}}^{CM} = M\mathbf{a}^{CM} \tag{4.2}$$

$$\Rightarrow \mathbf{a}^{CM} = \frac{\mathbf{F}^T}{M} \tag{4.3}$$

By using Equation 4.3, the acceleration for the center of mass can now be calculated. Next, the result can be integrated once or twice to obtain the velocity or position. This method is called *numerical integration of ordinary differential equations* as explained in [Hecker, 1996]. This way, the following equations can now be derived in order to incrementally calculate the velocity $\mathbf{v}_{n+1}$ and position $\mathbf{r}_{n+1}$ for a simulation step of **duration** h [Hecker, 1996, p.20].

$$\mathbf{v}_{n+1} \approx \mathbf{v}_n + h\dot{\mathbf{v}}_n = \mathbf{v}_n + h\frac{\mathbf{F}_n}{M} \tag{4.4}$$

$$\mathbf{r}_{n+1} \approx \mathbf{r}_n + h\dot{\mathbf{r}}_n = \mathbf{r}_n + h\mathbf{v}_n \tag{4.5}$$

Using the physics simulation of rigid bodies in the way explained above still lacks one important aspect of realistic physics: **angular effects** [Hecker, 1997a]. As an example, when a widget is pushed into one direction it not only starts moving into this direction. Depending on the way how and the position where the "push" was performed, it also gets an angular spin, resulting a change of its orientation over time.

For this purpose, another kinematic quantity is added: the **orientation**, denoted by a Ω. As shown in Figure 4.5, Ω is defined as the angular difference (in radians) between a world coordinate system (x_w, y_w) and a coordinate system fixed on the rigid body (x_b, y_b). Ω is positive in the counterclockwise direction. Now it becomes clear why the restriction to a two dimensional space makes things easier: the orientation is just a scalar. On basis of this definition, the next kinematic quantity, **angular velocity** (ω), can be defined in analogy to Equation 4.1:

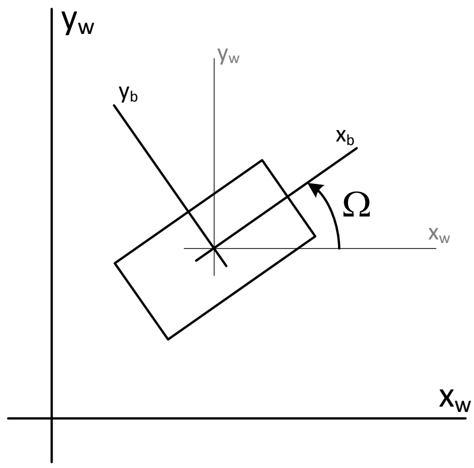

Figure 4.5: The definition of Ω (adapted from [Hecker, 1997a, p.15])

$$\frac{d^2\Omega}{dt^2} = \frac{d\omega}{dt} = \dot{\omega} = \alpha \tag{4.6}$$

Like in the example for linear movement (in which the body's new position was determined) the **angular acceleration** α can be integrated twice to gain the new orientation of the respective body. However, before this can be done, α needs to be known. For this purpose, the linear acceleration **a** and the angular acceleration α have to be calculated from a force **F** that is applied on the object.

With introducing angular effects, a novel problem arises. In contrast to a setting without angular effects, where the velocity of any point in the body is the same, in a rotating body every point might have a different velocity. As it is not possibly to keep track of an infinite amount of points in the rigid body, a simpler way needs to be thought of: using the angular velocity. For a body that is only rotating (and not translating) around a **fixed origin O** (see Figure 4.6) the resulting equation is as follows:

$$\mathbf{v}^{\mathrm{B}} = \omega \mathbf{r}_{\perp}^{\mathrm{OB}} \tag{4.7}$$

In the equation, v^{B} is the velocity of an **arbitrary point B** on the body. r^{OB} means the vector from the origin of the body O to point B. The upside-down T subscript is the "**perpendicular operator**" [Hecker, 1997a, p.18], which takes a vector (e.g. r^{OB}) and rotates it counterclockwise by 90 degrees. This creates a new vector which is then scaled by the angular velocity ω, resulting in the linear velocity v^{B} (right part of Figure 4.6). With this knowledge, Equation 4.7 can be explained. As shown in the left part of Figure

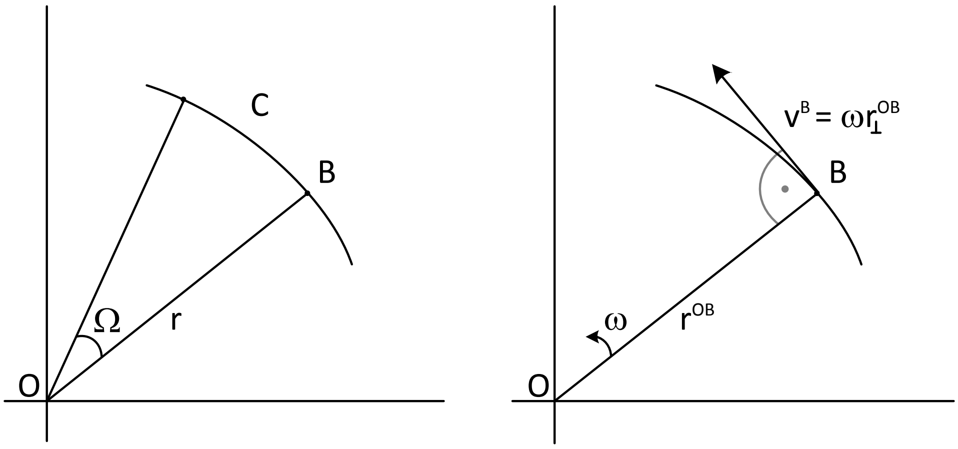

Figure 4.6: Linear velocity from angular velocity (adapted from [Hecker, 1997a, p.18])

4.6, point B is moving Ω radians during the body's rotation. The radius vector from the origin to point B is r units long. Hence, B has moved C $= \Omega r$ units of arc length on the circle (radian measure is the measure of arc length scaled by the radius of the circle). As the speed of a point is its change in position over time, the speed of point B can now be found by differentiating the equation for its movement (C) with respect to time. According to Equation 4.6, the time derivative of Ω is ω. As the radius is constant (the body is not translating) it drops out of the derivative:

$$\frac{d(\Omega r)}{dt} = \frac{d\Omega}{dt} r = \omega r \tag{4.8}$$

When regarding Equation 4.7, one can see that this magnitude is correct because the perpendicular operator does not effect a vector's length. The assumption that the velocity vector's direction must be perpendicular to the radius vector makes sense intuitively: A point rotating around another fixed point cannot move closer or farther away from that point because the movement would, otherwise, not be a rotation. Now only one thing remains: the direction (sign) of the velocity vector v. With Ω being measured counterclockwise, ω is positive when the point is also rotating counterclockwise. Consequently, the perpendicular operator points in the counterclockwise direction relative to the radius vector (cp. right part of Figure 4.6).

When considering the movement of a rigid body as a translation of a single point (in our case the origin O) with the rest of the body rotating around that point, an extension of Equation 4.7 for moving bodies can be made. For this purpose, a theorem by the mathematician Michel Chasles (1793-1880) (the so called **Chasles' Theorem**) can be used. According to this theorem, the motion of an object can be divided into a linear, followed by an angular component [Hecker, 1997a].

$$\mathbf{v}^{\mathrm{B}} = \mathbf{v}^{\mathrm{O}} + \omega \mathbf{r}_\perp^{\mathrm{OB}} \tag{4.9}$$

Now, the **angular momentum** L^{AB} of a point B to a point A can be defined as seen in Figure 4.7. The dot product of the "perpendicularized" radius vector with a point's (in our case: point B's) linear momentum is called the **perp-dot product** [Hecker, 1997a, p.19]). The perp-dot product is equivalent to the magnitude of the cross product of two 2D vectors (when assigning them a 'temporary' z-value of zero) and has the same characteristics. For example, the perp-dot is proportional to the sine of the angle between the two vectors, and is also proportional to the area of the triangle defined by the two vectors. In a more general approach which is not bound to a 2D space, the angular momentum is consequently calculated as a cross product of the original radius vector and the linear momentum of a point (such as it is the case in Equation 4.10). As shown in Figure 4.7, the dot product is measuring the cosine of θ between $\mathbf{r}_{\perp}^{AB}$ and the linear momentum p^{B}. If B's linear momentum is aiming directly at or away from A, L^{AB} is 0, since $\mathbf{r}_{\perp}$ forms a right angle with p. In analogy, if more of B's momentum is directed perpendicular to A, the angular momentum increases. In more easy words, the angular momentum is measuring the quantity of B's linear momentum that is in the "rotating-around direction" with respect to A. The angular momentum's derivative can now be used to calculate a **force's angular twin**, also known as **torque** and denoted by a τ (see Equation 4.10).

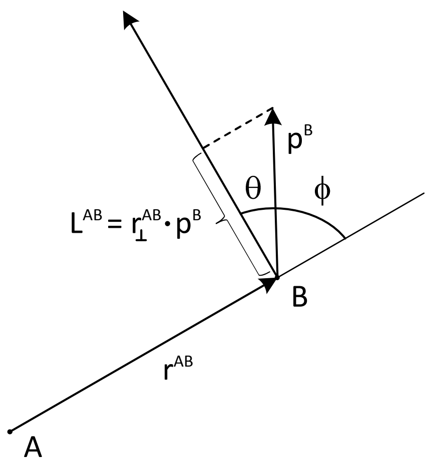

Figure 4.7: Angular momentum (adapted from [Hecker, 1997a, p.19])

$$\begin{aligned}\tau^{AB} &= \frac{dL^{AB}}{dt} = \frac{d(\mathbf{r}^{AB} \times \mathbf{p}^{B})}{dt} \\ &= \mathbf{r}^{AB} \times m\mathbf{a}^{B} = \mathbf{r}^{AB} \times \mathbf{F}^{B}\end{aligned} \tag{4.10}$$

By calculating the torque from a force that is applied on a specific point of an object and by then integrating it, the angular momentum can be calculated. In order to calculate the total angular momentum for an object, the sum of all angular momenta for each of these points has to be calculated. For a rigid body which is composed of surfaces rather than separate points, this can be performed by an integration instead of a discrete summation [Hecker, 1997a, p.20]). In our case of rectangular-only bodies only, this makes it even easier. On this basis, the final equation can be derived, giving an equivalent to $\mathbf{F} = m\mathbf{a}$ for angular dynamics.

$$\tau^{AT} = \frac{dL^{AT}}{dt} = \frac{d(I^{A}w)}{dt} = I^{A}\dot{w} = I^{A}a \tag{4.11}$$

For the equation, a new quantity called **moment of inertia** (I^A) is introduced as simplification. According to Hecker, "I^A *is the sum of the squared distances from point A to each other point in the body, and each squared distance is scaled by the mass of each point.* A more detailed explanation of the moment of inertia and how this equation can be deduced is given in [Hecker, 1997a, p.20-21]). There, also the final **dynamics algorithm** that is used in our approach is defined:

1. Calculate the CM and the moment of inertia at the CM → both are clearly defined fixed values for rectangular objects.
2. Set the body's initial position, orientation, and linear and angular velocities.
3. Figure out all of the forces on the body, including their points of application.
4. Sum all the forces and divide by the total mass to find the CM's linear acceleration (Equation 4.5).
5. For each force, form the perp-dot product from the CM to the point of force application and add the value into the total torque at the CM (Equation 4.10).
6. Divide the total torque by the moment of inertia at the CM to find the angular acceleration (Equation 4.11).
7. Numerically integrate the linear acceleration and angular acceleration to update the position, linear velocity, orientation, and angular velocity.
8. Draw the object in the new position, and go to Step 3.

To avoid objects "falling off" (= moving out of) the tabletop's edges, the physics simulation was further extended by a collision detection algorithm, also based on the previously discussed concepts [Hecker, 1997b]. This simulation of rigid body dynamics was then added to the currently existing implementation of the widgets by including corresponding methods in the `tisch::Zone` class. This way the physics is taken into account when a touch-based gesture is performed onto a spot on a widget's zone.

User Interface Elements: The Widgets

Finally, this section presents the implementation of the concrete widgets. Figure 4.8 shows a class diagram of all classes that belong to this implementation. It has to be mentioned that there exist relations to the data objects and services shown in Figure 4.3 (page 89), which are not included in the diagram for gaining more clarity. For example, an `AspectWidget` is associated to an `Aspect`, in which the information about its content (text, images, sketches) is stored. Furthermore, as pointed out earlier, all widgets extend from the `Widget` class (Figure 4.4) which is also hidden.

The central class to the implementation of the UI is the `Application` singleton. The `Application` singleton is responsible for instantiating and managing the application's widgets, keeps track of all users who are signed in at the tabletop device, and holds further information about the currently active session. For each user who signs in at the tabletop an instance of the `UserInfo` class is created, which stores information about the widgets belonging to this user. In the following, we introduce the graphical layout of these widgets

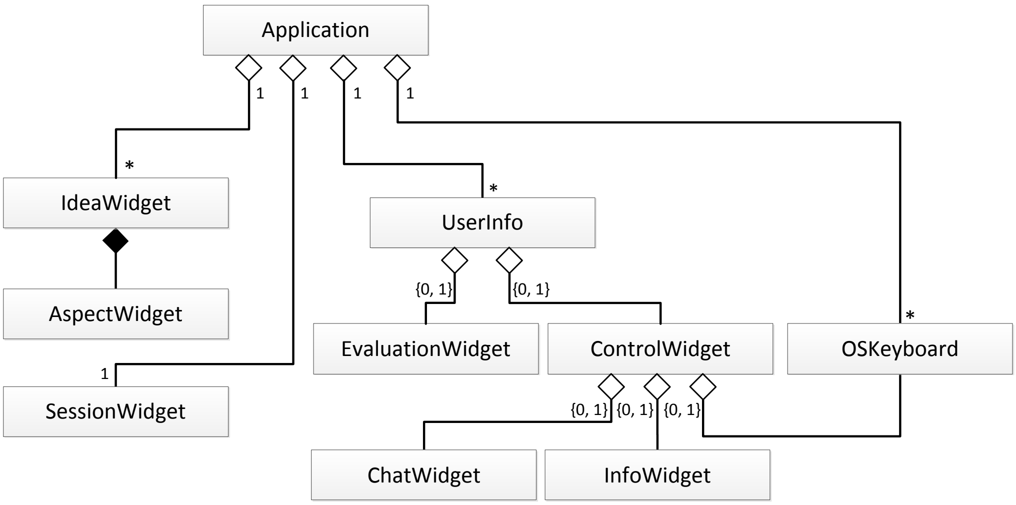

Figure 4.8: Architecture of the user interface

and describe their main functionalities. The implementation is based on a custom OpenGL toolkit that was brought in in the context of a bachelor's thesis [Kleinhans, 2009]. The widget-based approach was particularly designed for touch input. Hence, all widgets can be dragged and rotated and some of them also scaled. A live demonstration of the UI can be viewed in two demonstration videos [Frieß et al., 2009, Frieß and Klügel, 2011].

As pointed out in the flowchart from Figure 3.5 (page 81) in Section 3.3.1, initially all participating users have to sign in at the tabletop device. This functionality is provided by the `SessionWidget` class. Hence, the related session widget displays the **login screen** as shown in Figure 4.9. It contains a list of the users who are currently logged in at the tabletop device and an additional login form to add users. The `OSKeyboard`, whose exact functionality is explained later, is used to type in text (e.g. a login or the password). At this stage, only one user is able to interact with the application (log in) at the same time. When all users are logged in, touching the button at the bottom of the widget switches to another view, which shows a **list of all currently available sessions**. Selecting a session from this list by tapping onto its list entry activates the last view of the widget: the **session agenda**. At this point, a list of all participants (even the participants who join from other clients such as the web client) is shown. Furthermore, the textual problem statement as well as information about the creative process (the creativity technique) is shown. By tapping onto the start button at the bottom, the UI can now be switched into the session mode, which allows for the control of the application by multiple users simultaneously. Here, a variety of widgets is available to each user. These are described in the following enumeration. While the number of each enumeration item refers

Figure 4.9: Session widget

to the number shown in Figure 4.10, the related class-name (always provided in round brackets) can be referenced in Figure 4.8.

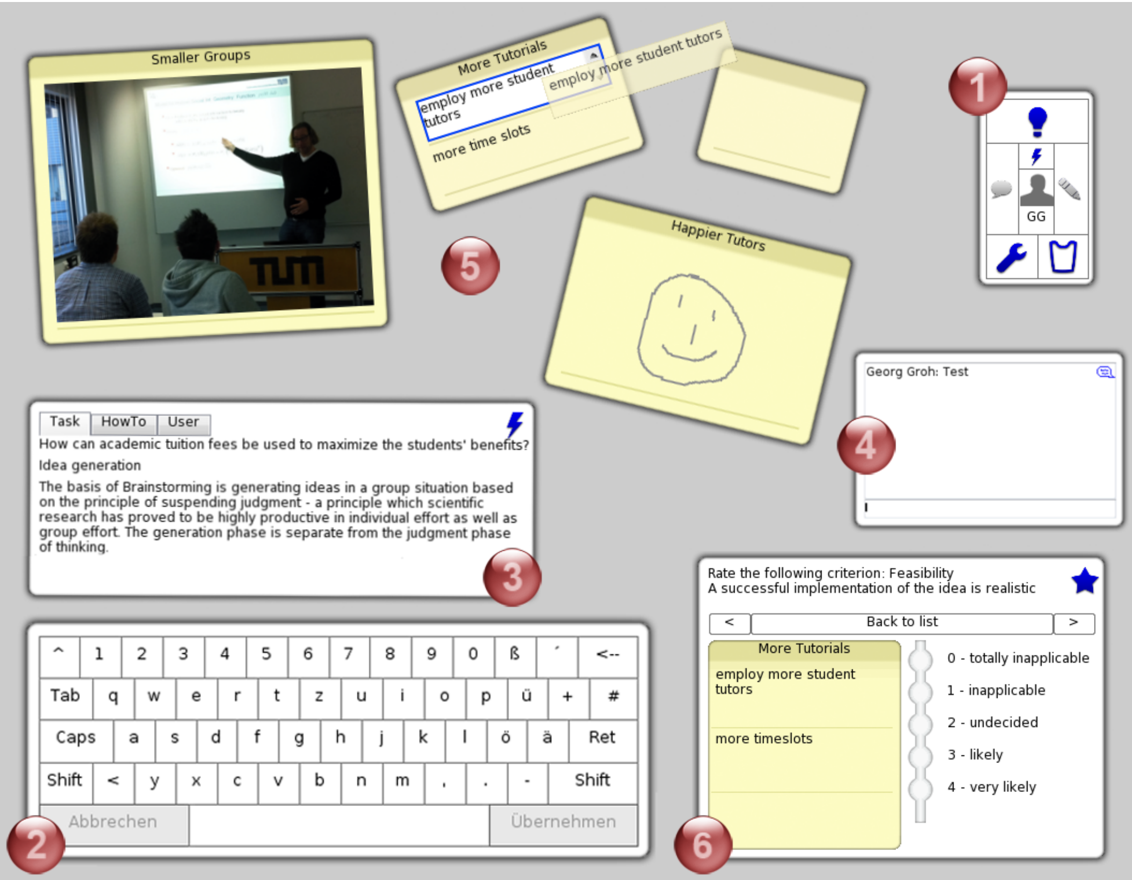

Figure 4.10: Widgets of the ISTC user interface (adapted from [Frieß et al., 2012a, p.60])

1. **Control Widget (`ControlWidget`):** The personal control widget acts as a starting point for most actions in the system. It is used to open and control three other widgets that are aggregated to it (see Figure 4.8). The first is the virtual onscreen keyboard ((`OSKeyboard`), "pen" button), the second the chat widget (`ChatWidget`, "speech bubble" button) and the third the information widget (`InfoWidget`, "flash" button). The use of graphical buttons for triggering actions instead of gestures has the advantage of providing visual clues for the user. Moreover, a user has to use his own control widget (ownership information is indicted by the user's color) to create new ideas and aspects or to mark existing ones for modification. This way contributions and actions of each user are accounted and the focus of input (e.g. from a user's onscreen keyboard) is directed to a specific widget, idea or aspect. This was needed, as typically a tabletop device does not provide any special mechanism or hardware for tracking a specific user. The interaction to create new ideas ("light bulb" button) or to mark them for modification (edit - "wrench" button, delete - "dustbin" button) works by a drag and drop mechanism. First, a user has to press

(= touch on) the button on the control widget and then drag his finger to an empty spot on the table or to an existing idea / aspect. As soon as the finger is released, the action is performed on its last position. To aid the user, accessible areas (e.g. aspects) are highlighted when the finger is dragged onto them. When moving a finger over the tabletop surface, a virtual shadow is shown on the position where the finger is currently positioned. If an aspect or an idea is edited, it is internally locked during the time of modification so that no other user (even those who are joining remotely via the web client) is able to change its content during this period. Therefore, this lock state has to be sent to the IdeaStream server. Also vice-versa, if an aspect is edited via another interface (e.g. web), it is locked for tabletop users and cannot be selected for modification. To visualize such a lock to a user, the locked area is grayed out. Using the control widget as starting point for most of the actions provides another benefit: it allows to activate or deactivate actions according to the rules of specific creativity techniques. For example, in Figure 4.10 (item 1) there are two deactivated (grayed out) buttons. Finally, the orientation of the control widget is used as an indicator to initialize the orientation of other widgets (e.g. new ideas), as it is to expect that the control widget is typically oriented towards the corresponding user.

2. **Onscreen Keyboard (`OSKeyboard`):** As already pointed out earlier, the ISTC application is equipped with virtual on-screen keyboards for textual input directly via the tabletop surface. An example of such a keyboard is shown in Figure 4.10 (item 2). One reason for using a machine friendly way for textual representations (in contrast to sketched / hand written words) was the need to be able to make modifications, which is an explicit requirement of some creativity-techniques (e.g. Brainstorming). Additionally, it allowed for easier interoperability with other possible clients being attached to IdeaStream (e.g. a web client). The textual representation of content also allows for supplementary services like searching through ideas or an automatic semantic evaluation. Multi-touch functionality enables the input of content via several of such keyboards in parallel, leading to less production blocking. Moreover, it allows a user to perform the same keyboard operations as in the real world. As an example, holding the "shift" key and pressing another key at the same time to write in capital letters is possible. In addition to their real world counterparts, the virtual keyboards can be resized (to a limited minimum and maximum size) via a two finger scale gesture. The keyboard can be used to enter text either into aspects or the idea title, to chat, but also to log in users in the beginning of a session. The latter is the reason why the `OSKeyboard` does not need to be aggregated to a `ControlWidget`, because it then cannot be associated with any user.

3. **Information Widget (`InfoWidget`):** To communicate the description of the problem and additional information about the creative process, an information widget is provided for each user (Figure 4.10, item 3). This widget displays information about the current process phase such as the main task, but also additional information such as constraints (e.g. a time-limit) or instructions belonging to a specific creativity technique. It also includes supplementary information like an overall "HowTo" of the current creativity technique and a list of users that are currently participating in the

session.

4. **Chat Widget (`ChatWidget`):** To communicate with other users who are connected remotely, e.g. via the web client of IdeaStream, the `ChatWidget` can be used (Figure 4.10, item 4). In a collocated context at the tabletop only, the chat could provide a means for "whispering" with other users.

5. **Idea and Aspect Widgets (`IdeaWidget, AspectWidget`):** According to the process model used in IdeaStream (see Section 2.3.3), two types of process phases need to be supported: divergent and convergent phases. For divergent phases, the main creative artifacts are ideas which are composed of different types of aspects. Each of these ideas is represented by an `IdeaWidget` which consists of one or more `AspectWidgets`. In the final version of the application, an `AspectWidget` can contain text, images and sketches. We decided to adapt the layout of ideas to real world index cards, a concept that has already been proposed in [Hilliges et al., 2007] and which is in line with the design principle "form ever follows function" [Sullivan, 1896]. Different aspects in the same idea are separated by a small horizontal line that can be dragged to increase the vertical size of an aspect. In terms of functionality, the following features are available: editing, reordering, moving (see the aspect "employ more student tutors" in Figure 4.10, item 5), and deleting an aspect. Additionally, the title of an idea can be edited and ideas can be deleted and resized as a whole (by a two finger scale gesture). It has to be mentioned that the image and sketch aspects were first introduced with the coupled display extension presented in the next section.

6. **Evaluation Widget (`EvaluationWidget`):** While in divergent phases ideas are generated, IdeaStream also allows the assessment of ideas in convergent phases. For this purpose, each user is provided with his own `EvaluationWidget` (Figure 4.10, item 6). The evaluation widget consists of two different views. The first lists all (previously) generated ideas. These ideas can then be selected for evaluation by tapping on their title. The second view (which is triggered when an idea is selected) displays the selected idea and its aspects. If an idea has too many or too long aspects, a slider is displayed on the right of the idea. In the same view, the user can evaluate the idea with respect to a specific criterion by selecting a rating score. In case of the example, the criterion is "feasibility" and the ratings range from 0 (totally inapplicable) to 4 (very likely). If the evaluation technique involves more than one criterion, two evaluation phases are conducted in succession, each involving their own instances of the evaluation widget. The "arrow"-shaped buttons on the top can be used to cycle through all ideas without returning to the main list view.

Figure 4.11 shows a photo of the prototype of the ISTC application in use. This prototype was then tested in a preliminary study (Section 5.3) to find out about potential weaknesses. Based on insights gained from this study, it was extended by a coupled display implementation that is subject to the next section.

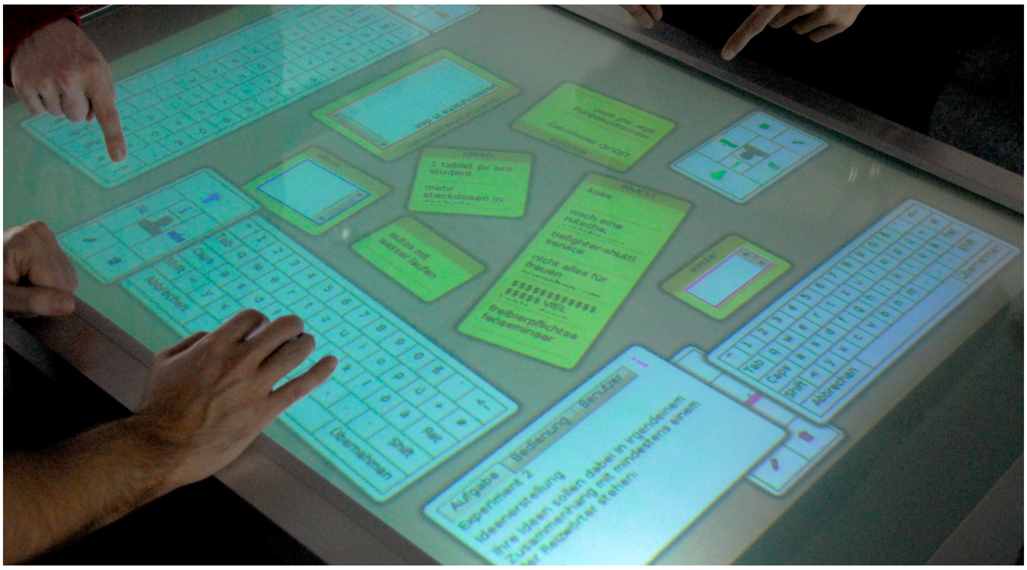

Figure 4.11: Prototype of ISTC in use

4.2 Extension of ISTC: Coupled Mobile Devices

As discussed in Section 3.2.3, in some cases the individual input via the tabletop display can be problematic. For example in the ISTC application, the onscreen keyboards are space-consuming and thus hamper the generation of creative artifacts on the tabletop. One improvement to this problem is the introduction of coupled displays to the tabletop environment. This section describes the changes that were made to the ISTC application to support multiple coupled mobile devices in real time. After that, the software architecture of the coupled display application itself is presented and its user interface is discussed.

4.2.1 ISTC Server Module

The functionality for the communication with the coupled displays is directly implemented into the ISTC application in the form of a **server module**. This way, communication takes place bidirectionally between ISTC (as server) and the coupled displays (as clients). This allows us to use our own communication protocol and reduces the probability of additional performance issues, as an unnecessary involvement of the IdeaStream server is avoided. The architecture of the server module is shown in Figure 4.12. Because it was first implemented for iPhone devices, the namespace of its classes is called "`iphone`" - according to the already established naming conventions. The "`istc::`" prefix was hidden in the previous diagrams for a better overview. It identifies that a class is part of the ISTC application, running on the computer attached to the tabletop display. For this section the prefix is switched in to distinguish classes that are part of ISTC from classes that belong to the application directly running on the coupled displays.

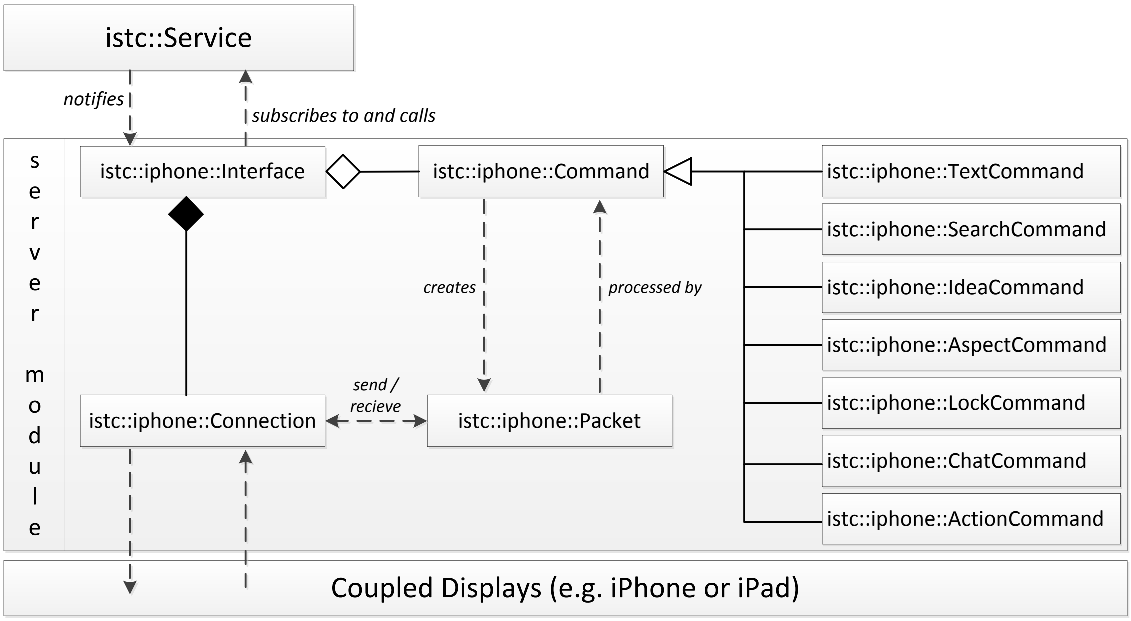

Figure 4.12: ISTC server module for the coupled display extension

The main class of the server module is implemented as a singleton and named `istc::iphone::Interface`. When this class is created during the startup procedure, it registers itself as a listener to various `istc::Services` to receive callbacks. The full list of available services was shown in Figure 4.3 (page 89). For the network communication with the coupled displays, an **additional thread** is used that is placed inside a member function of `istc::iphone::Interface`. This thread runs in an endless loop and waits for incoming or outgoing data to be processed. By default, a new server socket is opened. Additionally, it monitors the sockets of existing client connections. For communication, we chose to use a custom (TCP-based) binary protocol. This decision was made mainly to avoid data overhead as it is imposed by web service protocols (even Hessian). This would have been problematic as real-time communication between the coupled displays and the tabletop had to be possible for some of the implemented functionalities. The general rules of the protocol (that apply to all packages) are quickly described. A packet has to supply a five byte header containing its length (including the size of the header; 4 bytes) and a numeric type identifier (1 byte). As packets do not carry any further information about their content, this identifier is needed for the interpretation of the received data. For this purpose, a lookup table that maps a packet's identifier to its structure is provided. In this way, the start and end of a packet can be identified and its content validated up to a certain level. The class `istc::iphone::Packet` helps to compose and manage individual packets. It implements an abstraction of a byte buffer which can be dynamically resized. Depending on the packet structure, it offers methods to read and write the available data types to and from the underlying buffer.

To notify connected coupled displays about changes to observed objects - such as ideas or aspects - the server module forwards the events received from the `Services` to its subscribed clients (= the coupled displays). This process works as follows: By using the information provided by the instances of `istc::iphone::Connection` (for each coupled display an own instance is created), it can be determined whether or not any clients are subscribed to an idea or aspect. If one or more coupled displays are subscribed, only one matching packet has to be created. This packet is then appended to all the buffers managed by the respective `Connection` instances. Finally, the network thread is signaled to begin sending the data to the clients. The other way round (receiving packets from a client) is more complicated, as packets arrive in the network thread, but access to the data objects is restricted to the main thread only. Furthermore, some actions performed on a coupled display may additionally require that the IdeaStream server is notified. For example, if an idea is modified on a coupled display, the changed content not only has to be submitted to ISTC, but also forwarded to the IdeaStream server. As the communication only takes place via the server module, such an action has to be delegated to IdeaStream via the ISTC application.

A solution to both issues is introduced with the `Command` classes, a concept that is basically a simplified adaptation of the Command Design Pattern. `Commands` are created when the network thread parses an incoming packet. They are then added to a special queue and processed by the update routine of `istc::iphone::Interface` that is running in the main thread. This process is completed by running the `execute()` method which has to be implemented by every `Command`. This method is granted direct access to the `Services` in order to call arbitrary operations, depending on the packet that was used to initialize the `Command`. If further communication with the IdeaStream server is required, the `Command` stores an identifier of the requested operation and transitions into a "wait" state or, otherwise, simply returns a result packet to be sent back to the coupled display. `Commands` which run into the "wait" state are added to a second queue, where they are notified about the completion of all operations (involving the communication with the IdeaStream server). By using the identifier, they can detect the operation that initially required them to transition into the "wait" state and continue their execution. Each subclass of the `Command` super class bundles similar groups of functionalities (cp. Figure 4.12). E.g. the `istc::iphone::IdeaCommand` is used for all operations that relate to ideas, such as their creation, deletion, or modification.

4.2.2 Coupled Display Application

For an initial lightweight implementation of the coupled display concept, we migrated the onscreen keyboards from the tabletop to smartphones (more precisely: the iPhone, Figure 4.13). Hence, ideas still need to be created or selected for modification in public via the personal control widget and remain on the public (tabletop) workspace (→ full visibility of action is maintained). The following example illustrates this principle. If a user modifies an existing aspect, he first has to use his control widget to select that aspect on the tabletop. Now his iPhone displays an input field (see Figure 4.13) in which the textual content of the aspect can be edited. Every change is immediately synchronized with the tabletop and thus visible to the public. As such, everybody in the group is aware what a user is typing.

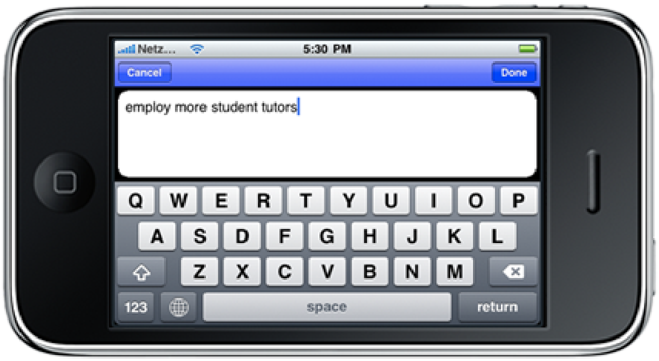

Figure 4.13: Textual input via the iPhone (adapted from [Frieß et al., 2012a, p.60])

However, we also went one step further and extended this application by implementing a cross section of the functionalities discussed in Section 3.2.3 for the iPad. The decision to use tablets (the iPad) instead of the iPhone was made, as the full-featured application would have been difficult to realize on the small screen size of a smartphone. The reason why the iPad and the iPhone were chosen for the project was that, at the time this thesis was started, both devices were the only established representatives based on the same operating system - iOS (e.g. Android was primarily used for smartphones). Using the same programming language (Objective-C) and the iOS SDK as a basis for developing the coupled display application allowed us to reuse our implementation. An additional reason for using multi-touch capable coupled display devices was to keep a similar (touch-based) interaction than it was already chosen for the interaction with the tabletop application.

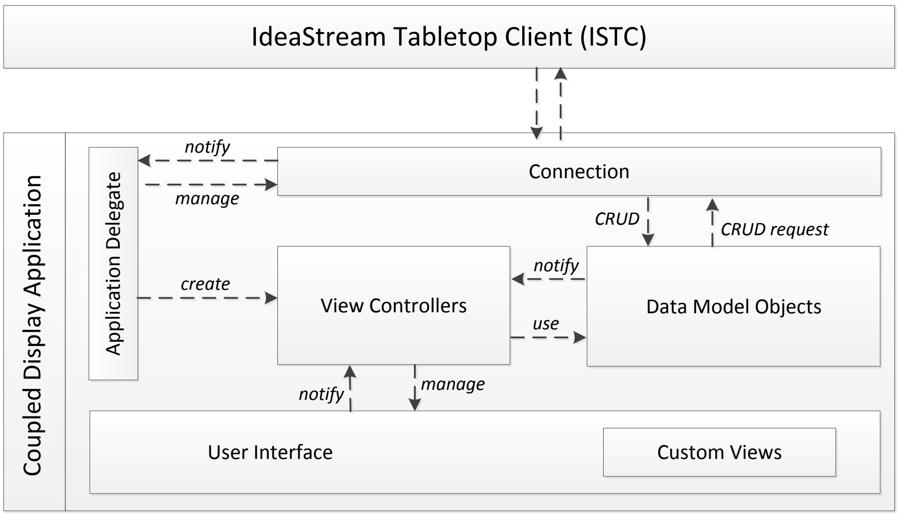

Figure 4.14: Architecture of the coupled display application

The architecture of the coupled display application (Figure 4.14) is mainly based on the Model View Controller (MVC) design pattern and implemented by using the UI framework `CocoaTouch` [iOS Cocoa Touch Framework, 2012], a core component of the iOS SDK.

There are five main components in the software architecture: The `Application Delegate`, the `Connection` object, `View Controllers`, `Data Model Objects` and the `Custom Views`. The `Application Delegate` - as the name already implies - is the delegate for the application instance controlled by iOS. As iOS does not permit much control over the behavior of the application itself, the main purpose of the delegate is to be informed of and react to changes. For example, the application delegate is called directly after the startup, when the application is about to enter the background, when the device resumes from sleep, or when the application is about to shut down. It is also responsible for switching between different views and acts as a delegate for the `Connection` to the ISTC application. The implementation of the `Connection` class is in large parts similar to the implementation of the `istc::iphone::Interface` class used in the server module. The reason is that the networking functionality was directly ported from C++ to Objective-C, with the main difference that no `Command` objects are needed. The `View Controllers` manage the functionality of the UI. They can be nested, thus inside a larger view managed by a specific controller, there might be several smaller views that are managed by additional `View Controllers`. As is typical for the MVC pattern, controllers directly interact with objects from the data model. Finally, the `Custom Views` are used to extend the default widgets provided by the iPhone SDK. As an example, a custom drawing view was implemented to allow for touch-based sketching.

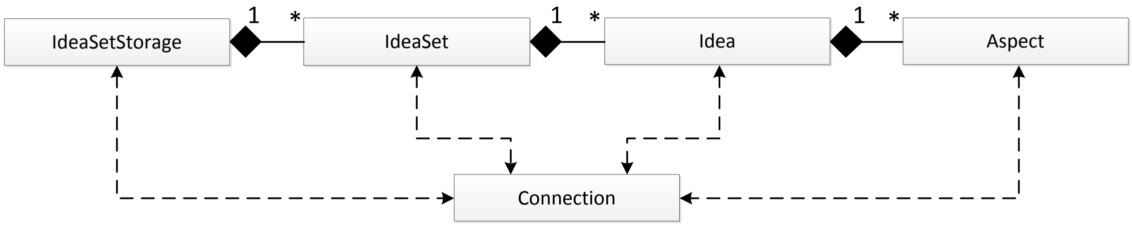

Figure 4.15: Coupled display data model

Figure 4.15 shows the data model used for the coupled display application. The main entities `Aspect` and `Idea` are again modeled similar to IdeaStream and ISTC. Different sets of ideas are bundled within so called `IdeaSet` containers that group ideas into one common context. This was necessary due to several reasons. One reason for using `IdeaSets` is to allow for an **offline workspace** which can be used even though a coupled display is not connected to the tabletop. This way, for example, the range of supported creativity techniques is broadened, as pointed out in Section 3.2.3. For the use in the context of the tabletop device, an `IdeaSet` for grouping the **(public) tabletop ideas** had to be provided. To avoid isolation (in terms of people working on their coupled displays only) and to maintain group awareness and a certain degree of visibility of action, such an `IdeaSet` is typically initialized empty. To add an idea to this `IdeaSet` (an action we refer to as "observing an idea") a new icon was added to the personal control widget (on the tabletop). This icon has to be dragged on an idea in public as shown in Figure 4.16. As soon as this drag operation is finished, the idea shows up on the coupled display where it now can be modified. When another idea is selected, it is also added to the `IdeaSet`, so that after some time, every coupled display contains its own "observed" subset of the ideas

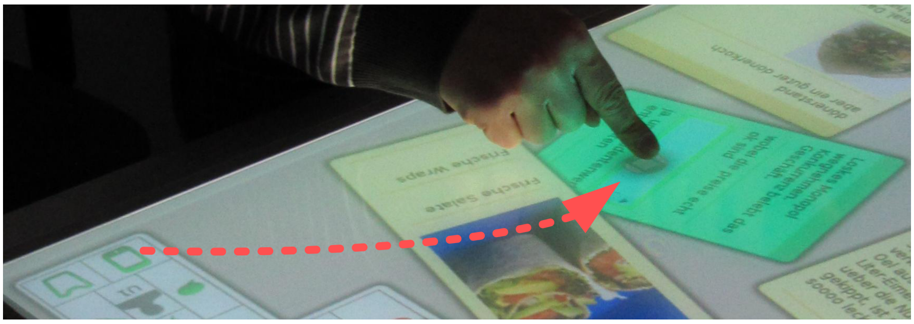

Figure 4.16: Adding an idea to a coupled display (= observing the idea)

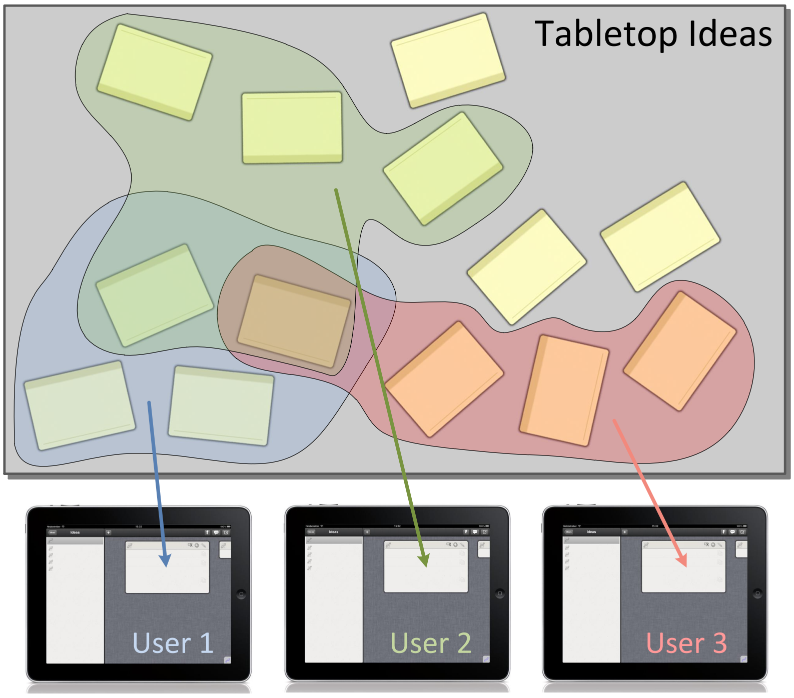

Figure 4.17: Tabletop workspace and iPad `IdeaSets` for each user

on the tabletop (Figure 4.17). Ideas which are observed by more than one user, need to be synchronized between the coupled displays and the tabletop workspace bidirectionally. The implementation of this mechanism was pointed out earlier in the context of the ISTC server module. For example, aspects need to be locked when somebody is editing them. As soon as such an edit operation is started on one coupled display, the lock state is sent to the ISTC server module which forwards it a) to the IdeaStream server and b) to other coupled displays observing the same idea. On the tabletop and on the other ("observing") coupled displays, the locked aspect is then visually grayed out. Whereas in the offline `IdeaSet`, all possible actions (create, update, delete, etc.) can be performed, several restrictions were issued on the observed ideas. As an example, we did not allow for deleting observed ideas or their aspects via the coupled displays, as we judged such an action as too invasive. Deleting ideas and aspects can only be triggered via the personal control widget in public. Moreover, new ideas still have to be created via the personal control widget (on the tabletop) but are then automatically added to the `IdeaSet` of the observed ideas. New aspects, however, can be directly added to an idea via the coupled display. A last purpose for which `IdeaSets` are used is grouping the **results of search queries**, e.g. when searching through archived sessions.

It has to be mentioned that when an `IdeaSet`, an `Idea`, or an `Aspect` is instantiated, a special `type` flag is set. This flag indicates if the object is local (offline) or observed (= synchronized with the tabletop and IdeaStream). For the latter, a reference to the `Connection` object is stored in order to process changes further on to the server module. For local storage in the offline `IdeaSet`, all data objects are serialized into a file and saved directly on the device as soon as the application terminates. The last missing class in the context of the coupled display application, the `IdeaSetStorage` (a singleton), acts as a central facility to access each of the available `IdeaSets`. For this purpose, it stores references to all instantiated `IdeaSets` and manages the dispatching of search queries to acquire the corresponding search results.

(a) Start screen

(b) Public workspace

Figure 4.18: Workspace view

Figure 4.18 shows the main view inside the coupled display application (referred to as workspace view). Initially, when the view is empty, a list of all available `IdeaSets` is shown on the left side (see Figure 4.18(a)). In the example provided, there is the “local” (offline) `IdeaSet` (Figure 4.18(a), item 2), the synchronized “tabletop” `IdeaSet` containing the observed ideas (Figure 4.18(a), item 3), as well as two search history `IdeaSets` (Figure 4.18(a), item 4). A new search query can be entered in the search field (Figure 4.18(a), item 1).

When an `IdeaSet` is selected, the UI switches into a different mode, shown in Figure 4.18(b). The list on the left side (Figure 4.18(b), item 2) now contains the individual ideas in the selected `IdeaSet`. These ideas, in turn, can now also be selected to show them in the

(a) Adding an aspect

(b) Searching for images

Figure 4.19: Workspace features

content area on the right side (Figure 4.18(b), item 1). Similar to the ideas on the tabletop, the aspects are separated via small horizontal lines (three aspects in the example). It is also possible to navigate between different ideas by doing a horizontal one finger slide. By using the "+"-shaped button (Figure 4.18(b), item 3) - which is only available in the offline `IdeaSet` - new ideas can be created and thus be added to the offline `IdeaSet`. When the button is pressed a small popover window allows for choosing whether the idea should contain text, a local image or an image searched via the World Wide Web. The popover is identical to the one which is shown when adding an aspect - see Figure 4.19(a). The image search via the WWW makes use of the Google Image Search API [Google Image Search API, 2012] and is shown in Figure 4.19(b).

Aspects of an idea can be copied or moved by using the button on an aspect's right side (Figure 4.18(b), item 4). On top of each idea, several buttons for modification are provided (Figure 4.18(b), item 5). From right to left, aspects can be rearranged and new ones be added. The leftmost button depends on the selected `IdeaSet`. In the `IdeaSet` of the observed ideas, which is synchronized with the tabletop workspace, ideas can only be removed from the observation list but not deleted. In the local, offline `IdeaSet`, the button is used to push a copy of an idea to the tabletop to share it with the group. Finally, when tapping onto an aspect's content area (Figure 4.18(b), item 6), a new edit view for modifying the content appears.

Editing the content of aspects takes place in a special edit window (Figure 4.20(a)) and is handled by a separate controller (`EditAspectVC`). This controller also manages the locking of the aspects that are currently edited. When the edit window first appears for a user, a loading animation is shown. In the meantime the controller tries to acquire the lock and, if successful, does not release the lock until the user closes the window using either the "cancel" (Figure 4.20(a), item 1) or "done" (Figure 4.20(a), item 2) button in the top bar. During the editing, the actual text or image contained in the aspect is displayed in

(a) Sketch/text aspects (b) Image aspects

Figure 4.20: Aspect view

the white content area along with any available sketches. For text aspects, this content area acts by default as an input field and can be switched into a sketch mode using a button in the upper right corner (Figure 4.20(a), item 3). Image aspects, however, only allow for sketches to be drawn on them and do not allow for additional input of text (a restriction which is grounded in the aspect model of IdeaStream). Therefore, when editing such an aspect, the sketch mode is enabled from the start and the button to switch into the text mode is hidden. Additionally, when adding a new image to an image aspect it can be resized by a two finger scale gesture.

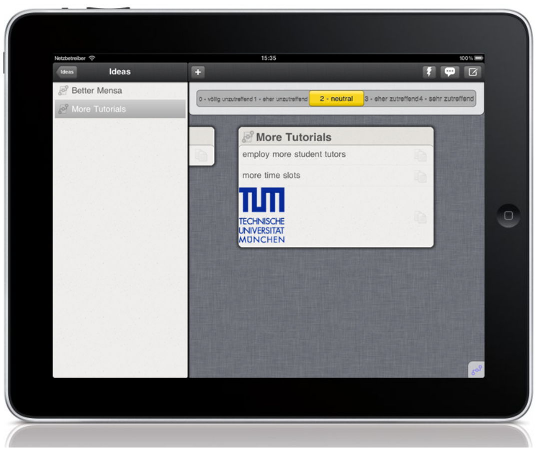

Figure 4.21: Rating an idea

For convergent phases, instead of being able to create and modify ideas, a functionality for rating an idea according to an arbitrary scale is required. Hence, all buttons for editing ideas are hidden in these phases and, instead, a rating widget (managed by the `RatingVC` controller) is displayed. This widget can be seen in Figure 4.21. It basically contains a slider showing the rating scale. By moving the slider along this scale, a user can select his personal rating. This rating is then saved to the idea that is centered in the workspace area. Switching between ideas is still done via the idea list on the left or by performing a horizontal slide in the content area, as explained earlier.

Figure 4.22: Final tabletop and coupled display application

The application also includes several other minor functionalities. Via the flash shaped button in the top panel, information about the current process phase and the creativity technique can be switched on (similar to the information widget on the tabletop screen). Moreover, the chat can be switched in to communicate with others (speech bubble icon). Finally, the button on the bottom right edge indicates, if the iPad is currently coupled with (synchronized with) an instance of the ISTC application (a tabletop device). Here, also the user's color is shown after he is logged in, so that he can identify his personal control widget on the tabletop. Figure 4.22 shows a photo of the final application environment including one coupled iPad and the tabletop workspace.

In the next section, we take a look at the implementation of the second use case which was considered and implemented in the scope of this thesis: the collaborative composition of music on a tabletop device.

4.3 LZRDM: Collaborative Composition of Music

This section introduces the implementation of the second use case, namely an application for the collaborative composition of (electronic) music on a tabletop device. The working title of this application, which was developed in the scope of a student's diploma thesis [Klügel, 2009], is referred to as “LZRDM”. As the scenario explicitly demanded for expert users, it has to be mentioned, that it seemed inappropriate for an evaluation in a university context. Hence, it is not included in the evaluation chapter (Chapter 5). As a compensation for the missing evaluation, the application was presented in a live demonstration session involving a published demonstration video [Frieß et al., 2010b]. Furthermore, the concept behind and the implementation of the application have been published in a conference article [Klügel et al., 2011]. Because this application is only of minor importance to this thesis, it is not described as detailed as the ISTC application. Hence, the focus of this section is set on the implemented concepts (mainly the used compositional structures), the related user interface, as well as the touch-based interaction with it. It also has to be mentioned, that the implementation of this use case did not address the full concept discussed in Section 3.2, as it is only realized for a tabletop device and does not include coupled display devices. However, prospects for using coupled displays in context of the application are discussed in the end of this section.

The main challenge for an implementation of this use case lies in the creation of a compositional structure that allows for synchronous collaboration on a public tabletop workspace (see Section 3.3.2). The problem of the traditionally linear representation of a composition is that it “grows” along two axes: horizontally in time and vertically with respect to the instrumentation (see Figure 4.23, upper part). This visualization of a composition on the screen poses a fundamental difficulty: the representation of an arbitrary number of instruments is space-consuming and the editing of musical events in different temporal granularities is difficult. For single-user applications, this problem is usually solved by using a Zoomable User Interface (ZUI) [Raskin, 2000]. An example where such ZUIs are used in music composition are state-of-the-art Digital Audio Workstations (DAW). For a collaborative environment, this paradigm of organization and visualization is problematic, as a single ZUI creates only the context for performing a single task. This was also pointed out in the study by Geyer et al. in Section 2.3.5. However, also multiple ZUIs in different parts of the composition do not foster group awareness and group articulation due to the imposed separation of the shared working environment. To overcome this inherent limitation, a different concept of representing the compositional structure (internally and interactively) had to be devised. This representation maps the compositional structure and the assignment of instruments onto a **directed acyclic graph** which can be modified in real time via the user interface. This graph is composed of two subgraphs for the respective functional domains: the **temporal order of musical events (sequence graph, white edges)** and the **audio synthesis (synthesis graph, purple edges)**. Figure 4.23 shows an example of how Johann Sebastian Bach’s French Suite No. 3 (BWV[1] 814) can be represented by using this graph structure.

With the exception of their root node, the nodes in the **first subgraph** are `Sequences` in the meaning of short musical phrases (cp. Figure 4.24, item 4a). Hence, a sequence node primarily contains chromatic control data in the form of notes and their length. The current position in a sequence (when it is played) is marked by a brownish colored sector. The edges between nodes are directed and denote the succession of sequences, thus forming the temporal order of a (meta-)arrangement. The type of succession expressed by linking nodes with edges can either form a sequential chain or branches of parallel sequences. New nodes can be created by dragging the respective button from the menu

[1] Bach-Werke-Verzeichnis (Bach Works Catalogue)

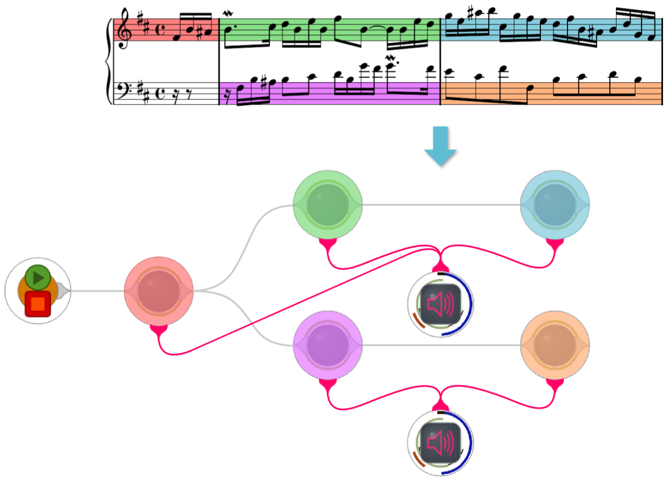

Figure 4.23: Graph structure for Johann Sebastian Bach's French Suite No. 3, BWV 814

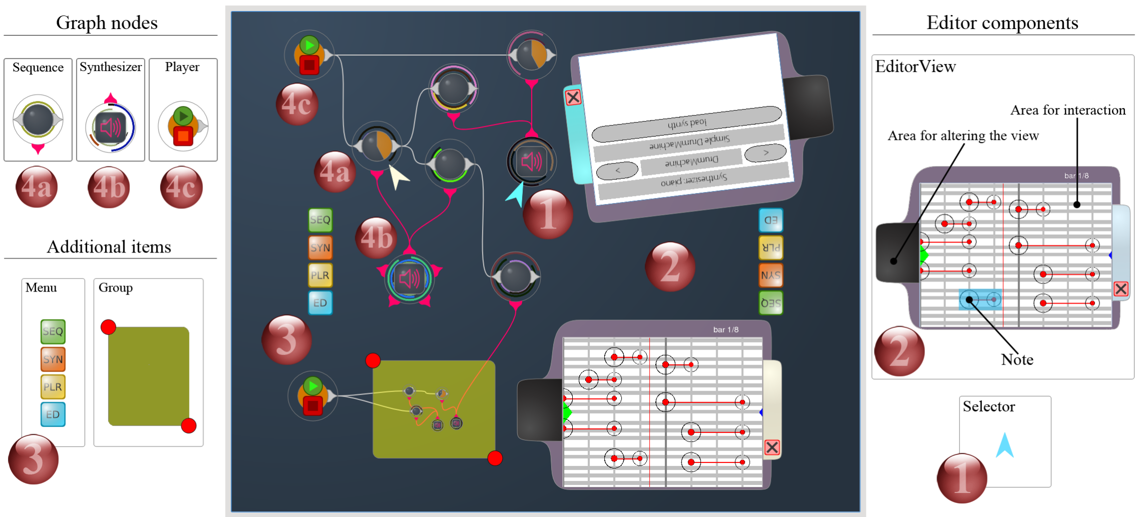

Figure 4.24: Overview of the application's user interface [Klügel et al., 2011, p.35]

(Figure 4.24, item 3) to an empty spot on the tabletop surface. Edges can be linked with other sequence nodes by a drag gesture starting from the pink connector attached to a node. The construction of parallel sequence chains equals several instrument staves with phrases - similar to traditional notation. As mentioned earlier, the root node of a sequence graph is formed by a special object that allows for the control of its playback (analogously named `Player`). As can be seen in Figure 4.24 (item 4c), the application allows for several players (and corresponding sequence graphs) in parallel. A `Player` not only controls the immediate start and stop of the playback but also enables its synchronization to the global tempo (in various bar intervals) and provides a means to trigger looped playback. All information regarding the timing of musical events is treated as relative to the beginning of a sequence (start and length can be changed).

The **second subgraph** is used to map the musical events of sequences to (parameters of) synthesizers. Hence, the first type of nodes in this graph are the `Sequence` nodes that are also elements of the first subgraph. These nodes are connected by directed edges (the purple edges in the UI) to `Synthesizer` nodes (cp. Figure 4.24, item 4b). Edges in the graph thereby describe the flow of control information in terms of a `Sequence` controlling pitch or loudness of a synthesizer. In more simple words, this means that instruments or groups of instruments (the synthesizers) are assigned to play the content of compositional objects (the sequences). Parallel edges are allowed if a sequence is to control more than a single parameter of a synthesizer. For a demonstration of the LZRDM application, the aim was to provide a basic set of synthesizers that offer a variety of timbres, suitable for diverse styles of compositions. For this purpose, the programming environment SuperCollider [McCartney, 2002,SuperCollider, 2012] was used. SuperCollider basically consists of an engine for processing arbitrary signal data with a focus on audio and is particularly suited for our setting, because it can be entirely controlled via the Open Sound Control (OSC) protocol [OpenSound Control Home Page, 2012]. Thus, the creation of instruments, the modification of audio signal routings, and the control of the parameters of instruments can be steered remotely from any application. The range of implemented synthesizers spans from percussive ones (a simple drum-machine including bass drum, snare drum, tom-tom, and hi-hat) to tonal ones that can be used either as lead or accompanying instruments (a piano, a string ensemble, and a 70s lead synthesizer).

In addition to the graph nodes, there are two more elements in the user interface. These allow for setting the properties of a node and are shown in the right column of Figure 4.24. The first element is called the `Selector` (cp. Figure 4.24, item 1) and is used for **selecting the node** whose properties are to be changed. The second element is called `EditorView` and is used for **visualizing and manipulating the contents** of a (previously selected) node (cp. Figure 4.24, item 2). For that, the `Selector` has to be dragged onto a node in the graph structure. As soon as the `Selector` is released, an associated `EditorView` is opened and displays an interface for manipulating the selected node's properties. The `EditorView` is similar to a window in the WIMP paradigm and floats above the compositional structure. It can be rotated and translated arbitrarily to match the user's orientation. It also provides facilities to pan and zoom the visualization and to close the `EditorView`. In case a sequence node is selected, the chromatic musical events can be manipulated by using the piano-roll metaphor that is common in modern DAWs. New notes or control events in a sequence can be added by tapping onto the desired position in the pitch/time value/time grid in the `EditorView`. By dragging the right part of a note (the smaller circle), its length can be set. When a synthesizer node is selected, the `EditorView` provides functionality to switch between the different (implemented) types of synthesizers (cp. Figure 4.24, upper `EditorView`). An arbitrary number of these `Selector`/`EditorView` pairs can be created by using the corresponding menu buttons (Figure 4.24, item 3). An integral feature of the application is that multiple users are able to edit the properties of graph nodes concurrently via different (synchronized) `EditorViews`. Hence, they gain mutual insight into their actions, again fostering group awareness.

As noted in Section 3.2.2, most multi-touch devices do not associate touch points

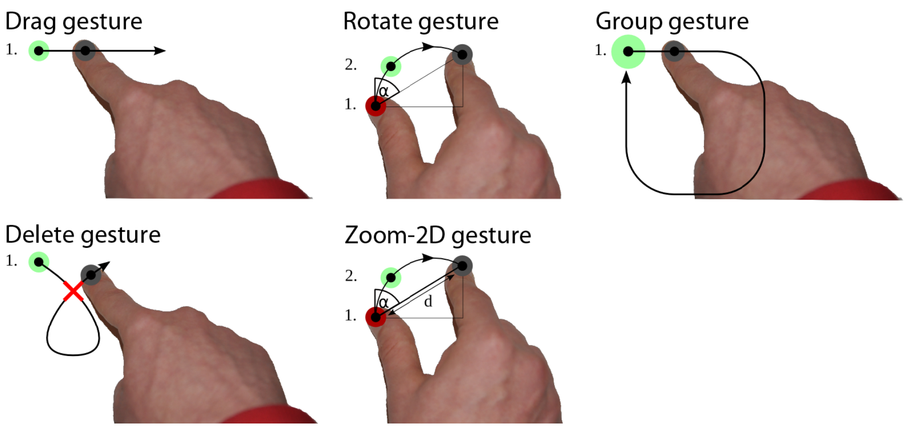

Figure 4.25: Overview of Used Gestures (adapted from [Klügel, 2009, p.46])

to a specific user. In consequence, collaborative gestural input can be prone to create ambiguous states in conjunction with multi-touch gestures. To avoid this problem for the LZRDM application, we decided to primarily use single-touch gestures for the interaction with objects that are intended to be shared with the group. Multi-touch gestures are only applied for controlling the `EditorView` (changing its orientation) and the visualization of its contents (zooming, panning). Figure 4.25 shows an overview of all used gestures. Regarding the single-point gestures, simple gestures which do not require further parsing of their path data (such as the drag gesture) can be distinguished from complex gestures that perform a geometrical analysis of the touch data. One of these is the delete gesture which is similar to marking a cross in a single path above the item that is to be deleted. This way,

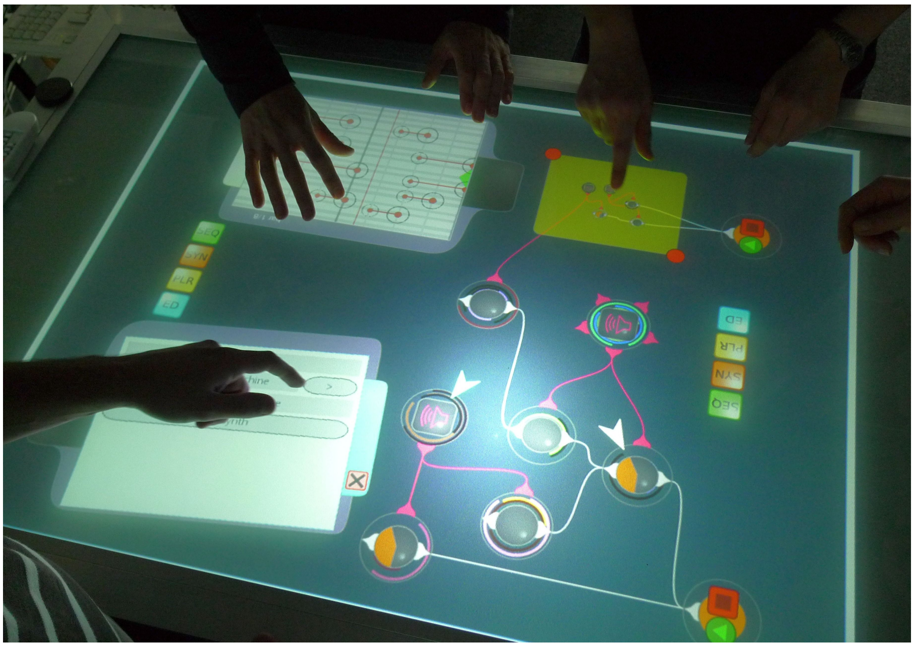

Figure 4.26: LZRDM: tabletop application for collaborative music composition

e.g. an edge connecting a sequence with a synthesizer can be removed. Another example is the group gesture, allowing users to group sequences and synthesizers by drawing a closed lasso-style path around these objects (cp. Figure 4.24, item “Group”). The resulting group item supports the scaling of its contents and allows to organize nodes and to regain screen space for more complex compositional structures. This follows the principle of supporting user storage territories as presented in [Scott and Carpendale, 2006] and discussed in Section 3.2.1.

A photo of the final application is shown in Figure 4.26. As pointed out earlier, we did not implement a coupled display extension for this particular application scenario. However, especially the `EditorView` provides an interesting basis for such an extension. An `EditorView` instance is typically only used by one user at a time and its contents are already synchronized with other instances - both making the `EditorView` ideal for being transferred to private devices. This way space on the tabletop is gained and the group activity focused on the compositional structure. Setting a note via the `EditorView` on the coupled display can then be regarded similar to using an instrument in an improvisational setting. Another aspect for extending the application targets the introduction of different audio channels. So far, only one single audio channel is available, playing the stream of the whole compositional structure - even with several `Players` present. Providing individual headsets which can be (virtually) connected to a `Player` (and the respective sequence graph) could help to avoid conflicts concerning the parallel composition of separate arrangements within the same compositional structure. Thus, more fine grained modes of coupling could be possible.

4.4 Summary

Within this chapter, the implementations of two Creativity Support Systems were presented, both being designed based upon the conceptual thoughts of a situative creativity support. First, the ISTC application and its coupled display extension were introduced. In this regard, the software architecture and the related user interfaces (and the underlying principles) were discussed. Next, the implementation of our second use case, the LZRDM application addressing the collaborative composition of music, was regarded. Thereby, the focus was set on the adaptation of the compositional structures (sequences and synthesizers) to collocated tabletop collaboration and on the design of a collaborative user interface. Comparing both applications, especially ISTC provides interesting perspectives for an evaluation in a university context, as creativity techniques are easy to learn and thus suitable for novice users. Even more, due to the architecture of the underlying IdeaStream application, the same creative process model (= the same creativity techniques) can be applied in different settings (e.g. collocated (tabletop) and distributed (web)). In the following chapter, we present three studies that were conducted with different versions of the ISTC application.

Chapter 5

Evaluation

This chapter focuses on the evaluation of the IdeaStream Tabletop Client (ISTC). First of all, Section 5.1 introduces the main evaluation goals. Next, Section 5.2 describes the technological infrastructure concerning the used tabletop device and a dedicated tracking environment for automatically observing the collaborative behavior inside and outside (in the physical environment) of the tabletop application. Next, Section 5.3 presents a preliminary study conducted with a prototype of the ISTC tabletop application and discusses the main problems and shortcomings that showed up. In this regard, we also point out ways how most of these issues were solved. As a central part of this chapter, Section 5.4 presents the main study, in the scope of which the ISTC application (with coupled iPhones for text input) is compared to the IdeaStream web application and to a setting without IT support. First, the applied creative process structure is explained and the different settings are described. Next, they are compared by examining quantitative data such as the idea quantity and quality and statistical results gained from a user survey. In addition, the data that was acquired via the tracking environment is examined for the ISTC application. Finally, Section 5.5 presents an additional study conducted with the full-featured coupled display extension of ISTC (based on the iPad). Section 5.6 concludes this chapter with a discussion of the main results

5.1 Evaluation Goals

As the design science methodology calls for an evaluation of the created IT artifacts, conducting different experiments with the developed IT applications forms a central goal of this thesis. The importance of gaining a holistic insight into creative collaboration by performing a comprehensive evaluation is also emphasized in [Mamykina et al., 2002, p.99]: "*Observations and analysis of the creative work of an interdisciplinary team, whether in industry or in academic settings, can greatly increase our understanding of factors that influence it and the driving forces behind it*".

Because the ISTC application was developed in iterative steps, also the evaluation activities were each conducted at a different stage of development. First, a series of thorough tests was made with a prototype of the ISTC application to obtain a stable version that could be productively used in further experiments. In this regard, we conducted a **preliminary study** which is discussed in Section 5.3. In addition, the final prototype was presented live in a demo session at an international conference [Frieß et al., 2009]. Thereby, valuable feedback by researchers and practitioners from the field of tabletop and surface computing was gained. On this basis, a **main study** was conducted with a mature version the ISTC application involving the use of coupled iPhone devices (Section 5.4). Finally, the full-featured coupled display extension of ISTC (based on the iPad) was evaluated in an **additional study** (Section 5.5). For establishing the goals and criteria to investigate in these studies, we took into account traditional measurements for the success of creative processes. Moreover, we derived novel metrics from our expectations concerning a situative creativity support that were discussed in Section 3.1.3. In the following, the different goals are briefly described.

Effectiveness: It is our first goal to investigate on the effectiveness of the ISTC application. For this purpose, the **number (quantity)** and the **quality** of the **generated ideas** were chosen as criteria. While the idea quantity has been used as a common measure of success in many studies on creativity (technology and non-technology oriented), for the idea quality no dominant best practice has emerged, although diverse criteria of measurement have been proposed so far [Reinig et al., 2007]. However, a commonly used approach is to rate an idea according to its **creativity** and **feasibility**, such as pointed out in Chapter 2 (e.g. [Diehl and Stroebe, 1991, Vangundy, 1988]).

Comparison of Different Settings: As pointed out in Section 3.1.3, we expect that the use of the ISTC application could lead to potential differences compared to more traditional methods of IT and non-IT based creativity support. To find out about these differences, a comparison of the ISTC application to two different IT and non-IT supported settings had to be made. For this purpose, we chose a distributed setting (with the web-based front-end of IdeaStream) and a setting without IT support (using index cards and a whiteboard). The comparison is presented in the context of the main study in Section 5.4.

User Interaction: To verify the conceptual assumptions for the design of and the interaction with a tabletop-based CSS, it is important to regard the user behavior "inside" and "outside" the application. Especially for the interaction "outside" - in the physical space around a tabletop device - a suitable tracking environment had to be devised. As this environment required a specially equipped room and additional preparation time for the used hardware, it was only applied in the main study. The analysis of the tracked data is presented in Section 5.4.5.

Group Effects: As pointed out in Section 3.1.3, it is also of interest how a situative creativity support influences the quality and the perception of the collaboration. For this investigation, we took into account how the users perceive different aspects of the collaborative activities such as productivity, fun, group satisfaction, and group cohesion, but also negative factors such as potential group conflicts. As all of these aspects are related to a subjective judgment of the users, they were addressed by a user survey.

Invasiveness and Isolation: Although invasiveness and isolation are closely connected to the former goal (group effects), they are mentioned as a separate goal. With invasiveness we refer to the effect that an action performed by one user exerts on other users. Hence, being able to do more invasive actions (e.g. due to more anonymity, such as when using a web application) can lead e.g. to an increased level of conflict within the group. Isolation means how much a user isolates himself from the group. Hence, isolation can lead to a lower degree of collaboration and social interaction. Both aspects are primarily of interest when comparing the ISTC application to the web setting and when regarding its full-featured coupled display extension based on the iPad.

User Satisfaction: As a last goal, the satisfaction of the users with using the ISTC application was of particular interest. This investigation mainly targeted aspects of the usability, e.g. the novel way of (touch-based) interaction and the physics engine. We also asked about the influence of the size of the tabletop (= the space on the screen) and the users' feelings about combining face-to-face interaction and IT support (e.g. if they experienced more freedom of movement than when sitting at a PC). Additionally, we investigated on the provided functionality.

In addition to these evaluation goals, also the technological infrastructure for performing the evaluation activities had to be regarded. This primarily concerns the selection of a suitable tabletop device that allows for the simultaneous collaboration of at least four participants. The functionality of this device is described in the following. Furthermore, the tracking environment that was needed to monitor the activity in the physical space around the tabletop device is introduced.

5.2 Technological Infrastructure

Before any evaluation activity could be conducted, a tabletop device had to be chosen to deploy the ISTC application. As this device influenced several of the results of the three studies, it is worthwhile to describe it in more detail.

5.2.1 The Tabletop Device

During the beginnings of this thesis, the number of available multi-touch capable tabletop devices was very limited, with Microsoft Surface [Microsoft Surface, 2012] being the only representative that was distributed on a commercial basis. However, the Microsoft Surface device is only equipped with a 30-inch (76cm) display, making it too small to be used by more than two users at the same time for most application scenarios. At the same time, another tabletop device had recently been developed in the context of a PhD-thesis at the Chair for Computer Aided Medical Procedures & Augmented Reality at the Technische Universität München: Florian Echtler's TISCH [Echtler et al., 2008] (Figure 5.1). This device features a 42-inch display, and (similar to the Microsoft Surface) provides a native pixel resolution of 1024x768. Although this resolution may seem a bit too low, the large display size turned out to be large enough to be used by two to six users concurrently, a fact that is also stated by its developers [Echtler et al., 2008, p.389]. Hence, due to the availability on-site and its suitability for multi-user collaboration, we decided to use this device for the evaluation. In the following, a short summary of its functionality is given (also refer to Figure 5.1 and [Echtler et al., 2008]). The surface (item 5) is built of a frosted

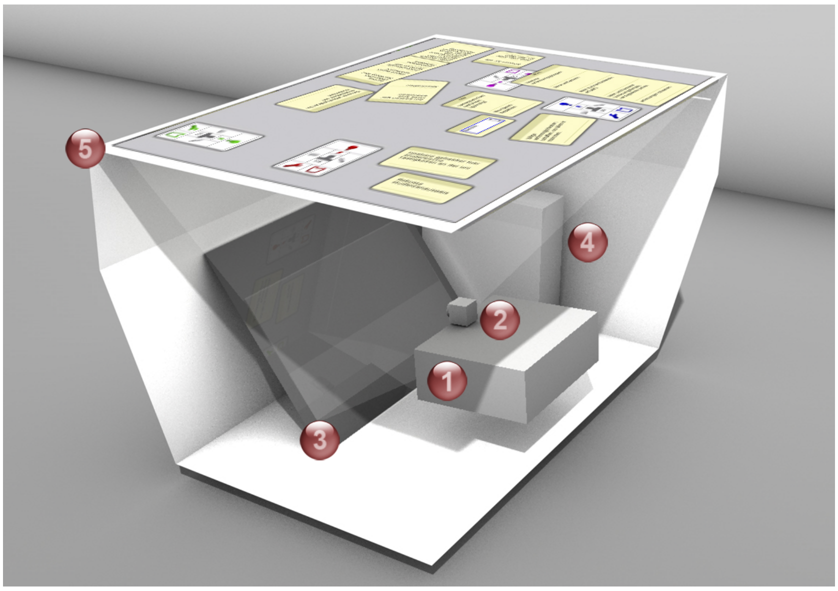

Figure 5.1: Technical overview of the used tabletop device

glass plate which is used as a back-projection surface and which is mounted on a robust aluminum frame. This frame contains a projector (item 1), an infrared (IR) camera (item 2) and a computer (item 4), on which e.g. a tabletop application is deployed. An acrylic glass sheet placed on top of the projection area has 70 infrared LEDs attached around its rim to provide multi-touch input to the computer via the IR camera. To project to the glass plate and to monitor IR signals reflected from actions performed on it, a mirror (item 3) is used.

For multi-touch tabletop devices optical touch surfaces appear to be a good solution as they are used in all of the currently available commercial tabletop devices. According to [Schöning et al., 2008], one reason for this is that they are are the only technology that does not require industrial quality fabrication facilities - what makes them comparably cheap in price. Moreover, they can handle a large amount of contact points at the same time (theoretically only limited by camera resolution and processing power). A negative aspect, however, is their comparatively low precision and the space they require - which can be overcome in a device as large as a table. In [Schöning et al., 2008], also a short description and comparison of other currently available multi-touch technologies with their individual strengths and weaknesses is provided.

5.2.2 The Tracking Environment

For evaluating the tabletop setting and the involved collaboration activities on a broad scale, we assembled a dedicated tracking environment that was used in the main study (Section 5.4). This tracking environment (and the related analysis) have been presented in the scope of a journal article [Frieß et al., 2012b]. Figure 5.2 shows the components of the tracking environment that are to be discussed in the following.

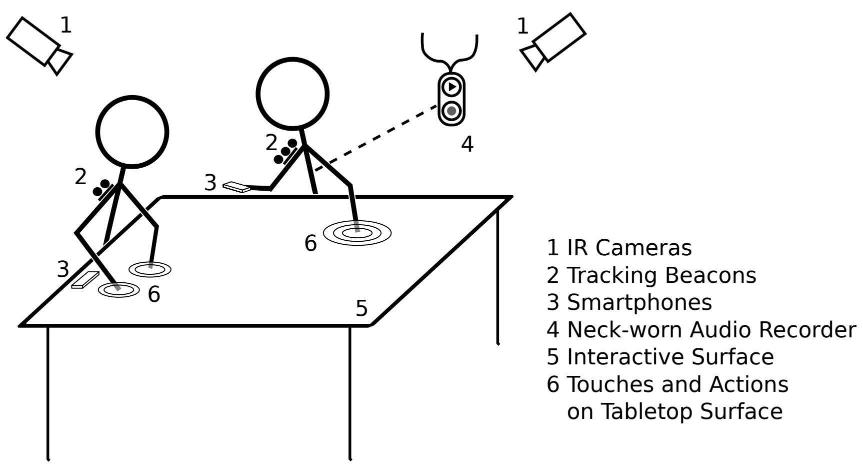

Figure 5.2: Tracking environment [Frieß et al., 2012b, p.345]

External Environment (Items 1 and 2): To track the real world interaction and **collaboration patterns** in the **physical environment around** the tabletop display, we limited ourselves to measuring the positioning of the body center and the torso orientation of each participant. In contrast to gestures and facial expressions, these interaction geometry parameters can be measured and interpreted in a relatively easy way. As an example, we used the positions of the participants' body centers to calculate the interpersonal distances between them. Practical experiences from using these parameters were already gained from a previous experiment which aimed at detecting social situations within a group of persons in a "party"-like situation [Groh et al., 2010]. For tracking the geometry data, we used a commercial infrared camera-based tracking system [ARTTRACK2 System, 2012]. The cameras of this tracking system are mounted on the ceiling, each at a corner of a rectangular setup. They emit and detect infrared light that is reflected by the surface of small spheres. A set of such spheres in a unique spatial arrangement is attached to a plastic beacon roughly the size of a human hand. This beacon is carried on the shoulder and defines the body axes of a user. The system tracks the spatial location and orientation of a beacon with an accuracy of < 1mm and $< 1°$. This accuracy was determined by the manual [ARTTRACK User-Manual, 2007] and its own calibration measurement. In order to gain some human interpretable data (and to verify the gathered information), we additionally recorded all sessions on traditional video.

Audio Recording (MP3) (Item 4): For recording the **verbal communication** of each participant, we used MP3 recorders worn on a chord around their necks. These recordings were intended to give a rough quantified estimate on the amount of each of the participant's verbal communication throughout the experiment. For the conducted analysis, both the **relative duration** of each participant's speaking time and the patterns of communication (so called **turn taking patterns** [Weilhammer and Rabold, 2003]) between collaborators are of particular interest. The former may help to identify verbally dominant or disengaged persons, while the latter may allow deduction of a characterization of the dialog between participants, which also contributes evidence as to when people interact and when they do not [Groh, 2012]. As pointed out in [Terken and Sturm, 2010] the plain speaking time indicates the flow of control in a conversation and therefore the influence of the speaker on others. This may help to identify verbally dominant or disengaged persons. The flow of conversation reflects on the social dynamics within a group [Terken and Sturm, 2010], such as the current speaker selecting the next one.

Human-Computer-Interface (Items 5 and 6): Concerning the interaction with other users via the **surface of the tabletop display**, we mainly aimed at investigating **territoriality** and the **exchange of artifacts** in the context of object-based interaction between the different team members. The interaction of individual users with the application is also of interest. For this purpose, we recorded all relevant and available interaction data that can be tracked when a user is interacting with the tabletop surface, such as Blobs (raw touch points) and interaction-paths with the widgets (especially with the idea and aspect widgets). Most of these interaction paths can be directly assigned to a user because the personal control widget has to be used to carry out all CRUD[1] operations. Using touch / interaction paths as one way to examine tabletop collaboration was for example proposed in context of the VisTACO application [Tang et al., 2010]. In order to examine the sharing (and the rotations) of ideas between users more precisely, we also tracked the orientation and movement of all widgets over the time. As a fallback option (e.g. if the automatic tracking fails), we also made a screen recording of each session by using the software recordMyDesktop [recordMyDesktop, 2012].

Application Environment: Within the application's core, a detailed accounting of all performed actions and an assignment to the corresponding users was made. For this purpose, each modification of an idea (that is e.g. made via the **iPhone (item 3)**) is saved to a database - a feature that is already provided by the IdeaStream server (to which all data is sent). Thus it is possible to keep automatically track of all

[1]Create, Update, Delete

generated ideas, their ratings, and the contributions of the users for each phase of the creative process.

5.3 Preliminary Study

To find out about potential weaknesses of a prototype of the ISTC tabletop application, a preliminary user study involving twelve student participants was made (see meta data in Figure 5.3). The students were partitioned into groups of four participants each. Figure 5.3 presents a photo taken during this study. As can be seen, at the stage where this experiment was conducted, it was only possible to commit ideas in a textual form by using the onscreen keyboard. A first examination of the results of the preliminary user study was published in [Frieß et al., 2010a].

Preliminary Study (Tabletop)

Participants: 12
Male: 91.7% **Female:** 8.3%
Age (avg.): 24.0 years
Experience Crea. Tech.: 66.7%

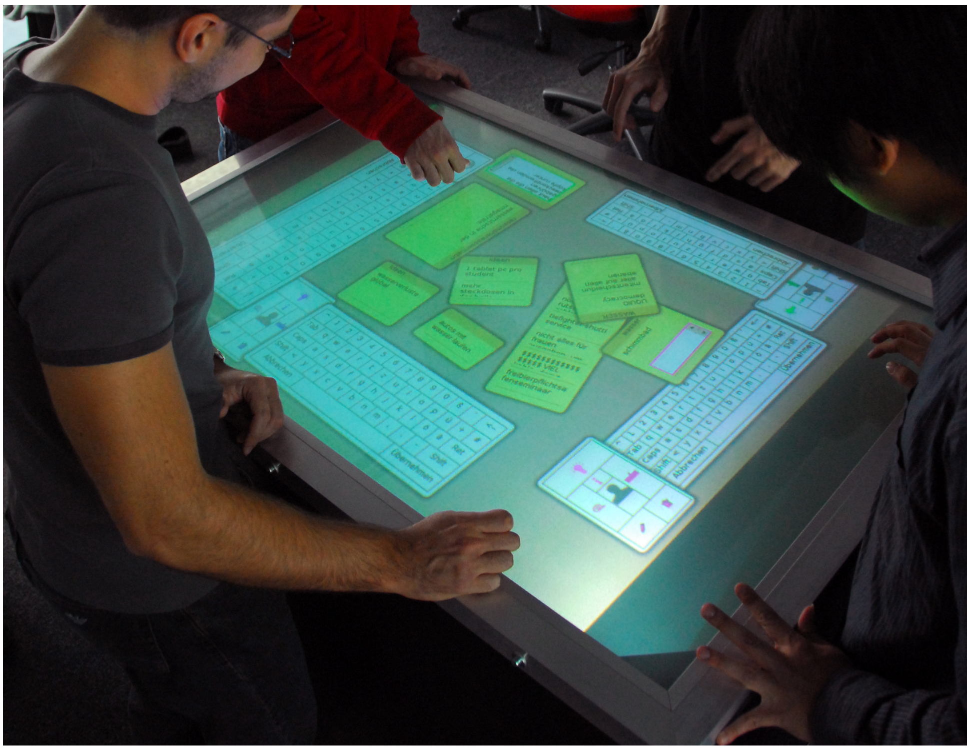

Figure 5.3: Preliminary user study with ISTC application

During the experiment the student participants were asked to find possible solutions to the problem statement: "*For which purposes could student fees be used?*". For this purpose, a three phase and 30-minutes long creative process was applied. As this process is only of little importance for the results presented in this section, its structure is explained in greater detail in the context of the main study (Section 5.4.1). Following each session of the experiment, a paper-based user survey was handed out to the participants. The survey questions were then rated according to a seven point Likert scale [Likert, 1932], ranging from -3 (strongly disagree) to +3 (strongly agree). In the following, we briefly discuss the main results of this survey regarding the usability of the application as well as the technological issues that arose.

In the study it showed up that the tabletop-only setting led to several shortcomings that were mainly caused by the used tabletop device. The main difficulty which developed in this regard resulted from the onscreen keyboards on the tabletop display. This problem is not completely related to the keyboards itself because, when conducting the study, the touch recognition of the tabletop device produced a problematic offset of about 1.5cm when touching its surface (as we found out later, mainly due to defect infrared LEDs). Hence, striking the correct keys on the keyboards when typing in text was rather difficult, hampering the input of text and decreasing the participants' motivation. In addition to that, the video projector in the tabletop device had difficulties projecting precisely on a short distance (the image was distorted and displaced relative to the camera image of the optical touch recognition), which made the inaccuracies even worse. In this regard, also a recalibration of the touch recognition did not bring a major improvement. However, the large size of the keyboards caused another problem which is not related to hardware. The four onscreen keyboards (that were needed for four users) consumed approximately 50% of the screen and limited the available space for generating ideas considerably (see Figure 5.3).

These problems also appeared in the survey results. The participants stated, that the computer support made the sessions more complicated (mean: 0.58, *stdev*: 0.93). A key reason for this was the problematic handling of the virtual onscreen keyboards (mean: 0.50, *stdev*: 0.70) and the limited space on the tabletop display. Its size (and resolution) restricted the participants in their work (mean: 0.92, *stdev*: 0.92). In consequence, the benefit of the IT support for the session efficiency was judged around a value of zero (mean: 0.17, *stdev*: 1.13), which may also be due to the technical shortcomings that made it hard to type in text. Even though these shortcomings had an undeniable impact on the results of the preliminary study, also positive indications of using the tabletop environment were found. About 60% of the participants stated that they felt more freedom of movement than when sitting at a single-user PC (mean: 0.58, *stdev*: 1.35). Furthermore, the realistic behavior (the physics engine and the direct manipulation) of the virtual objects was judged as intuitive (mean: 1.00, *stdev*: 0.80) and the participation as more active because of the IT support (mean: 1.00, *stdev*: 1.05).

In summary, the preliminary study gave valuable insights into the handling, the functionality, and the reliability of the application at an early stage of development. In this way, bugs and usability problems were identified and solved in order to gain a more stable application environment. The experiment also aided in addressing the remaining technical problems of the hardware as good as technologically possible for future studies. Hence, the video projector and the broken infrared LEDs were replaced in advance of the main study. It also laid the foundation to do further research into the integration of coupled displays, e.g. for outsourcing individual input and to free up space for the collaborative work.

5.4 Main Study

The primary goal of the main study is to **evaluate the ISTC application** (with coupled iPhones for text input) and to **compare** it to two **different settings** (working from PCs via a web-application and working without IT support) in order to discover potential differences of a situative creativity support to more traditional forms of being creative. Section 5.4.1 first introduces the applied **creative process structure** in the style of a combination of different creativity techniques. Next, Section 5.4.2 describes the three different experiment settings. The main results concerning the **number** and the **quality** of the generated **ideas** are examined in Section 5.4.3. A **statistical analysis** of the conducted **user survey** is made in Section 5.4.4. For the contents of both sections, a comparison of the ISTC application to the other two settings is performed. First parts of this comparison were published in [Frieß et al., 2012c]. Finally, Section 5.4.5 presents an **analysis of the collaboration** with the ISTC application (and around the tabletop device) based on data gained via the tracking environment.

5.4.1 Creative Process Structure

For the study, we again selected computer science students pursuing their Bachelor's and Master's degree as our main target group. They were chosen due to their availability since the students were on campus frequently. This became particularly important since the tabletop device which was used for the ISTC application was not portable enough to transport it to any other location (e.g. a company partner). With the given problem statement, "*For which purposes could student fees be used?*", the students were able to generate ideas for a problem common to all of them. Furthermore, this problem domain explicitly demanded creativity as the public discussion about that topic has been ongoing in Germany for years leading to controversial results. It must also be mentioned that for each setting distinct students were selected. Hence, their expertise concerning the given problem statement stayed roughly the same.

First, each group worked through a three-phase (divergent) creative process, each following a different (divergent) creativity technique for idea generation. The techniques were chosen according to the different ways they address functional patterns of human thinking. **Brainwriting** encourages the group members to generate as many ideas as possible (with criticism not being allowed). The **Unrelated Stimuli technique** provides a set of completely off-topic stimulus terms (in our case "lawnmower", "water", and "outer space") to find associations which should lead to more novel and radical ideas. Finally, the **Forced Combination technique** instructs the group to merge ideas together. In this manner, the group members are encouraged to work with the ideas of other team members, leading to increased collaboration and communication activity. The duration of each phase (= each technique) was ten minutes, so a group spent a total of 30 minutes for idea generation, which is a typical period for such sessions [Prante et al., 2002, Helquist et al., 2007].

In a second step, the generated ideas were evaluated in two convergent phases (also ten minutes each) with respect to creativity and feasibility by using a five point Likert scale [Likert, 1932] from 0 (worst) to 4 (best). In each setting we automatically logged or - in the setting without IT - manually noted how many ideas (and correspondingly aspects) the users generated in each phase.

5.4.2 Experiment Settings

This section describes the three different experiment settings that were compared in the main study: distributed web-based collaboration (setting 1), traditional creativity techniques without any IT support (setting 2), and the ISTC tabletop environment with coupled iPhones (setting 3). For each of the IT-supported settings, we began with a 15-minute introductory training session to help the participants familiarize themselves with the application and the handling of the respective user interface. Then the previously introduced creative process was applied and, afterwards, a paper-based user survey was handed out.

Setting 1) Distributed: Web Client

Figure 5.4: User study with web front-end of IdeaStream [Frieß et al., 2012c, p.49]

For the distributed setting, we selected a total of 78 students which split up into twelve groups of three and six groups of four participants. Each group member was provided with a PC. Each PC was set up with the same configuration (Windows XP and Firefox web browser). For starting the experiment, the IdeaStream web front-end (cp. Section 2.3.3) was opened in the browser. As we had to carry out the experiment in a lab setting, the participants of three different groups

> **Main Study (Setting 1)**
>
> **Participants:** 78
> **Male:** 79.5% **Female:** 20.5%
> **Age (avg.):** 21.7 years
> **Experience Crea. Tech.:** 30.8%

were placed in the same room at the same time. To simulate a distributed scenario, we then mixed the groups and placed people randomly at each PC, so that the participants did not know which person in the room belonged to their group. A photo of the students using IdeaStream during the experiment is shown in Figure 5.4. An examination of the chat usage in this experiment was published in [Forster et al., 2010]. We focused on the more distributed setting (even with people being in the same room) because we expected to see potential differences to the ISTC application more pronounced. However, as pointed out in the interviews (Section 3.1.2) and as observed in the Open-I workshops (Figure 2.2 (page 15)), using laptops in a face-to-face setting (where members of the same group sit opposite of each other) can lead to a similar behavior. Even there, the people's attention is drawn to the PC and away from the group so that all communication and collaboration activity takes place primarily electronically.

Setting 2) Collocated: Without IT Support

Figure 5.5: User study without IT support

Main Study (Setting 2)
Participants: 24
Male: 87.5% **Female:** 12.5%
Age (avg.): 22.1 years
Experience Crea. Tech.: 4.1%

In the collocated setting without IT support, 24 computer science students were divided into seven groups. This study was made in the context of a diploma thesis which was conducted for the Chair of Psychology of the Technische Universität München [Müller, 2010]. The lab was prepared as follows. Three to four chairs were ordered in a row, in a distance of about 1.5m away from a whiteboard. On the table in front of the chairs, 35 self-adhesive index cards (9.5 x 20.5cm) were placed for each participant. Each card was assigned a distinct number which allows to assign cards to users at the end of a session (e.g. to track how much ideas a user contributed). When an idea was written on a card, this card was given to a moderator, who then placed it on the whiteboard. The problem statement and the three stimulus terms for the second phase (Unrelated Stimuli technique) were also pinned to the whiteboard as supplementary information. The third phase (Forced Combination technique) was realized in the following way: To avoid ideas falling of the whiteboard when relocating them, the participants got extra sheets, where they were instructed to write down the idea numbers which they wanted to combine to a new idea. For the ratings in the two convergent phases, each participant got an individual sheet of paper containing all the numbers of the available idea cards. The setting as a whole can be seen in Figure 5.5. The whiteboard was chosen over a table (as space for putting the idea cards) because pinning index cards to a whiteboard is one of the most common ways how creativity techniques are conducted within companies (cp. the interviews in Section 3.1.2).

Setting 3) Collocated: Tabletop

Figure 5.6: Main study with ISTC application [Frieß et al., 2012b, p.346]

For evaluating the ISTC application, we selected a total of 31 computer science students. These were divided into eight different, randomly composed groups ranging from three to six persons. To cope with the problem of running out of space on the public tabletop display (which showed up in the preliminary study described in Section 5.3), we provided this application with the virtual keyboard running on coupled iPhone devices, as introduced in Section 4.2.2. Moreover, the tracking environment was used to track the interactions of the users in the physical space around the tabletop device. For this purpose, the participants first had to be prepared with the tracking beacons taped to their right shoulders and the MP3 recorders around their necks. A photo of a beacon can be seen in Figure 5.6 (upper left corner). Then,

Main Study (Setting 3)
Participants: 31
Male: 87.1% **Female:** 12.9%
Age (avg.): 24.8 years
Experience Crea. Tech.: 32.3%

a 15 minute training session was made to get familiar with the application and its user interface. Before the main session was started, the camera-based tracking system had to be calibrated. For this purpose, all participants had to line up on their side of the tabletop, looking into the same direction so that their their body axes could be identified. Finally, the MP3 recorders were switched on and the session was started. A photo taken during a session is shown in Figure 5.6.

In the next section, the results of the main study are described by discussing quantitative data such as the number and the ratings of the ideas for the three different settings. Additionally, we present an analysis of the user surveys by comparing setting 1 (web) and setting 2 (without IT support) to setting 3 (tabletop). A direct comparison between the web setting and the setting without IT support has already been presented in [Forster, 2010]. Finally, an analysis of the collaboration in the tabletop setting, for which the tracking environment was used, is presented.

5.4.3 Idea Quantity and Quality

Table 5.1 and Table 5.2 show the results of the idea quantity and quality in comparison. As it is not the goal of this thesis to examine the different involved creativity techniques in detail, we decided to only count the number of aspects created at the end of each of the three phases (ergo the end of each creativity technique). Using the aspects as an indicator for the "number of ideas" resulted from the slight differences in the experiment without IT support (setting 2). There, in the first two phases, ideas were always regarded as single aspect entities. In the third phase, when several aspects were merged into a new idea, the original aspects were not removed from the whiteboard and consequently not subtracted from the total number of ideas. In contrast, in the IT supported cases, the original ideas were removed. After the third divergent phase, the number of ideas and aspects is final (because in convergent phases ideas are only attributed by a rating). For comparing the results between the different group sizes, the number of ideas generated by each group was divided by the number of group members. In the two convergent phases, each participant of a group rated the creativity and feasibility of an idea independently as explained in Section 5.4.1.

Idea Quantity (per Person)	Setting 1) Distributed: Web Client		Setting 2) Collocated: Without IT		**Setting 3) Collocated: Tabletop**	
	Mean	Median	Mean	Median	Mean	Median
End of Phase 1	8.14	8.50	5.80	5.75	7.58	8.75
End of Phase 2	12.67	12.00	8.81	8.33	10.94	12.33
End of Phase 3	12.87	13.00	12.38	13.00	11.35	12.50

Table 5.1: Number of ideas

Regarding the percentage increase of ideas between the first two phases, the use of the

	Setting 1) Distributed: Web Client			Setting 2) Collocated: Without IT			**Setting 3) Collocated: Tabletop**		
	Mean	Median	*stdev*	Mean	Median	*stdev*	Mean	Median	*stdev*
Idea creativity	2.10	2	0.89	2.41	3	1.01	2.30	2	1.21
Idea feasibility	2.39	3	1.08	1.80	2	0.92	2.34	3	1.27

Table 5.2: Idea ratings

ISTC application (setting 3) resulted in a slightly lower value (44.3%) than in setting 1 (web, 55.7%) and in setting 2 (without IT, 51.9%). Regarding the total number of ideas after phase 1 and phase 2, the ISTC application reached almost the same level as the web application (7.58 to 8.14 (mean, phase 1) and 10.94 to 12.67 (mean, phase 2)), both outperforming the setting without IT (5.80 and 8.81). For the total number of ideas after the third phase, we measured a mean of 12.87 per participant in setting 1 (web). Compared to that, the collocated settings (settings 2 and 3) lag behind with 12.38 (without IT) and 11.35 (tabletop). One reason for this is that both introduce physical boundaries (size of whiteboard / tabletop) which limit the total number of ideas. Thereby, the technological restrictions of the tabletop device (pixel resolution of 1024x768 and size of 42 inch) limit the available space for new ideas even more than the whiteboard in the setting without IT support (cp. Figure 5.5 (page 127) and Figure 5.6 (page 128)). Hence, it is reasonable that in the tabletop setting the lowest final number of ideas could be observed. In contrast to these boundaries, the virtual whiteboard in the web setting can be scrolled and zoomed independently for each user and thus provides a much larger whitespace for generating new ideas. The focus group of computer science students may be another reason why more ideas than in the other two settings can be observed. This group is familiar with a keyboard and a mouse for their daily work. For them, this method can be regarded as more efficient for entering data than a touch or pen-based approach. A last reason for the larger number of ideas when using the web application could be that the participants are less distracted from the actual task of generating ideas. This is particularly fostered by our setting, where the participants were provided with PCs and did not use their own machines (where they would possibly have been distracted by emails or instant messaging applications). Finally, the distributed web setting has the least possibilities for social interaction, which additionally reduces distraction from the task and influences the rate of idea generation.

With regard to the creativity ratings of the ideas (0 = worst . . . 4 = best), the tabletop setting (mean: 2.30, median: 2, *stdev*: 1.21) ranges in-between the setting without IT support (mean: 2.41, median: 3, *stdev*: 1.01) and the distributed (web) setting (mean: 2.10 median: 2, *stdev*: 0.89). Although no statistical significance could be found, the mean of the creativity rating in the tabletop setting (which is slightly higher than the one that resulted from using the web application) shows certain evidence that increased social interaction can lead to more creative ideas. In a professional setting this may be different than in a student-only setting, because the presence of hierarchies may prevent the expression of more radical ideas. Concerning the feasibility of the ideas, the tabletop application performed similar to the web application (mean: 2.34, median: 3, *stdev*: 1.27 vs. mean: 2.39, median: 3, *stdev*: 1.08). The setting without IT support led to a lower feasibility (mean: 1.80, median: 2, *stdev*: 0.92).

5.4.4 User Survey

Table 5.3 gives an overview about the questions that were asked in the user survey. It must be mentioned that not every question was asked in each setting. For example, questions regarding computer support could only be asked in the IT-supported settings (settings 1 and 2). Consequently, only some of the survey questions are compared across all three settings. The questions are grouped into four categories: general questions (Q1, Q2), group related questions (Q3 - Q12), questions regarding the computer support (Q13 - Q22), and questions regarding the usability of the ISTC application (Q23 - Q27). We did not consider specific questions about the applied creative process, as those were already examined in [Forster, 2010]. Again, a seven point Likert scale [Likert, 1932] from -3 (strongly disagree) to +3 (strongly agree) is applied (as used in the preliminary study).

Based on the survey results, we calculated the mean, the median, and the standard deviation (*stdev*). Furthermore, in some selected cases, a two-sample Mann-Whitney U-test [Bortz and Döring, 2006, p.678] was made to investigate on the statistical significance of the results. This test is well-suited to testing hypotheses on small distributed samples [Nachar, 2008] without assuming that they follow normal distribution. It helps to decide whether the population distributions are identical or, alternatively, whether observations in one sample tend to be larger than observations in the other. In the case of this thesis the test was performed with two independent data samples[2] in order to mainly compare the distributions of the web setting and the tabletop setting. If not written otherwise, the p-value given in the following discussion refers to this comparison. All necessary calculations and tests were made by using the statistical computing and graphics framework R [The R Project for Statistical Computing, 2012].

Figure 5.4 shows the mean, the median and the standard deviation (*stdev*) for the questions that were asked in all three of the experiment settings. Figure 5.5 shows the same information for the questions asked only in the web and the tabletop settings. Finally, Figure 5.6 shows the remaining results which only target questions directly addressing the tabletop setting. In the following discussion we refer to these questions by the **question ID** and the **table number** (in round brackets).

In comparison to the other two settings, the tabletop setting was judged as most fun with a mean of 2.19 versus 1.68 in setting 1 (web) and 0.39 in setting 2 (without IT) (Q1: Table 5.4). The Mann-Whitney U-test showed that the difference in distributions between

[2]Two data samples are independent if they come from distinct populations and the samples do not affect each other.

ID	Table	Question
General		
Q1	5.4	The creativity sessions were fun.
Q2	5.4	Within a session I always knew what to do.
Group		
Q3	5.4, 5.10	The collaborative work in the group helped me to find ideas that otherwise would not have come into my mind.
Q4	5.4, 5.10	I perceived the simultaneous and collaborative work on the ideas as positive.
Q5	5.4, 5.10	I did not like that others were able to modify my ideas.
Q6	5.4	The group composition was optimal for idea generation.
Q7	5.4	The group composition was optimal for idea evaluation.
Q8	5.5, 5.10	The number of group members was optimal for the task.
Q9	5.4, 5.10	The group collaboration was fun.
Q10	5.5	There were people in my group that did not fit into the team.
Q11	5.4	There were people in my group that hindered me in my work.
Q12	5.5	On the basis of the results, I would like to work in the same team again.
Computer Support and Usability		
Q13	5.5	Due to the computer support the sessions were more effective.
Q14	5.5	Due to the computer support I participated more actively.
Q15	5.5	Due to the computer support all participants were able to bring in their ideas and opinions more equally.
Q16	5.5	Due to the computer support our group was able to produce better ideas.
Q17	5.5	Due to the computer support our group was able to produce more ideas.
Q18	5.5	The computer support distracted me from my creative task.
Q19	5.5	The computer support restricted me in my creativity.
Q20	5.5	I was able to express/describe my ideas the way I wanted to.
Q21	5.5	The computer support cost us more effort than the benefits it brought.
Q22	5.5	The application is easy to use.
Usability (Tabletop only)		
Q23	5.6	The realistic physical behavior of the virtual objects made the interaction with others more intuitive.
Q24	5.6	By using the tabletop application I experienced more freedom of movement than being at a single-user PC.
Q25	5.6	The size of the tabletop screen restricted me in my work.
Q26	5.6	I already have experience with the virtual iPhone Keyboard.
Q27	5.6	The virtual iPhone-based keyboard hampered me in my work.

Table 5.3: Survey questions (main study)

Question	Setting 1) Distributed: Web Client			Setting 2) Collocated: Without IT			**Setting 3) Collocated: Tabletop**		
	Mean	Median	*stdev*	Mean	Median	*stdev*	Mean	Median	*stdev*
Q1	1.68	2	1.08	0.39	0	1.55	2.19	2	0.79
Q2	2.03	2	1.20	1.21	2	1.73	1.61	2	1.42
Q3	1.82	2	1.24	-0.17	0.5	2.13	1.00	2	1.68
Q4	2.17	3	1.13	0.79	1	1.73	2.07	2	1.17
Q5	-1.60	-2	1.73	-2.13	-3	1.53	-2.13	-2	1.38
Q6	0.83	1	1.34	-0.04	0	2.02	1.03	1	1.35
Q7	0.74	1	1.35	-0.38	-0.5	1.90	1.23	1	1.08
Q9	1.91	2	1.12	0.60	0	1.75	2.32	2	0.74
Q11	-2.35	-3	1.27	-2.05	-3	1.72	-2.26	-3	1.18

Table 5.4: Survey results (all three settings)

the tabletop and the web setting is statistically significant with a p-value of 0.019. In analogy to the discussion in Section 3.1.3 this is not surprising. The tabletop environment combines the advantages of IT support with true face-to-face collaboration. Furthermore, the observations made during the experiment showed that especially the touch-based interaction and the realistic physics engine bring in certain elements of gamification which also make the application more fun for the participants. This is also supported by (Q23: Table 5.6), which shows that the participants judged the realistic physics applied to the virtual objects helpful for a more intuitive interaction. Moreover, when collaborating in the tabletop environment they experienced increased freedom of movement (Q24: Table 5.6). As a result, the participants enjoyed using this application more than the web-based setting, where they were sitting isolated in front of their PCs. Interestingly, the setting without IT support was judged as least enjoyable. Reasons may be the restricted interaction (all actions were performed via the moderator) as well as the fact that novel ways of IT support are such a new experience for the participants, that they enjoy them even more than working in a traditional way.

Both types of computer support made it possible for the participants to check the task description during the whole experiment. That way, they were always directly informed what to do in the current phase/creativity technique (Q2: Table 5.4). Here, the web setting is judged as preferable (mean: 2.03) to the tabletop setting (mean: 1.61) and the setting without IT support (mean: 1.21). One reason is that when sitting at individual PCs, each participant can take his time to read the task description for each phase individually. At the tabletop, the personal information widget also provides that option, but due to the group pressure to work on the ideas, this time is limited. Another reason is situated in the design of the user interface. The web application directly (and at any time) displays the problem description and the current task on top of the screen. At the tabletop, this description can only be seen when explicitly switching in the information widget.

In both IT settings, the participants stated that the collaborative work helped them to find novel ideas - more precisely - ideas that they would not have thought of without the stimulation by other team members (Q3: Table 5.4). As both IT settings allow for the modification of the ideas of others, these ideas themselves can act as a stimulus for novel ideas. At this, using the web application was rated significantly better (p-value: 0.015) than the tabletop (mean of 1.82 vs. 1.00). One reason may be that in the web setting, the collaboration directly focuses on the ideas and the whiteboard itself, while in the collocated settings much conversation and collaboration activity is taking place in the physical space as well. In the setting without IT Support, the direct collaboration via the idea cards is restricted due to the role of the moderator, who controls the access to the whiteboard. Furthermore, it is harder to read the ideas of others due to handwriting variance and the large whiteboard in front of the participants. Hence, this setting lags far behind with a mean of -0.17. The advantages of IT support for collaboration can also be seen in (Q4: Table 5.4). The results show that the participants perceived the simultaneous and collaborative work on the ideas in the IT-supported settings (mean: 2.17 (web), 2.07 (tabletop)) as significantly more positive than in the setting without IT support (mean: 0.79). The computed p-values in comparison to the setting without IT support are 0.003 (tabletop) and 0.0001 (web).

The fact that ideas can be modified and discarded by all participants was seen as less problematic in both the collocated settings (Q5: Table 5.4), both having an equal mean of -2.13 (vs. -1.60, web). Here, as discussed in Section 3.1.3, social norms form a basis for how people interact with others and with their owned and shared artifacts. For example, utilizing someone else's idea becomes more likely when using the web application, where everyone is more anonymous and, consequently, has more courage to perform more invasive actions.

The group composition was judged as more optimal for idea generation (Q6: Table 5.4) and for idea evaluation (Q7: Table 5.4) in the tabletop setting. While the Mann-Whitney test of the first question (tabletop vs. web) only resulted in a p-value of 0.325, the latter was expressed more significantly with a p-value of 0.055. This undermines that the quality of the group perception and the group collaboration is judged better when being in a collocated face-to-face situation. This is especially the case when talking about ideas is needed (as may be the case in an evaluation phase, e.g. for comprehension) because questions can be asked and answered faster. Hence, this difference between the web and the tabletop setting is expressed in the survey (mean: 0.74 vs. 1.23).

The resulting faster interaction and the better group collaboration in the tabletop setting also shows up in (Q8: Table 5.4) concerning the question of whether the number of group members was optimally suited for the given task. Here, statistical significance compared to the web setting could be found (p-value: 0.096) - with a mean of 1.52 (tabletop) vs. 1.08 (web). Further evidence is gained by regarding (Q9: Table 5.4). According to the results of this survey question, the group collaboration was judged to be more fun in the tabletop setting (mean: 2.32) than in the web setting (mean: 1.91, p-value: 0.105). This results from issues discussed earlier (gamification, interactivity, user experience) which directly affect the group collaboration. For example, realistic physics makes the exchange of

Question	Setting 1) Distributed: Web Client			**Setting 3) Collocated: Tabletop**		
	Mean	Median	*stdev*	Mean	Median	*stdev*
Q8	1.08	1	1.47	1.52	2	1.54
Q10	-2.01	-3	1.31	-2.03	-3	1.57
Q12	0.69	1	1.39	1.16	1	1.41
Q13	1.15	1.5	1.64	0.74	1	1.52
Q14	1.17	1.5	1.64	1.26	2	1.54
Q15	1.50	2	1.45	0.81	1	1.31
Q16	0.92	1	1.50	0.51	0	1.11
Q17	1.80	2	1.41	1.61	2	1.19
Q18	-1.37	-2	1.44	-1.10	-1	1.29
Q19	-1.23	-2	1.60	-1.71	-2	1.31
Q20	0.62	1	1.67	0.26	1	1.47
Q21	-1.19	-1.5	1.67	-1.16	-1	1.03
Q22	1.99	2	1.17	0.84	1	1.64

Table 5.5: Survey results (web vs. tabletop)

ideas with other group members (e.g. by a slide) easier. Even though the tabletop application provides more interactivity and playfulness, its use is not seen as significantly more distracting from the creative task than working distributed via the web application (Q18: Table 5.5, p-value: 0.232). In fact, the participants even stated that when using the web application, they were more restricted in their creativity (Q19: Table 5.5)).

Interestingly, in the web as well as in the tabletop setting, the presence of other group members was not judged as problematic. People did not felt hindered in their work (Q11: Table 5.4, mean: -2.35 (web) vs. -2.26 (tabletop)) or judged by someone else as being unsuitable for their team (Q10: Table 5.5, mean: -2.01 (web) vs. -2.03 (tabletop)). Consequently, they also stated that they would like to work in the same team again (Q12: Table 5.5). Here, the tabletop setting (mean: 1.16) is in favor of the web setting (mean: 0.69) with a p-value of 0.120.

While the sessions with the web client were rated as more effective (Q13: Table 5.5, mean: 1.15 (web) vs. 0.74 (tabletop), p-value: 0.104), the participants also stated that when using the tabletop application, they participated more actively (Q14: Table 5.5, mean: 1.17 (web) vs. 1.26 (tabletop)). The higher effectiveness in the web setting may result from the more focused work on the creative ideas. In contrast, in the tabletop setting, more group and face-to-face collaboration is taking place, leading to a comparatively reduced effectiveness but also to a more active way of working. This is in accordance to the theoretical work on nominal groups in Brainstorming sessions. It also demonstrates the potential influence of face-to-face interaction on the creative collaboration, presented and discussed in Section 3.1.3. This also reflects on the judgments of the number and the quality of the ideas produced (Q16 and Q17: Table 5.5) where the web setting beats the tabletop. However, as pointed out in Section 5.4.3, another factor which mainly limited the number of ideas is the display size and resolution of the tabletop. The increased anonymity and the increased focus on the creative process when working in a distributed setting is also expressed in (Q15: Table 5.5). According to this survey question, in the web setting ideas and opinions can be brought in more equally (mean: 1.50). Compared to the tabletop setting (mean: 0.81), this difference is expressed significantly better with a p-value of 0.012.

Question	**Setting 3) Collocated: Tabletop**		
	Mean	Median	*stdev*
Q23	0.74	1	1.84
Q24	1.32	2	1.58
Q25	-0.74	-1	1.61
Q26	-0.52	-2	2.71
Q27	-0.81	-1	2.18

Table 5.6: Survey results (tabletop only)

Although the results above show that the ISTC application agreed with the main assumptions about the positive impact on group collaboration, participant satisfaction, and motivation when using a tabletop environment, some critical issues arose. Because the prototype was still limited to textual ideas, some participants stated that they were not able to express their ideas as they wanted to, compared to the web setting (Q20: Table 5.5) - mean: 0.26 vs. 0.62. Also, the intuitive use of the touch-based application did not show up as clearly as one could have imagined, with the mean being similar to the web application (Q21: Table 5.5, mean: -1.19 vs. -1.16). Considering the still present technological restrictions, such as a not 100% accurate touch recognition and the fact that the target group were computer science students who are very familiar to web applications, this result can be seen in a different light and judged as not too bad for a novel way of application control.

Compared to the preliminary study (Section 5.3), the size of the tabletop screen was considered significantly less problematic (Q25: Table 5.6 - mean: -0.74 vs. 0.92 (preliminary study), p-value: 0.008). Hence, the decoupling of the virtual keyboard from the tabletop to individual iPhones resulted in fairly good results. The potential counterargument that a virtual touch-based keyboard is difficult to use was also factored into the survey. Previous experiences with the iPhone keyboard were stated as diverse (Q26: Table 5.6) with a mean of -0.52 and a relatively high standard deviation of 2.71. The number of users hampered by the iPhone keyboard was comparatively low (Q27: Table 5.6 - mean: -0.81). However, the equally high standard deviation of 2.18 indicates that users who are more experienced with touch-based keyboards are also less likely to consider their use as problematic (what was also confirmed by our observations).

5.4.5 Collaboration in the Tabletop Environment

As pointed out earlier, for a more comprehensive evaluation of the interaction in the tabletop setting, a dedicated tracking environment was assembled (Figure 5.2 (page 121)). In this way, we gained insight into the collaborative behavior of the users and their handling of the application itself. A first examination of the data presented in this section was published in [Frieß et al., 2012b].

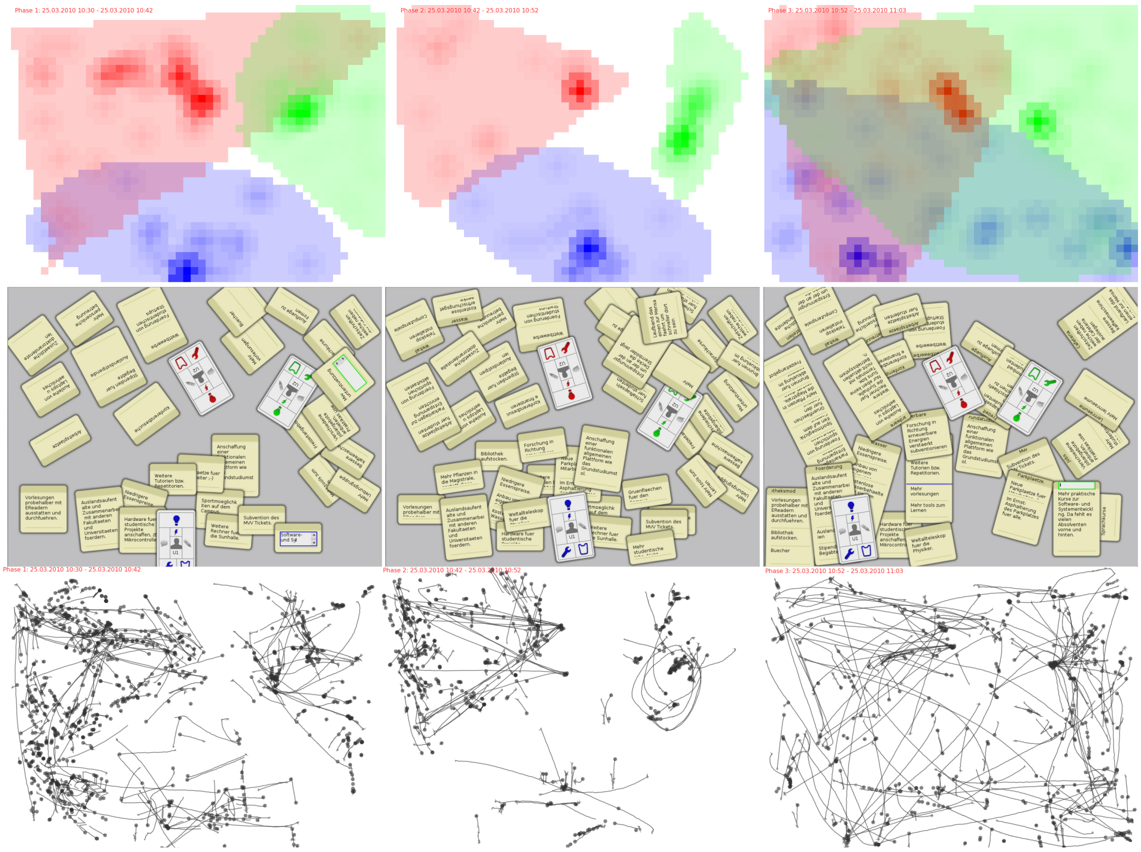

Figure 5.7: Territories and related workspaces for phase 1 - 3 (example from session 5)

Figure 5.7 shows an example of the data gained in regard to user territories. The example which is taken from session 5, starts from phase 1 (Brainwriting - column 1), through phase 2 (Unrelated Stimuli - column 2), and into phase 3 (Forced Combination - column 3). Row 2 displays a screenshot of the tabletop surface at the end of each phase, taken from the automatic screen-recording done with the tool recordMyDesktop [recordMyDesktop, 2012]. Row 1 shows the users' territories in the style of a heat map colored by the relative intensity distribution of their actions. Heat maps are typically used for usability analysis (e.g. of web applications [Bigham and Murray, 2010]) and can help identify hot spots of the users' interactions similar to the activity plots proposed in [Scott et al., 2004]. To determine the territories, we took into account all actions our system could clearly associate with a user (all those that have to be performed by using the personal control widget: creating, updating and deleting ideas). Next, we calculated the convex hull of their start- and end-points. In row 3 a plot of the raw touch events, performed in each phase, is shown. Starting-points are drawn bigger than other touch-points.

Looking at the screenshots in the second row, one can see that the individual territories are reflected by the orientation of the ideas. Almost all the ideas in a user's personal space are oriented towards his position. This also applies to the personal control widget to which ideas get aligned when they are created. This observation also proved to be true for the other sessions. When a user moved an idea into his private territory, we observed that its orientation was adjusted according to the user's position. However, we also noticed some users were editing ideas upside down. This was probably caused by the fact that the iPhone application, which was used for text-entry, allowed them to see the idea correctly and independently from its position on the table. In fact, some users avoided the additional effort for rotating the ideas.

While comparing the derived territories within the different phases, it appears that in phase 1 and 2, mostly isolated personal territories can be accounted for. In phase 3 individual territories lose their strength and tend to increasingly overlap, thus forming larger group territories. These observations hold true for most of our sessions, as only the users during one session showed a different behavior. In this session, even in phase 1 and 2, group territories were favored. However, in contrast to the other sessions, these users knew each other from outside the session, indicating that personal territories are less favored when group members are very familiar with each other. Another reason why the personal territories lost their strength in phase 3 may be that when a certain amount of ideas was generated (so that no free space was left), personal territories cannot be preserved. In summary, the observations show that free positioning and territoriality is widely accepted and used by the experiment participants.

Another interesting observation was made regarding the spatial distribution of the aforementioned group territories. Most of these showed up along the borders of the personal territories of adjacent users, whereas less cooperation (expressed by smaller overlapping areas) was observed between users standing on opposing sides of the table. This might directly relate to the preferred positions (around a table) for different kinds of social interactions described in Figure 3.4 (page 70), meaning that opposing users are often regarded as competitors.

This assumption is further supported by the data from Table 5.7, which shows the amount of ideas moved between different territories and the number of ideas rotated by 90° / 180°. As one can see, at least in the first two phases, there are more 90° rotations than 180°. Furthermore, we observed more territory changes and rotations in phase 3 than in phase 1 and phase 2. This result, combined with the observations regarding the group territories, supports that there was more interchange of ideas between the users in the

	Territory Changes	Rotations of 90°	Rotations of 180°
Phase 1	26,17%	35,52%	29,17%
Phase 2	30,63%	24,40%	14,58%
Phase 3	43,20%	40,08%	56,25%
Total	493	507	93

Table 5.7: Territory changes and rotations (averaged over all sessions)

third phase.

In the physical space around the tabletop device, we first analyzed the interpersonal distances by using the tracked user positions. For this purpose, we assumed that the average as well as the minimum and maximum distance (for each phase) would be the most interesting information. Table 5.8 lists the minimum, maximum and average values for each phase, again averaged over all eight sessions. As can be seen, interpersonal distances stayed in between the ranges of the casual-personal zone (minimum and average values) and the socio-consultive zone (maximum values). In accordance with the theoretical background (Figure 3.3 (page 69)), only three users (out of all 31) approached each other closer than a minimal distance of 500 mm (intimate zone) with a closest distance of 344 mm. Hence, Scott's statement in regard to tabletop collaboration that "*group members may temporarily be permitted to interact within a person's "intimate" space, but interaction at this distance for prolonged periods will often feel socially awkward*" [Scott et al., 2003] proves to be true in our experiment. Regarding the three phases, the averaged minimal distances decrease slightly towards phase 3. This can be explained by more inter-territorial and interpersonal activity taking place in this phase, thus moving the tracking beacons closer together.

	Phase 1	Phase 2	Phase 3	Total
Min.	818,81	808,32	698,20	775,11
Max.	1772,73	1600,40	1608,11	1660,41
Avg.	1202,67	1169,52	1101,98	1158,06

Table 5.8: Averaged distances between the users [in mm]

To visualize the change of positions and the body orientations during each session, we converted the tracked data frames (coordinates and rotation matrix) to videos. A still-frame from such a video can be seen in the upper left corner of Figure 5.8. As can be seen, there are four users identified by their beacon IDs (numbers 2 to 4). The red "x" at each user's shoulder line indicates the right shoulder (where the beacon was placed) and the smaller line the viewing direction. In a second step, we used the coordinates to calculate a heat map of each user's area of movement (in each phase). The color intensity reflects the amount of time that a user spent at one position. As can be seen in Figure 5.8, the area of movement was slightly larger in phase 1 than in the other phases. In the example, this was due to two users moving away from their initial positions. Apart from that, the users mostly stayed at their initial position. As all sides of the table were occupied from

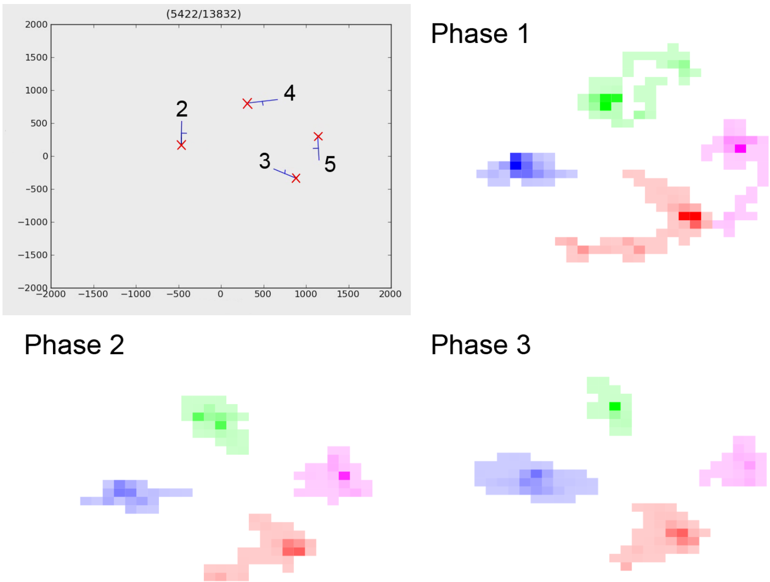

Figure 5.8: Recording and heat map of user movement (example from session 3)

the beginning, this indicates that a user regards his side as his “own”. Although we did not observe any significant movement during the experiment, the option to take free positions can still be regarded as important in the beginning of a session to take positions according to the social relations of the participants.

Additionally, the evaluation of the body orientation demonstrated predicted results. As it was expected, the orientation of the users was most of the time parallel to the tabletop’s edges. In a very few cases, people at the corner of the table were oriented towards each other, as can be seen in Figure 5.8 - for beacons 3 and 5. Sometimes this led to nearly parallel shoulder orientations. The study pointed towards increased social interaction during this period. But, as already mentioned, these cases were rarely observed and only lasted for short time periods. The main maxima of the relative body orientation were at $\pm\pi/2$ and $\pm\pi$ with only small deviations.

For regarding the verbal communication, an automated audio analysis of the recorded MP3 tracks was devised. This analysis was intended to investigate on the relative duration and the patterns of communication. It is based on two techniques of audio analysis. The first calculates the plain speaking time by tracking spectral changes in the signals that happen above the threshold of the averaged loudness at a certain period of time [Hainsworth, 2004]. These events of spectral change are then clustered within a time frame (of minimal size), thus segmenting the recording into a set of time frames. The segments obtained from all participants are then evaluated for overlapping regions that exist in the recordings of several participants. For each of these overlapping regions the power of the signal is calculated. Since the power of the sound propagation falls off quadratically with growing distance, it is to expect that the speaking person wearing the MP3 recorder can be separated from other speakers and background noise. Such regions are subtracted from the original segments except for the overlapping region with the maximum power. As a result only segments of the recording are obtained that are classified as carrying different information and having the most loudness. The averaged sum of all segments of a recording is then used to roughly estimate the amount (length) of verbal communication of each participant. To gain insight on the flow of conversation, these results were converted into a graph structure. Segments (as nodes) are connected by edges (indicating their timely order), thus forming a path for a single user. Such paths are then connected pairwise if there exist segments in both paths that happened in the same time-frame. Finally, the amount of interconnecting edges is used to estimate how much communication is carried out per participant in dialog in comparison to the edges solely in the path. However, when analyzing the data and comparing it to the video recordings, it became apparent that its quality was insufficient for an exact automatic analysis of the communication patterns. One reason were the used devices and the involved standard (directional) microphones that only provided a low recording quality. Moreover, their placement on a necklace resulted in additional noise, e.g. when the device was shaken. A second reason is that every face-to-face situation with more than two persons involves background noise and cross talk between different subgroups (because of different levels of coupling). This makes it difficult and even impossible to differentiate between different speakers. In literature, this problem is often referred to as the so called cocktail party problem [Haykin and Chen, 2005].

In a last experiment, we investigated further on the effects of using coupled display devices in the context of the ISTC application. For this purpose, the iPhone application was extended by several features and migrated to iPad devices, as already presented in Section 4.2. The experiment setting as well as the main results are the focus of the next section.

5.5 Additional Study

In the evaluation of the full-featured coupled display extension of the ISTC application, 27 students (also computer science) were partitioned into seven groups. For this experiment, a simpler creative process structure was applied than for the main study. After a 15 minute introductory tutorial session (to become familiar with the handling of the application and the iPads), we chose a standard 20 minute long Brainstorming phase to find solutions to the problem statement "*How could we improve the food supply at the campus?*". Besides the requirements of Brainstorming (criticism is ruled out, freewheeling is welcome, quantity is wanted, combinations of ideas are sought) [Vangundy, 1988] and the 20 minute time limit, no other constraints were imposed. As in the experiments before, the final ideas were evaluated with regard to their creativity and feasibility on a five point Likert scale [Likert, 1932] from 0 (worst) to 4 (best). Afterwards, again a paper-based user survey was handed out. The focus of this

Additional Study

Participants: 27
Male: 81.5% **Female:** 18.5%
Age (avg.): 30.2 years
Experience Crea. Tech.: 77.8%

survey was to determine differences compared to the main study, to gain insights into the invasiveness of the approach, to estimate the effect of media discontinuities (transitions between the different workspaces), and to find out if the coupled display functionality provided an added value to the participants. Table 5.10 shows a comparison to some of the questions that were asked in the main study. These can be referenced by their question ID in Table 5.3 (page 132). In addition, Table 5.11 presents the questions that were asked in the additional study only. A photo from the experiment can be seen in Figure 5.9. Aspects of the evaluation of this study were published in [Frieß and Kleinhans, 2011].

Figure 5.9: Additional coupled display study (with iPads)

Throughout all sessions a **total of 91 ideas** was generated, making an **average of 13 ideas** per group, similar to the main study. This again emphasizes that the maximum number of ideas is mainly limited by the size and resolution of the tabletop device. The two convergent (rating) phases resulted in a **mean creativity score of 2.51**, while the **feasibility score** ranges at a **mean of 2.47**. Compared to the experiment from the main study, the creativity and feasibility ratings are higher (see Table 5.9). One reason for this could be the different and more simple problem statement that was applied and which led to a broader and more diverse spectrum of ideas. However, another reason might relate to the higher media richness when expressing an idea (not only text, but also images and sketches are possible via the iPad). For instance, the participants were able to use the Google Image Search API to retrieve images according to a search query. Due to the functionality provided by that API, sometimes unwanted and random results showed up. For example, images were displayed that were completely off-topic to the entered search string (possibly due to a wrong assignment to keywords in the underlying database). In these cases, the image itself acted as a stimulus for novel and more creative ideas similar to the Unrelated Stimuli technique applied in the main study.

Table 5.10 shows the survey questions that were compared to the two IT-supported settings presented in the context of the main study (IdeaStream web client (setting 1) and ISTC with coupled iPhones (setting 3)).

	Setting 1) Distributed: Web Client			Setting 3) Collocated: Tabletop			**Setting 4) Collocated: Coupled Displays**		
	Mean	Median	*stdev*	Mean	Median	*stdev*	Mean	Median	*stdev*
Idea creativity	2.10	2	0.89	2.30	2	1.21	2.51	3	1.25
Idea feasibility	2.39	3	1.08	2.34	3	1.27	2.47	3	1.34

Table 5.9: Idea ratings compared to the main study (presented in Section 5.4.3)

Question	Setting 1) Distributed: Web Client			Setting 3) Collocated: Tabletop			**Setting 4) Collocated: Coupled Displays**		
	Mean	Median	*stdev*	Mean	Median	*stdev*	Mean	Median	*stdev*
Q3	1.82	2	1.24	1.00	2	1.68	0.44	1	2.09
Q4	2.17	3	1.13	2.07	2	1.17	1.15	2	1.65
Q5	-1.60	-2	1.73	-2.13	-2	1.38	-1.56	-2	1.61
Q8	1.08	1	1.47	1.52	2	1.54	1.44	2	1.73
Q9	1.91	2	1.12	2.32	2	0.74	1.63	2	1.44

Table 5.10: Survey results (comparison)

When using the full-featured coupled display extension based on the iPad (setting 4), the participants stated that the collaborative work in the group was less useful (mean: 0.44) for finding novel ideas and associations than in the other two settings (Q3: Table 5.10). This is also supported by (Q34: Table 5.11), stating that other participants spent more time working on their iPad than with the group. However, with a mean of 0.33, Q34 is neither on the upper nor the lower end of the applied scale. Despite this, the simultaneous collaborative work was still regarded as considerably positive (Q4: Table 5.10) but less pronounced than in the other two settings - with a mean of only 1.15.

The influence of the more isolated way of working when using the full-featured coupled display application also showed up in Q5 (Table 5.10). Asking the participants if they disliked others being able to modify their ideas resulted in a similar mean as in the web setting (-1.56 vs. -1.60). One reason for this could be that the coupled displays introduce similar options for modifying an idea as when using the web-front end of IdeaStream. For example, ideas can be modified more anonymously so that social norms apply considerably less. A comparison of the distributions of setting 3 (tabletop) and setting 4 (coupled displays) by using the Mann-Whitney test resulted in a p-value of 0.151. Despite that, the possibility of creating whole ideas in the offline workspace (on the iPad) and then pushing them to the tabletop workspace anonymously was not frequently used (Q32: Table 5.11, mean: -0.59). In accordance to that, the participants stated that they would also have

Question	**Setting 4) Collocated: Coupled Displays**		
	Mean	Median	*stdev*
Q28: The coupled display user interface is intuitive to use.	1.37	2	1.22
Q29: The functionality of the coupled displays brought an added value to the tabletop application.	1.74	2	1.35
Q30: The functionality of the coupled displays helped me to express my ideas.	1.15	1	1.36
Q31: Switching between the coupled displays and the tabletop was easy.	1.00	2	1.50
Q32: I used the possibility to anonymously create ideas in the offline workspace on the coupled display.	-0.59	-1	2.42
Q33: Without being able to create ideas anonymously, I would not have committed some of those ideas.	-2.12	-3	1.51
Q34: Other participants did work more time on their iPad than with the group.	0.33	0	1.85
Q35: Using the coupled display application helped me to be less distracted by others when working on the ideas.	1.00	1	1.71
Q36: I could imagine using the coupled display application on a smartphone.	0.07	1	2.11

Table 5.11: Survey results (coupled displays)

committed their ideas without having that option (Q33: Table 5.11, mean: -2.12). First, this may be due to the student setting, where most participants did not know each other before and where no different hierarchy levels were present. Hence there were less inhibition to express radical ideas in public. Even more, the social interaction in this constellation even stimulated the commitment of such ideas. Second, it may also point out that creating an (empty) idea in public via the personal control widget and then editing its contents on the coupled display already provides a sufficient degree of anonymity and thus is the preferred working style. In this regard, the participants also stated that the working on the iPad in a more private atmosphere helped them to be less distracted by others (Q35: Table 5.11, mean: 1.00).

The question if the number of group members was optimal for the given task (Q8: Table 5.10) was rated similar to the tabletop setting from the main study (setting 3), with a mean of 1.44 vs. 1.52. In this regard, the physical properties of the device could play a certain role - if all four sides are occupied, people might get the feeling that the group is filled. The decreased interactivity by and the more focused / isolated work on the coupled displays manifested in Q9 (Table 5.10). The group collaboration was judged as significantly less fun in the coupled display experiment (mean: 1.63) than in the tabletop setting (mean: 2.32) of the main study with a p-value of 0.051. However, a mean of 1.63 asserts that the fun when working with other team members was still perceived as positive.

Most participants agreed that the user interface of the coupled display (iPad) application is intuitive to use (Q28: Table 5.11, mean: 1.37). Furthermore, the functionality which was deployed on the coupled displays was judged as important (it provided an added value to the tabletop application) with a mean of 1.74 (Q29: Table 5.11). This is strongly related to the enhanced input methods like the image search or the sketching, which helped to express the ideas better (Q30: Table 5.11, mean: 1.15). Especially the images were used actively, as can be seen in Figure 5.9. The participants also stated that switching between the coupled displays and the tabletop was easy (Q31: Table 5.11, mean: 1.00). In combination with the intuitive use (Q28: Table 5.11) this shows that the consequent adherence to touch-based input methods combined with the same (visual and logical) idea representation on the tabletop and the coupled displays was successful and that media discontinuities between both types of devices did only play a minor role. Finally, the participants were undecided when being asked if they could imagine the same functionality and the same type of application on a (smaller) smartphone (Q36: Table 5.11) - with a mean of 0.07 and a standard deviation of 2.11.

5.6 Discussion of the Results

In summary, the evaluation of the ISTC application within the scope of the preliminary, the main, and the additional study led to several valuable insights into creative collaboration and prospects of using a situative creativity support.

Concerning the **number of ideas**, the ISTC application proved to be remarkable in its ability to keep up with the IdeaStream web application, even in early phases of the applied creative process. This indicates that not only anonymity may be a reason why IT-supported creativity sessions can lead to an increased amount of ideas. Instead, the possibility of parallel input and the broader range of opportunities for collaboration via the creative artifacts (modifying the ideas of others, merging ideas, working synchronously, etc.) are also important contributors to the benefits of IT-support in creative work. However, in the end of each session, in all compared settings approximately the same number of ideas was obtained. This is in accordance with the results from the study by Hilliges et at. [Hilliges et al., 2007] that was presented in Section 2.3.5. In this study, the quality and the number of the ideas generated with a tabletop application was similar to a traditional paper-based Brainstorming session. The advantages of combining a collocated face-to-face setting with a novel way of IT support also show up when regarding the **quality** (= the ratings) **of the ideas**. Here, only in the tabletop settings a high creativity **and** a high feasibility score were achieved. This might indicate that a situative IT support encourages the participants to commit more radical ideas (so that the creativity increases) and that the face-to-face collaboration at the same time helps to consolidate the resulting ideas (so that the feasibility increases).

The results from the **user survey** have shown that a situative IT support, which allows for IT-based collaboration in a true face-to-face setting, can foster group perception and user motivation. The participants stated that they experienced a high degree of satisfaction and fun when working with the group. Furthermore, they perceived the group work and the group composition as ideal for the given task, especially in later phases of the creative process. By being able to implicitly make use of social norms, additional collaboration via the tabletop workspace was generated and group conflicts were avoided. Consequently, the effects of the group work concerning the generation as well as the evaluation of ideas was judged as most positive when using the ISTC application. In this regard, some of the results from the setting without IT support were unexpected. For example, the sessions were judged as least fun compared to the IT supported settings. A potential cause may be that a human moderator was needed for many parts of the idea-related collaboration. In this regard, it becomes again obvious why IT support (of whatever kind) can provide a general advantage to creativity sessions as it automatically moderates a creativity session. However, another reason could be that for our focus group (computer science students) the IT support was more fascinating than traditional methods.

Concerning the **analysis of the usability and the user collaboration**, it became apparent that the conceptual thoughts on the design of a tabletop workspace were widely accepted by the participants. They particularly made use of territoriality, although in later phases private territories decreased and the focus shifted more and more towards collaboration. Although most participants kept their initial position at the tabletop for the whole experiment, a free positioning can still be considered as important, e.g. to adapt to different group configurations and forms of collaboration in the beginning of a session. Despite keeping their side, the participants stated that they experienced more freedom of movement than when sitting at a personal computer. Another aspect which contributed to this experience might be that the participants were fascinated by the realistic interaction with the application. This can be mainly attributed to the integrated physics engine and the direct touch-based input via the display. Both led to a gamification of the application scenario and to more interactivity. Furthermore, the physics engine helped the participants to exchange artifacts with others and made the collaboration more intuitive. Hence, a more active use of the application was fostered and barriers for getting started reduced. All this caused the participants to state that they experienced the most fun when using the ISTC application.

Despite these benefits, there were still **technical limitations of the used hardware** that hampered the interaction via and with the tabletop surface. A first issue was caused by the video projector and the optical touch recognition. As both had to work on a very short distance (and via a mirror), it could not be avoided that the projected image on the tabletop surface was slightly displaced relative to the recorded camera image. Furthermore, also due to the mirror, the rectangular projection was slightly distorted. These problems still occurred after the preliminary study (but in a weaker form) with the exchanged video projector in place. Differences of up to 1.5cm showed up, a value which is typical for large touch screens (see Section 3.2.3 or [Wigdor and Wixon, 2011]). Hence, it was not always possible to hit an object 100% accurately, especially for small areas on the screen. Moreover, sometimes touches were lost when a finger was not pressed hard enough against the tabletop's surface. This happened, for example, when an object was dragged over a longer distance. Although we tried to counteract this problem in the tutorial session by explaining how to interact with the display in an optimal way, some users still experienced these problems during the experiments. In sessions where the tracking environment was used, in rare cases the infrared cameras on the ceiling interfered with the touch-tracking at the tabletop. This, in consequence, led to "ghost" touches which caused unwanted and distracting effects like ideas unintentionally "flying away". Finally, the display size and the screen resolution of the tabletop device limited the collaborative space on the screen, especially in settings where each side was occupied and even with coupled displays in use. In this sense, novel tabletop devices that are based on larger LED displays and which are capable of a resolution of 1920x1080 pixels (or higher) should be considered for future studies. However, despite these technical limitations and shortcomings, the application and the used hardware proved to meet the users' needs for an intuitive interaction.

According to the user survey, the full-featured **coupled display extension** provided an added value to the tabletop application. In this regard, the most important functionality provided by the coupled displays was their use as an **enhanced editor**, allowing for a more comfortable and precise editing of diverse types of content. The image search was widely used by the participants and stimulated their creativity up to a certain level. A few users also took the opportunity to draw sketches with their fingers. Typing in text by hitting the characters on the virtual keyboard on the iPhone (but also on the iPad and on the tabletop) posed a problem to some of the participants. The two main reasons were the missing haptic feedback and (especially on the iPhone) the "fat finger problem" (cp. Section 3.2.2). The latter mostly happened when they tried to hit the small characters on the onscreen keyboard. Here, the statistical results showed that although touch-based interaction is argued as intuitive and easy to learn for novice users, they still need time to adapt for performing more complex operations (such as hitting small areas). However, the results also showed that more experienced users are able to get efficient in doing so. Creating ideas anonymously was not considered of major importance. This can be justified by the student setting in which hierarchies were not an issue. In a business context this might be different. The same applies to the possibility of searching an idea database. This functionality was not used, because no previous sessions were made that could have been searched. In a more realistic setting, this feature might be more valuable as well.

A main lesson that can be drawn from the studies is that people who are in a collocated situation truly want to work face-to-face. In this regard, editing an idea via the coupled displays in manifold ways is accepted and already provides a satisfying degree of anonymity and privacy. However, the focus of collaboration should be maintained in public on the tabletop workspace. Thus, all invasive actions such as deleting ideas or marking them for modification should also be kept in public, visible for all participants (as it is the case in our approach). Accessing more than one idea via the coupled displays (as it was introduced with the `IdeaSets`) should therefore be avoided if a higher level of group collaboration (and a lower degree of isolation) is wanted. In contrast, allowing for such a feature can shift the focus of the collaboration towards the more anonymous web setting, which may also be preferable in some cases. Moreover, IdeaSets might still be useful for an offline mode that allows for creating, modifying, and deleting ideas when working separately from the tabletop or for creativity techniques that require to work alone during some phases of the creative process. For the evaluation phases, the coupled displays provided a more convenient and private way to rate the ideas while still being able to communicate face-to-face. Here, the coupled displays could fully substitute the tabletop.

In summary, these results indicate that the assumptions on the impact of a situative creativity support (that were established in Section 3.1.3) can be maintained. A main conclusion is that a situative creativity support based on a tabletop device can combine most of the benefits of traditional IT applications while preserving the advantages of face-to-face collaboration. However, the samples gained from our studies were relatively low so that further research should be conducted. As pointed out earlier, for a final assessment of such an environment a long term study in a business setting needs to be made.

5.7 Summary

Within this chapter three different studies were discussed. Initially, we established the main evaluation goals and described the technological infrastructure in which the studies took place. Second, a preliminary study with a prototype of the ISTC application was regarded. In this context, we determined weaknesses of the prototype that were mostly solved for later studies. On the basis, the main study was presented. This study involved three different experiment settings: distributed (web-based) IT support, a setting without any IT support, and the ISTC tabletop application with coupled iPhone devices for text input. The results of these experiments showed that a situative tabletop-based CSS can fairly compete with traditional (distributed) IT applications concerning the number and the quality of the resulting ideas. Furthermore, the collaboration analysis performed with the ISTC application proofed that most of the conceptual assumptions regarding its design and implementation could be widely supported. Finally, an additional study with the extended version of the coupled display application for ISTC (based on the iPad) was presented. The chapter concluded with a discussion of the main results.

Chapter 6

Lessons Learned

In this thesis, a variety of results and insights into a situative creativity support was gained. In the scope of this section, we summarize the main ideas discussed in each chapter. In a critical discussion we then revisit the main problems, technological constraints, and insights which came up during the evaluation. In the same section, we also highlight the main contributions of this thesis. Finally, diverse prospects for future work are raised. For this purpose, we refer to novel technology that could be applied to our approach, discuss hybrid approaches combining distributed and collocated IT environments, and describe a different application field to which a tabletop environment (combined with coupled mobile devices) could be successfully applied.

6.1 Summary

In the introduction (**Chapter 1**), the motivation for this thesis was provided. Furthermore, the main research question was introduced and explained. Next, the methodology, which is based on the seven design-science research guidelines by Hevner et al. [Hevner et al., 2004, p.83], was described. In this regard, the different activities done in the scope of this thesis were named for each guideline. Additionally, the main contributions were listed and the content of each chapter was briefly summarized.

In **Chapter 2** the fundamental terms and concepts relevant to this thesis were introduced. Starting with a general definition of the term creativity, we introduced the 4P framework of Mel Rhodes [Rhodes, 1961] as the main theoretical basis. Moreover, we discussed its four dimensions of person, press, process, and product in detail. Next, a closer look at IT systems supporting creativity - so called Creativity Support Systems - was made. These systems were then categorized and framed into the broader context of Information Systems and Groupware. Thereby, we regarded different classifications for Groupware that can also be applied to CSS. The last section concluded this chapter with an examination of different types of IT environments. Starting from Electronic Meeting

Systems used in the 1980s and 1990s, these ranged from today's web-based applications and applications for mobile devices (both mainly used in distributed scenarios) to Single Display Groupware and Multi Display Environments used especially in collocated settings.

Based on this foundation, in **Chapter 3** we considered which types of creative situations are common in today's business life. For this purpose, a series of ten interviews was made with experts from the creative domain. After describing the applied interview methodology, we discussed diverse creative situations by directly quoting or referring to concrete interview statements. We then made a deeper examination of the creative collaboration situation and studied related aspects such as social interaction, group awareness, intuitive interaction, the need for face-to-face interaction, and the role of social structures. On this basis we defined our understanding of a situative creativity support and discussed its implications on an IT support. Finally, we regarded why a multi-touch tabletop display - combined with coupled mobile devices - provides an ideal basis for meeting the requirements of a situative creativity support. The chapter concluded with the description of and the reasoning for two concrete application scenarios for an implementation: collaborative creativity techniques and the collaborative composition of electronic music.

Chapter 4 introduced the concrete implementations of both application scenarios, based on the conceptual thoughts discussed in Chapter 3. First, a tabletop application addressing collaborative creativity techniques was described (referred to as ISTC). This application is built upon IdeaStream [Forster, 2010], which implements a generic process model for creativity-techniques. In addition, the chapter presented an extension of ISTC by a coupled display application designed for smartphones (the iPhone) and tablets (the iPad). Finally, the implementation of the second application scenario - allowing for the collaborative composition of music - was discussed. Here, primarily the adaptation of the compositional structures for multi-user collaboration and the tabletop user interface were regarded.

In **Chapter 5**, first the main evaluation goals and the used technological infrastructure were presented. Next, results gained from a preliminary study made with a prototype of the ISTC tabletop application were discussed. These results raised some problematic issues, mainly reasoned by technological limitations of the used tabletop device. Most of these issues were resolved by improvements of the hardware, but also by introducing coupled displays to the application. In the context of the main study, three different experiments were described. One was conducted with the web front-end of IdeaStream, another without any IT support, and the third with the ISTC application (combined with coupled iPhones for text input). Moreover, further insights that were gained from the ISTC experiment only, such as tracked interaction data, were discussed. In a next step, we examined the full-featured coupled display extension of ISTC (based on the iPad) in an additional study. Finally, a discussion of the main results concluded the evaluation chapter.

6.2 Critical Discussion

Although the ISTC application had been thoroughly tested throughout several iterative test sessions, some technological limitations were still present in the final evaluation experiments. In the following, these are briefly summarized. A more detailed explanation can be referenced in Section 5.6. The low pixel resolution and the small screen size of the tabletop display limited the number of ideas which could be generated, especially when all sides of the device were occupied. Second, the projection and optical touch recognition technology used in the tabletop device caused inaccuracies in the touch-based input (e.g. touches were lost and the touch recognition was not 100% accurate). Finally, also the integration of the coupled display devices introduced problems related to technology: the wireless network that was used produced connection losses. Certainly most of these problems did only occur occasionally but, nevertheless, exerted a certain influence on the ratings of the user survey.

Also in the applied experiment settings some weak points could be identified. Especially the setting without IT support was designed as too restrictive. The dedicated moderator acted as a bottleneck and a barrier for collaboration and the physical whiteboard imposed a different way of collaboration than a tabletop workspace would have. However, using index cards and a whiteboard is still the most common way how creativity techniques are conducted in companies. Additionally, the relatively low number of participants in all studies lowered the statistical comparability of the gained results. In this regard, it has also to be stated that performing an experiment in a tabletop setting can be a challenging and demanding task. Especially with the tracking environment in place, lots of effort was needed for the preparation of each participant and for the initialization of the tracking instruments. For gaining more evidence on the investigated topics, a large scale and long term study in a (productive) business environment should be made.

Despite these limitations, the gained results can be seen as fairly good and promising for future research. The evaluation showed that a multi-touch tabletop application allows for complex creative tasks and collaboration activities to be applied in a practical setting. Using the ISTC application led to a similar number and a slightly better quality of ideas as when using a traditional web-based application. Even more, most of the subtle differences which we expected to discover when evaluating a situative creativity support showed up in our studies. For example, the increased gamification and the interactive usage of the application (mainly due to the physics engine and the touch-based input) influenced the participants' motivation in a positive way. Hence, they stated that they experienced a high degree of fun during their collaboration with the tabletop application environment. Additionally, the perception of positive group effects increased because of the better support of social interactions and face-to-face collaboration. By intuitively and directly making use of social norms while collaborating via the IT device, conflicts and misunderstandings were alleviated and collaboration and coordination activity simplified. In contrast, when using the web application, the more anonymous style of IT-based interaction allowed the participants to be more defiant, e.g. by deleting or modifying the ideas of others. The coupled display extension showed to mediate between these two settings. When providing more functionality and more invasive actions on the coupled displays, the style of collaboration was aligned to the style when using a (distributed) web application on a PC. Reducing the functionality and shifting the main focus of collaboration to the tabletop display help, on the other side, to improve group effects and teamwork quality. The resulting conclusion is not entirely in favor of one method of IT support or another to be applied in collocated situations. The concrete decision still needs to be made by a human facilitator by taking into account the group configuration, the problem statement, the used creativity techniques, etc.

In summary, the **main contributions of this thesis** are as follows:

- A comprehensive analysis of the **theoretical background** of creativity and related work was made. This mainly refers to an analysis of the four dimensions of creativity (the 4P framework of Mel Rhodes [Rhodes, 1961]). In addition, we also regarded related work on **electronic support of creativity**, so called Creativity Support Systems and corresponding IT environments. From both sources we gained knowledge about specific aspects of creative collaboration to be kept in mind when supporting it with IT.

- Semi-structured interviews showed **practical insights** into **typical creative situations in companies**, characteristics of and requirements for creative collaboration, and IT and non-IT support tools. On this basis, particularly a **high quality** of **collaboration** and **social interaction** was determined to be an important factor which is still neglected by state-of-the-art IT applications and environments. By performing a deeper analysis of the creative collaboration situation, our view on a situative creativity support was shaped and a **concept** for a **novel IT environment** based on a **multi-touch tabletop display** and **coupled mobile devices** established.

- A **practical realization** of the **concept** for a situative creativity support was implemented in the scope of two application scenarios. The first application, the IdeaStream Tabletop Client is dedicated to the support of **collaborative creativity techniques**. It was first implemented on a tabletop device and then extended by a separate coupled display (client) application running on smartphones and tablets. In this regard, we mainly discussed the software architecture and answered concrete questions that emerged during the implementation. Furthermore, the user interface and the integration of the coupled display devices were presented. The second application concerned itself with the **collaborative composition of electronic music** on a **tabletop device**. This scenario involved a discussion about the adaption of compositional structures for multi-user collaboration on a shared large display.

- Different experiments with student participants were conducted in order to evaluate different versions of the ISTC application. For this purpose, the **tabletop / coupled display environment** was compared to **distributed web-based IT support** and a **more traditional creative scenario** involving index cards and a whiteboard. One main conclusion of these experiments was, that the **number and the quality** of the resulting ideas could **compete** with the other two settings. Concerning the quality, the ISTC application even outperformed them. In addition, the tabletop environment **preserved the benefits of face-to-face collaboration** which fostered group effects. An (automatic) **analysis of the tabletop collaboration** proved that the conceptual assumptions that were made regarding the design of a tabletop-based IT environment were in major parts accepted (and used) by the participants.

6.3 Prospects for Future Work

Based on these results, there are various prospects for future work that can be conducted with the applications and the hardware environments developed and used within this thesis.

With novel tabletop devices being available, the overall usability of the application can be further improved. For example, at the time this thesis was completed, a broader palette of commercial products had become available. In contrast to the hardware prototype used for this thesis, these are based on flat screens capable of a higher resolution (1920x1080 pixels) and include a more precise and stable touch recognition (such as the Microsoft Surface 2 [Microsoft Surface, 2012]). As they are not built on projection technology anymore, they also provide a better picture quality (contrast, colors) than the prototype used for our studies. Novel touch technology based on capacitive screens as they are already common in smartphone and tablet technology could also provide an improvement but, so far, the production of this technology is still too expensive. With the ongoing spread of touch-based smartphone and tablet devices, we also expect that more and more people will adapt to Natural User Interfaces. Furthermore, there are recent developments showing how to improve touch-based input even more. One is the use of tangible silicone widgets such as the SLAP Widgets [Weiss et al., 2009]. These can make the handling of the application (e.g. the entry of text) simpler for novice users who are not familiar with touch-based interaction. A similar approach has been recently developed by Apple Inc. and can be referred to in a patent application [United States Patent Application 20120068957, 2012]. The idea is a layer with one or more actuators configured to supply a haptic feedback on a touch-based input device.

Another option for future research activities could be to investigate a hybrid approach, combining a collocated tabletop environment and a distributed web-based application. One example would be to direct some users to join a collocated session (that is taking place at the tabletop) remotely via the web client. The ISTC application is already prepared to handle such a scenario: A chat is provided to communicate with remote users and actions are synchronized via the IdeaStream server. Nevertheless, it has to be tested to discover whether such a mixed-mode interaction can really work. Do collocated users realize that someone is participating remotely? What are the implications on the collocated collaboration? Another scenario to explore would be the development of new creativity techniques which make use of a combination of the different IT devices. There could be phases where participants sit down at a PC to benefit from the more anonymous style of interaction and the rapid input speed when using a physical keyboard. Moreover, some techniques such as the Brainwriting 6-3-5 technique require that the participants work on individual workspaces, which is not possible when using a tabletop display only. Here, coupled display could provide an additional benefit to the tabletop environment. Another possible scenario would be to use the coupled displays in a preceding incubation phase. Following such a technique, people can gather ideas for e.g. one week and then come together at the tabletop to further refine and discuss the results as a group. This scenario could profit from an interesting extension of the coupled display application. When meeting at the tabletop the smartphones or tablets could automatically sense the tabletop device (e.g. by Bluetooth) and switch into a different application mode (e.g. an enhanced editor) for collocated work when approaching the tabletop.

The dynamic tracking of the social context of the users (e.g. verbal communication, spatial positions, and shoulder orientations) can be used to foster the collaboration. For example, in [Terken and Sturm, 2010] information about the social dynamics within a meeting was displayed in real time on the meeting table by using automatically tracked communication data (speaking time, eye gaze). As a result, participants who normally speak less than average significantly increased their speaking time in meetings where live feedback was provided. Participants who tend to be at the other (higher) extreme of the speaking time range also tended to change their behavior so it became less extreme. Hence, providing real time information about the social interaction can help to optimize collaboration in collocated settings and help to mediate when the team composition is too heterogeneous. When exploring creativity techniques, an automatic tracking of the interaction in collocated situations could be further used as a means of automatic moderation, e.g. to enforce the regulations of certain creativity techniques. Another scenario could be to adapt the workflow of the application and the related creative process to the intensity and extension of the discussion, such as choosing creativity techniques according to the inferred level of discussion activity or balancing the IT represented parts of the interaction with the non-IT represented parts. However, such an approach of off-table social situation detection requires an integration of various logical sensors such as orientation, position, and verbal communication.

Finally, also other collaborative application fields could benefit from the advantages of touch-based tabletop workspaces combined with coupled mobile devices. An example proposed by the author of this thesis is the use of a multi-touch tabletop device for a conversational or critique-based group recommender system [Wörndl and Frieß, 2012]. Here, in addition to just providing the possibility for setting a group rating, it is proposed that users should also be able to change the ranking (by scaling the corresponding item on the tabletop, for example) or to dismiss items altogether (by moving them to a designated area on the screen). In the latter case, the system could provide new recommendations by taking into account the previous actions of the current group. For example, items that are similar to an already dismissed item could be no longer considered, even if the individual ratings of users would predict that the group might like these items.

Appendix A

Selected Interview Statements

Key	Statement
`stmt1`	"*Es gibt kein Standardvorgehen, keinen Standardprozess und keinen Standardablauf.*"
`stmt2`	"*Das hängt natürlich sehr stark davon ab, was für eine Art Problem das ist, wie groß die Gruppe der Beteiligten ist und ob diese Gruppe verteilt ist oder nicht.*"
`stmt3`	"*Ich glaube aber, dass man den Leuten auch ein wenig Freiheit geben sollte, so dass sie sich in alle Richtungen entwickeln können und nicht gleich eingeschränkt werden.*"
`stmt4`	"[...] *Wir erfinden das Rad gelegentlich neu. Das Problem, das wir lösen, hat bestimmt in unserem Unternehmen schon jemand anderes gehabt. Das ist das, was Zeit und Geld kostet.*"
`stmt5`	"*Wir haben da wirklich die 17-jährige Azubine mit dabei. Die kann natürlich ganz andere Dinge beitragen, weil sie beispielsweise jeden Tag 3 Stunden in Facebook verbringt und beurteilen kann, ob eine Idee gut im "Social Field" zu positionieren ist. Aus diesem Thema sind wir schon ein wenig raus.* [...] *Deswegen ist es mir wichtig, dass ich möglichst viele Meinungen bekomme und nicht nur die vom Teamleiter.*"
`stmt6`	"*Wenn wir Workshops haben, dann wären das zwei Tage, vielleicht auch ein halber Tag.*"
`stmt7`	"*Wenn man weiß, dass das ein ganz wichtiges Thema ist, dann will man auch direkt kommunizieren, das Problem vor Ort mit den Leuten besprechen.*"
`stmt8`	"*Mimik, Gestik und Atmosphäre sind über ein Netmeeting nicht vermittelbar, sondern nur in einem gemeinsamen Raum möglich.*"

`stmt9`	*"Wenn ich also Probleme habe, bei denen wirklich viel Kreativität gefragt ist, dann würde ich das vor Ort machen."*
`stmt10`	*"Richtig, dann schaue ich, ob mein Kollege gerade beschäftigt oder im Stress ist und wenn nicht, dann frage ich ihn, ob er mitmachen möchte."*
`stmt11`	*"Die Leute können auf dem Workspace nicht parallel arbeiten. Alle schauen zu, aber nur einer tippt. Das ist kein wirklich paralleles Arbeiten."*
`stmt12`	*"In dieser Firma war es letztendlich die Kultur, an der ganz normalen Büroarbeit in der Besprechung weiterzuarbeiten."*
`stmt13`	"[...] *Als ich im Bett lag gingen mir viele Sachen durch den Kopf. Dann habe ich mein iPhone genommen und habe mir selber zwei E-Mails geschrieben."*
`stmt14`	*"Aber es ist trotzdem nicht das Gleiche als wenn man vor Ort ist. Es ist anstrengender, denn man hat dann das Problem, dass in dem entfernten Meeting-Raum drei Mikrofone auf dem Tisch stehen. Das ist schon ganz schön toll für ein Videokonferenzsystem. Aber dann setzt sich jemand hinten auf die Couch und ich sehe und höre ihn nicht mehr."*
`stmt15`	*"Ich glaube, das kommt daher, dass der Mensch nicht dazu geeignet ist, von verschiedenen Orten aus kreativ zusammenzuarbeiten. Er ist noch nicht "netmeetingfähig", das heißt er hat nicht die Konzentration und Disziplin, so etwas in einem virtuellen Meeting zu machen."*
`stmt16`	*"In einer Videokonferenz wird man niemals eine informelle Konversation anfangen, einfach weil es viel zu mühselig ist und weil die Videokonferenz irgendwann endet. Danach ist dann der Meeting-Raum blockiert, und es kann keine weitere Kommunikation zustande kommen."*
`stmt17`	*"Wir haben auch Tools, um Fragen zu stellen und zu bewerten, speziell für große Meetings an denen mehrere hundert Leute teilnehmen."*
`stmt18`	*"Bei uns ist es eher so, dass die Idee irgendwann von jemandem, der höher in der Hierarchie ist, als seine eigene ausgegeben wird.* [...] *Fakt ist also, dass auf jeden Fall Ideen aufgenommen werden und darüber freut man sich auch. Aber Fakt ist auch, dass Ideen gestohlen werden. Früher war es so, dass man damit Karriere machen konnte. Kurz gefasst: Nach einer Besprechung kommt die Hierarchie und pickt sich die besten Ideen heraus.* [...] *Mit der Kreativität ist ab diesem Zeitpunkt dann Ende. Der wirkliche Ideengeber tritt somit in den Hintergrund und ist dann auch nicht mehr von Bedeutung."*
`stmt19`	*"Die weiße Wand, auf die ich etwas geschrieben habe, hätte ich gerne als JPEG.* [...] *Das hätte ich alles gerne digital um es dann ausdrucken zu können."*

stmt20	*"Aber ohne das Gemeinschaftsgefühl geht es nicht. Wenn man kreativ tätig sein will, muss man im Team arbeiten, sonst hat man keinen Ansporn bzw. keine Lust. Den richtigen Impuls bekommt man durch andere. Asynchron geht schon, doch das menschliche Verhalten spricht dagegen. Aber ich könnte es mir in Stufen mit Teilgruppen vorstellen, d.h. eine Zweiergruppe arbeitet heute und die andere morgen. In Stufen, das könnte beispielsweise heißen, die einen machen den Plan des Hauses und die anderen die Statik in einem gemeinsamen Workflow. Aber das wird nicht ganz selbstorganisierend funktionieren, da brauche ich jemanden, der das strukturiert."*
stmt21	*"Wir haben Brainstorming meist virtuell gemacht und uns danach im Konferenzraum getroffen, um die Ideen weiterzuspinnen. Wir haben nicht "entweder - oder" gedacht. Die Kombination war gut."*
stmt22	*"Inzwischen verwende ich das iPad sehr gerne als Online-Zugang auf Webseiten, da ich meinen Laptop nicht in das Meeting mitnehmen möchte."*
stmt23	*"Mit der räumlichen Trennung ergibt sich oft auch eine zeitliche Trennung."*
stmt24	*"Wenn mir das Thema wirklich wichtig ist und etwas Zählbares dabei entstehen soll, finde ich wichtig, dass die Leute zumindest zum Start eines Themas alle zur gleichen Zeit an einem Tisch in einem Raum sitzen. [...] Die Kommunikation ist einfach eine andere. Viele Teilnehmer zusammen in einem Raum sind vielleicht auf den ersten Blick nicht so effizient, denn es wird immer etwas herumgeblödelt. Aber es entsteht dabei auch eine Atmosphäre, aus der gerade kreative Ideen kommen. Dieser kreative Raum entsteht in einer Telefonkonferenz oder E-Mail nicht so gut."*
stmt25	*"Wenn ich auf dem Fahrrad oder im Auto sitze und in Gedanken ganz woanders bin, dann kommen die Ideen einfach von selber."*
stmt26	*"Wenn es der Dringlichkeit und der Thematik bedarf, wird man die Leute auch am Wochenende an einem Ort zusammenbringen."*
stmt27	*"Es gibt auch die Angst vor der Technik. Wenn ich mit dem System nicht umgehen kann, dann schreibe ich es eben hier auf meinen Zettel."*
stmt28	*"Es muss gewährleistet sein, dass jeder das Tool auch nutzt. Dazu muss man den Teilnehmern auch ein Tool hinstellen, das ihnen Spaß macht."*
stmt29	*"Bestimmte Ideen werden oft erst im Einzelgespräch geäußert. Das liegt vor allem auch an der Angst vor der großen Runde. Es könnte nämlich ein Thema sein, das jeden betrifft und ihn eventuell vor den anderen in einem schlechten Licht erscheinen lässt."*

stmt30	*"Üblicherweise halte ich Meetings in einem Zeitraum von einer Viertelstunde bis zu 2-3 Stunden ab."*
stmt31	*"Wir benutzen in der Regel das Whiteboard oder das Flipchart. Dabei wird sehr viel diskutiert."*
stmt32	*"Wir machen schon mal die 6-Hut Methode oder Kreation mit Bildern."*
stmt33	*"Es gibt kein festes Prozedere, exakt sich wiederholende Situationen kenne ich hier nicht."*
stmt34	*"Vom Whiteboard machen wir Fotos, die dann in einem Projektordner abgelegt werden."*
stmt35	*"Wenn ich mir große Projekte anschaue, bei denen 10-15 Leute an einem Tisch sitzen, halte ich das für Zeitverschwendung, weil nicht jeder mit jedem etwas auszutauschen hat. Hier bevorzuge ich Kleingruppen. Es ist auch völlig ermüdend für die Teilnehmer, wenn drei Leute vorne stehen und reden und der Rest hört nur zu. Ein Workshop in einer Großgruppe widerspricht schon dem Wort "Workshop"."*
stmt36	*"In der Gruppe vor Ort teilen sich alle einen einzigen Rechner und sitzen vor einer Projektion oder einem Großbildschirm."*
stmt37	*"Das hängt davon ab. Wenn wir es per E-Mail lösen können, dann geht das asynchron. Das ist der bevorzugte Modus, weil der alle Beteiligten am wenigsten von ihrer regulären Arbeit abhält und sie in keinen Zeitablauf zwingt."*
stmt38	*"Die Hürde ist über mehrere Zeitzonen sehr hoch, weil das für alle unbequem ist. Man muss beispielsweise abends länger bleiben oder morgens früher aufstehen. Und dann hat das Team in den USA eine sehr unregelmäßige Arbeitszeit. Das heißt einige kommen zwar morgens um 7 Uhr und gehen nachmittags um 16 Uhr, aber andere kommen auch erst um 14 Uhr und sind dementsprechend von Deutschland aus nur nachts erreichbar. Daher ist es schwierig Meetings anzusetzen. Das ist daher ein unbeliebtes Mittel."*
stmt39	*"Wir nutzen den virtuellen Raum überproportional häufig.* [. . .] *Im Laufe eines Projekts läuft ca. 40% der Kundenkommunikation virtuell. Im Unterschied zum Telefon wird dabei automatisch mitdokumentiert und beide Seiten sehen, was man gerade vereinbart hat. Beispielsweise nutzen wir dazu Adobe Connect Professional."*
stmt40	*"Wir führen Kreativitätstechniken auch räumlich verteilt durch, aber ohne ein bestimmtes IT Tool zur Prozessunterstützung. Das Ganze findet synchron statt, da so schneller Ergebnisse erzielt werden."*
stmt41	*"Unsere virtuellen Gruppen bestehen aus 4 oder 5 Personen."*

stmt42	*"Es gibt genug Menschen, die eine Tippschwäche oder eine Rechtschreibschwäche haben. Wenn ich jemandem eine schriftliche volltextliche Kommunikation ersparen kann, mache ich das. Es ist zeitaufwändig, mit Missverständnissen verbunden und für viele eine Hemmschwelle."*
stmt43	*"Vor Ort zu arbeiten ziehe ich vor. Da man dies aber oft nicht machen kann, ist eine Kombination aus virtuellen Konferenzen und einer Gruppe von Leuten am selben Ort besser."*
stmt44	*"Wenn ich ein Tool hätte, das mir neue Kreativitätstechniken zeigt, dann würde ich diese auch verwenden."*
stmt45	*"Wenn wir ein normales Brainstorming machen, muss ich es sowieso in den MindManager übertragen. Wenn dies das System selber könnte, wäre das so herum viel schöner."*
stmt46	*"Während der Durchführung eines Projektes ist es möglich, dass die Mitarbeiter an den unterschiedlichsten Orten sitzen. Beispielsweise sitzt unser Kollege aktuell in Mexiko."*
stmt47	*"ICQ wird genutzt, obwohl die Leute im gleichen Raum sitzen. Sie reden zwar auch miteinander, und es könnte sein, dass sie den Messenger gar nicht bräuchten. Aber es ist nicht so unruhig und die anderen werden nicht gestört."*
stmt48	*"Wir nutzen zum Teil auch Tools um gemeinsam Dokumente zu bearbeiten. Beispielsweise GoogleDocs, mit dem man Tabellen und Textdokumente gemeinsam bearbeiten kann, quasi in Echtzeit, die erweisen sich als sehr nützlich."*
stmt49	*"Wenn jemand sehr schüchtern ist und über das Telefon teilnimmt, wird relativ wenig Input kommen, weil das Telefon eine zusätzliche Schranke darstellt."*
stmt50	*"Wenn es sich um eine kritische Projektsituation handelt, dann ist es besser hinzufahren und persönlich das Gespräch zu suchen, anstatt immer nur zu telefonieren."*

stmt51	"*Vor Ort ist es immer besser, weil man gut aufeinander eingehen kann. Wenn Sie über Telefon oder Webkonferenzen arbeiten, dann muss man das erst lernen. Das heißt wirklich mit einer Antwort zwei bis drei Sekunden warten, ob vielleicht noch jemand anderes etwas sagt. Wenn Sie in einem Raum sitzen, sehen Sie, der will antworten, der hält schon seit drei Minuten die Hand hoch. Bei Telekonferenzen oder bei Videokonferenzen sind solche Sachen schwierig. Es gibt zwar inzwischen Videokonferenzen, bei denen Sie zwei halbe Tische vor einer Leinwand haben. Dort sieht es fast wirklich so aus wie bei einer Konferenz. Aber auch da haben Sie immer noch die halbe Sekunde Verzögerung. Ohne persönliche Treffen, bei denen man den Leuten direkt in die Augen sehen kann, funktioniert nichts.*"
stmt52	"*Wenn Sie ein kreatives Problem lösen müssen, dann brauchen Sie in einer Sitzung für jeden Bereich mindestens eine Person, die diesen Bereich abdecken kann.*"
stmt53	"*Wir haben uns einfach einmal in einem Raum eingeschlossen, haben Whiteboards aufgestellt und Brainstorming gemacht. Die Leute haben sich hingesetzt, die Programmierer, jemand der fachlich genau wusste was los ist, und dann haben wir uns mit Ideen nur so beworfen. Nach vier Stunden hatten wir ein neues Konzept für dieses Programm.*"
stmt54	"*Entweder schreibt jemand mit, oder man fotografiert es mit dem Handy und schreibt es hinterher ab.*"
stmt55	"*In unseren kreativen Teams sind meist bis zu drei verschiedene Hierarchieebenen vertreten. Trotzdem dutzen wir uns und haben eher keinen formellen Umgang miteinander.*"
stmt56	"*Die E-Mail eignet sich sehr gut zur Dokumentation. Ich kann meine E-Mail-Basis prima und sehr effizient nach Stichwörtern durchsuchen, Nachrichten taggen, das ist eigentlich ein gutes Ablagesystem.*"
stmt57	"*Wir haben zum einen eine zentrale Ideendatenbank. Da kann man mit wenig Aufwand eine Idee informell reinschreiben, andere Leute können dann darauf kommentieren und bewerten, also ein Ranking durchführen.*"
stmt58	"*Das Problem ist, dass es an Ideen nicht mangelt. Der Mangel besteht in den Ressourcen, sie auszuwerten. Ideen gibt es viel zu viele.*"
stmt59	"*Ich erinnere mich an einen Fall, bei dem wir externe Hilfe benötigt haben. Da gab es ein Problem, das wir intern nicht lösen konnten. Daher haben wir einen externen Experten angerufen, der zur Lösung des Problems beigetragen hat.*"
stmt60	"*Man kann von den neuen Ideen anderer Leute profitieren.*"
stmt61	"*Ein neuer Kollege von der Uni hat vielleicht neue Ideen. Das bringt Schwung in die Sache.*"

stmt62	*"Ich kann mich an Situationen erinnern, bei denen ich wusste, dass eine Person ein unangenehmer Diskussionspartner sein wird. Und trotzdem habe ich ihn eingeladen, weil er mir in dem Augenblick als jemand erschien, der Wesentliches beiträgt, auch wenn er mir menschlich Schwierigkeiten bereitet."*
stmt63	*"Ich liebe Whiteboards. Sie können da Post-its drankleben, die können Sie hin und her verschieben, Sie können beschriften, Sie können wegwischen, Sie können neu zeichnen, Sie können abfotografieren.*
stmt64	*"Wenn wir verteilt arbeiten, können wir häufig viel mehr Mitarbeiter einbinden als wir das sonst machen würden. Zudem können wir das spontan genau dann machen, wenn wir es brauchen. Dadurch muss ich nicht mit fünf Leuten zum Kunden fahren, wenn einer davon eigentlich nur für zehn Minuten gebraucht wird.*
stmt65	*"Wir haben ein Video-Konferenz System, sogenannte Tandberg Video Konferenzanlagen, die haben zwei Kanäle, einen für das Video und einen weiteren für eine Präsentation, bei der man den Laptop anschließen kann. Das übliche Verfahren ist, dass der Moderator seinen Laptop anschließt und dann sehen alle anderen auf ihrem Bildschirm, was er schreibt. Er kann dann auch z.B. direkt in eine GoogleDocs Tabelle schreiben und diese dann hinterher allen freigeben oder auch gleichzeitig freigeben, so dass alle daran editieren können.*
stmt66	*"Dann habe ich die Latenz als Problem, ein ganz großes Problem mit den Videokonferenz-Systemen. Wenn dort eine engagierte Diskussion läuft und ich sage etwas, hören mich die anderen erst 1,5 Sekunden später. Dann bin ich bereits jemandem ins Wort gefallen, die anderen hören auch auf zu reden und die Diskussion stockt.*
stmt67	*"Wir ziehen es immer dann vor, am selben Ort zu sein, wenn sich die Teilnehmer noch nicht kennen. Beispielsweise um sich dabei besser kennenzulernen und natürliche Beziehungen zueinander aufzubauen. Ich habe so was auch schon über Netmeetings gemacht, aber da war meine Erfahrung bisher nicht besonders gut.*
stmt68	*"Wir haben das virtuelle Brainstorming sehr genossen, weil wir aus verschiedenen Bereichen sind und wir uns sehr gut darüber austauschen konnten. Aber wir haben auch das Reale gebraucht, wir müssen den Leuten in die Augen schauen können, da ist der Spirit einfach besser.*
stmt69	*"Wir sehen den Rest vom Team jedes halbe Jahr mal persönlich. Das ist meist eine sehr produktive Zeit, wenn man dann am selben Ort ist und die ganzen Sachen, die im letzten halben Jahr zusammengekommen sind, mit allen auf dem kurzen Weg ausdiskutieren kann.*

Bibliography

[Adamczyk et al., 2007] Adamczyk, P. D., Hamilton, K., Twidale, M. B., and Bailey, B. P. (2007). Tools in support of creative collaboration. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, C&C '07, pages 273–274, New York, NY, USA. ACM.

[Adobe Ideas, 2012] Adobe Ideas (2012). `http://www.adobe.com/products/adobeideas/`, Last Access 06/10/2012.

[Albert and Runco, 1999] Albert, R. S. and Runco, M. A. (1999). A History of Research on Creativity. In Sternberg, R. J., editor, *Handbook of Creativity*, chapter 2, pages 16–31. Cambridge University Press.

[Aldous, 2007] Aldous, C. R. (2007). Creativity, problem solving and innovative science: Insights from history, cognitive psychology and neuroscience. *International Education Journal*, 8(2):176–186.

[Amabile, 1983] Amabile, T. M. (1983). *The Social Psychology of Creativity.* Springer-Verlag, New York.

[Amabile, 1996] Amabile, T. M. (1996). *Creativity in Context: Update to the Social Psychology of Creativity.* Westview Press.

[Amabile, 1997] Amabile, T. M. (1997). Motivating Creativity in Organizations: On Doing What You Love and Loving What You Do. *California Management Review*, 40(1).

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

[Antonites, 2003] Antonites, A. J. (2003). *An action learning approach to entrepreneurial creativity, innovation and opportunity finding.* PhD thesis, University of Pretoria, Business Management.

[Applegate et al., 1986] Applegate, L. M., Konsynski, B. R., and Nunamaker, J. F. (1986). A group decision support system for idea generation and issue analysis in organization planning. In *Proceedings of the 1986 ACM conference on Computer-supported cooperative work*, CSCW '86, pages 16–34, New York, NY, USA. ACM.

[Arnold et al., 1972] Arnold, W., Eysenck, H.-J., and Meili, R. (1972). *Lexikon der Psychologie*. Freiburg: Herder.

[ARTTRACK User-Manual, 2007] ARTTRACK User-Manual (2007). *ARTTRACK & DTrack User-Manual V1.24.3*. advanced realtime tracking GmbH, Germany.

[ARTTRACK2 System, 2012] ARTTRACK2 System (2012). `http://www.ar-tracking.com/products/tracking-systems/arttrack-system/arttrack2.html`, Last Access 07/11/2012.

[Autodesk SketchBook Pro, 2012] Autodesk SketchBook Pro (2012). `http://usa.autodesk.com/adsk/servlet/pc/item?id=15119465&siteID=123112`, Last Access 07/11/2012.

[Bacot et al., 2000] Bacot, M., Basadur, M., Pringle, P., and Speranzini, G. (2000). Collaborative Problem Solving Through Creativity in Problem Definition: Expanding the Pie. *Creativity and Innovation Management*, 9(1):54–76.

[Besemer and O'Quin, 1987] Besemer, S. P. and O'Quin, K. (1987). Creative product analysis: Testing a model by developing a judging instrument. In Isaksen, S. G., editor, *Frontiers of creativity research: Beyond the basics*, pages 341–379. Bearly Limited, Buffalo, NY.

[Beynon-Davies, 2009] Beynon-Davies, P. (2009). Neolithic informatics: The nature of information. *International Journal of Information Management*, 29(1):3–14.

[Bigham and Murray, 2010] Bigham, J. P. and Murray, K. (2010). WebTrax: visualizing non-visual web interactions. In *Proceedings of the 12th international conference on Computers helping people with special needs*, ICCHP'10, pages 346–353, Berlin, Heidelberg. Springer-Verlag.

[Borghoff and Schlichter, 1998] Borghoff, U. and Schlichter, J. (1998). *Rechnergestützte Gruppenarbeit*, volume 2. Springer, Berlin.

[Bortz and Döring, 2006] Bortz, J. and Döring, N. (2006). *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler*. Springer.

[Bostrom and Nagasundaram, 1998] Bostrom, R. P. and Nagasundaram, M. (1998). Research in Creativity and GSS. In *Proceedings of the 31. Hawaii International Conference on System Sciences*, pages 391–405, Washington, DC, USA. IEEE Computer Society.

[Brocco et al., 2011] Brocco, M., Forster, F., and Frieß, M. R. (2011). 360° Open Creativity Support. *Journal of Universal Computer Science (JUCS). Special Issue on Virtual Environments for Collaborative Innovation and Learning*, 17:1673–1689.

[Bubbl.us, 2012] Bubbl.us (2012). Website. `http://www.bubbl.us`, Last Access 06/10/2012.

[Buisine et al., 2007] Buisine, S., Besacier, G., Najm, M., Aoussat, A., and Vernier, F. (2007). Computer-supported creativity: evaluation of a tabletop mind-map application. In *Proceedings of the 7th international conference on Engineering psychology and cognitive ergonomics*, EPCE'07, pages 22–31, Berlin, Heidelberg. Springer-Verlag.

[Burnside et al., 1988] Burnside, R., Amabile, T., and Gryskiewicz, S. (1988). Assessing organisational climates for creativity and innovation: Methodological review of large company audits. In Iijiri, Y. and Kuhn, R., editors, *New directions in creative and innovative management*. Cambridge, MA: Ballinger.

[Buzan and Buzan, 1995] Buzan, T. and Buzan, B. (1995). *The Mind Map Book*. BBC Books, London, 2 edition.

[Campo, 2006] Campo, C. (2006). Bremse oder Gaspedal: Web Services manchmal besser ohne SOAP? *Java Magazin*, 11:98–106.

[Carte et al., 2006] Carte, T. A., Chidambaram, L., Garfield, M. J., Hicks, L., and Cole, C. (2006). Group Creativity and Collaborative Technologies: Understanding the Role of Visual Anonymity. In *12th International Workshop on Groupware CRIWG*, pages 12–21.

[Cartwright, 1968] Cartwright, D. (1968). *The nature of group cohesiveness*, pages 91–109. Tavistock Publications, London, UK.

[Chandler, 1990] Chandler, A. (1990). *Scale and Scope: The Dynamics of Capitalism*. Belknap, Cambridge.

[Chesbrough, 2003] Chesbrough, H. W. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business Press.

[Cohen and Levinthal, 1990] Cohen, W. M. and Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1):128–152.

[Connolly et al., 1990] Connolly, T., Jessup, L. M., and Valacich, J. S. (1990). Effects of anonymity and evaluative tone on idea generation in computer-mediated groups. *Manage. Sci.*, 36:689–703.

[Couger, 1995] Couger, J. D. (1995). *Creative Problem Solving and Opportunity Finding*. Boyd & Fraser Publishing Company.

[Couger and McIntyre, 1993] Couger, J.D., L. H. and McIntyre, S. (1993). (Un)Structured Creativity in Information Systems Organizations. *MIS Quarterly*, 17.

[Csikszentmihalyi, 1997] Csikszentmihalyi, M. (1997). *Creativity: Flow and the Psychology of Discovery and Invention*. Harper Perennial.

[Csikszentmihalyi and Sawyer, 1995] Csikszentmihalyi, M. and Sawyer, K. (1995). Creative insight: The social dimension of a solitary moment. In Sternberg, R. J. and Davidson, J. E., editors, *The nature of insight*, pages pp.329–363. Cambridge, MA, US: The MIT Press.

[de Bono, 1985] de Bono, E. (1985). *Six Thinking Hats: An Essential Approach to Business Management*. Little Brown and Company.

[Delbecq and de Ven, 1971] Delbecq, A. L. and de Ven, A. H. V. (1971). A Group Process Model for Problem Identification and Program Planning. *Journal of Applied Behavioral Science*, 7:466–492.

[Dennis and Reinicke, 2004] Dennis, A. R. and Reinicke, B. (2004). Beta Versus VHS and the Acceptance of Electronic Brainstorming Technology. *MIS Quarterly*, 28(1):1–20.

[Diehl and Stroebe, 1991] Diehl, M. and Stroebe, W. (1991). Productivity loss in idea-generating groups: Tracking down the blocking effect. *Journal of Personality and Social Psychology*, 61:392–403.

[Dix et al., 1993] Dix, A., Finley, J., Abowd, G., and Beale, R. (1993). *Human-Computer Interaction*. Prentice Hall, New York, NY, USA.

[Dourish and Bellotti, 1992] Dourish, P. and Bellotti, V. (1992). Awareness and coordination in shared workspaces. In *CSCW '92: Proceedings of the 1992 ACM conference on Computer-supported cooperative work*, pages 107–114, New York, NY, USA. ACM.

[Drazin and Kazanjian, 1999] Drazin, R., M. G. and Kazanjian, R. (1999). Multilevel Theorizing About Creativity in Organizations: A Sensemaking Perspective. *Academy of Management Review*, 24:286–307.

[Dropbox, 2012] Dropbox (2012). `https://www.dropbox.com/home`, Last Access 07/11/2012.

[Dunn and Roppolo, 2010] Dunn, K. and Roppolo, S. (2010). Creative Cognition. `http://www.pureprocess.com/about/86-guest-post-creative-cognition.html`. Last Acess 05/11/2011.

[Echtler et al., 2008] Echtler, F., Huber, M., and Klinker, G. (2008). Shadow tracking on multi-touch tables. In *Proceedings of the working conference on Advanced visual interfaces*, AVI '08, pages 388–391, New York, NY, USA. ACM.

[Echtler and Klinker, 2008] Echtler, F. and Klinker, G. (2008). A multitouch software architecture. In *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*, NordiCHI '08, pages 463–466, New York, NY, USA. ACM.

[Eden et al., 2002] Eden, H., Scharff, E., and Hornecker, E. (2002). Multilevel design and role play: experiences in assessing support for neighborhood participation in design. In *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques*, DIS '02, pages 387–392, New York, NY, USA. ACM.

[Edmonds, 1994] Edmonds, E. (1994). Introduction: Computer-based Systems that Support Creativity. In Dartnall, T., editor, *Artificial Intelligence and Creativity*, pages 327–334. Kluwer Academic, Dordrecht, NL.

[Ekvall, 1996] Ekvall, G. (1996). Organizational Climate for Creativity and Innovation. *European Journal of Work & Organizational Psychology*, 5(1).

[Evernote, 2012] Evernote (2012). http://www.evernote.com/, Last Access 07/11/2012.

[Farooq et al., 2005] Farooq, U., Carroll, J. M., and Ganoe, C. H. (2005). Supporting Creativity in Distributed Scientific Communities. In *Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work*, GROUP '05, pages 217–226, New York, NY, USA. ACM.

[Feist, 1998] Feist, G. (1998). A meta-analysis of the impact of personality on scientific and artistic creativity. *Personality and Social Psychological Review*, 3:290–309.

[Fellers and Bostrom, 1993] Fellers, J. and Bostrom, R. (1993). Application of group support systems to promote creativity in information systems organizations. In *Proceedings of the Twenty-seventh Hawaii International Conference on Systems Sciences*, pages 332–341.

[Fernald and Nickolenko, 1993] Fernald, L. W. and Nickolenko, P. (1993). The creative process: Its use and extent of formalization by corporations. *Journal of Creative Behaviour*, 27(3):214–220.

[Finke et al., 1992] Finke, R. A., Ward, T. B., and Smith, S. M. (1992). *Creative Cognition: Theory, Research, and Applications.* Bradford, The MIT Press.

[Fischer, 2005] Fischer, G. (2005). Social Creativity: Making All Voices Heard. In *Proceedings of the HCI International Conference (HCII)*, Las Vegas.

[Fischer, 2007] Fischer, G. (2007). Meta-design and social creativity: making all voices heard. In *Proceedings of the 11th IFIP TC 13 international conference on Human-computer interaction - Volume Part II*, INTERACT'07, pages 692–693, Berlin, Heidelberg. Springer-Verlag.

[Fischer et al., 2005] Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M., and Ye, Y. (2005). Beyond binary choices: integrating individual and social creativity. *Int. J. Hum.-Comput. Stud.*, 63:482–512.

[Fokusgruppe Management offener Innovationsprozesse, 2012] Fokusgruppe Management offener Innovationsprozesse (2012). http://www.management-offener-innovationsprozesse.de, Last Access 07/11/2012.

[Forster, 2008] Forster, F. (2008). Distributed Creative Problem Solving over the Web. *International Conference on Internet and Web Applications and Services*, 0:283–288.

[Forster, 2010] Forster, F. (2010). *Computerunterstützung von kollaborativen Kreativitätsprozessen.* PhD thesis, Technische Universität München. http://mediatum2.ub.tum.de/?id=818195.

[Forster and Brocco, 2008] Forster, F. and Brocco, M. (2008). Understanding Creativity-Technique Based Problem Solving Processes. In *Proceedings of the 12th international conference on Knowledge-Based Intelligent Information and Engineering Systems, Part II*, KES '08, pages 806–813, Berlin, Heidelberg. Springer-Verlag.

[Forster and Brocco, 2009] Forster, F. and Brocco, M. (2009). A unified process model for creativity-technique based problem solving processes. In Ulrike Cress, Vania Dimitrova, M. S., editor, *Learning in the Synergy of Multiple Disciplines - 4th European Conference on Technology Enhanced Learning*, pages 615–620, Nice, France. Springer. EC-TEL 2009.

[Forster et al., 2010] Forster, F., Friess, M. R., and Brocco, M. (2010). On the Impact of Chat Communication on Computer-Supported Idea Generation Processes. In *Proceedings of the First International Conference on Computational Creativity (ICCC X)*, pages 165–174. http://eden.dei.uc.pt/~amilcar/ftp/e-Proceedings_ICCC-X.pdf.

[Frieß et al., 2012a] Frieß, M. R., Groh, G., Klügel, N., and Kleinhans, M. (2012a). A Tabletop Application Environment for Generic Creativity Techniques. *International Journal of Computer Information Systems and Industrial Management Applications(IJCISIM)*, 4:55–65.

[Frieß et al., 2012b] Frieß, M. R., Groh, G., Klügel, N., and Kleinhans, M. (2012b). An Analysis Framework for Quantitatively Characterizing Collaboration in Tabletop Based CSCW Environments. *International Journal of Computer Information Systems and Industrial Management Applications(IJCISIM)*, 4:341–351.

[Frieß et al., 2012c] Frieß, M. R., Groh, G., Reinhardt, M., Forster, F., and Schlichter, J. (2012c). Context-Aware Creativity Support for Corporate Open Innovation. *International Journal of Knowledge-Based Organizations (IJKBO). Special Issue on Corporate Open Innovation*, 2:38–55.

[Frieß and Kleinhans, 2011] Frieß, M. R. and Kleinhans, M. (2011). Coupled Mobile Displays for Creativity Technique Based Problem Solving Processes in Tabletop Environments. In *Proceedings of the IADIS Multi Conference on Computer Science and Information Systems (MCCSIS): Interfaces and Human Computer Interaction*, pages 249–256, Rome, Italy.

[Frieß et al., 2009] Frieß, M. R., Kleinhans, M., Echtler, F., Forster, F., and Groh, G. (2009). A multi-touch tabletop interface for applying collaborative creativity techniques. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ITS '09, pages 14:1–14:1, New York, NY, USA. ACM.

[Frieß et al., 2010a] Frieß, M. R., Kleinhans, M., Forster, F., Echtler, F., and Groh, G. (2010a). A Tabletop Interface for Generic Creativity Techniques. In *Proceedings of the IADIS Multi Conference on Computer Science and Information Systems (MCCSIS): Interfaces and Human Computer Interaction*, pages 203–210, Freiburg, Germany.

[Frieß and Klügel, 2011] Frieß, M. R. and Klügel, N. (2011). IdeaStream - Situative Creativity Support. TU München Forschungs-Highlights, http://www.in.tum.de/

forschung/forschungs-highlights/ideastream-situative-creativity-support.html, Last Access 09/02/2012.

[Frieß et al., 2010b] Frieß, M. R., Klügel, N., and Groh, G. (2010b). lzrdm: collaborative multi-touch sequencer. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10, pages 303–303, New York, NY, USA. ACM.

[Fritz, 1991] Fritz, R. (1991). *Creating: A guide to the creative process.* Fawcett Columbine, New York, 1st edition.

[Garfield, 2008] Garfield, M. J. (2008). Creativity Support Systems. *Handbook on Decision Support Systems 2*, pages 745–758.

[Geschka, 2006] Geschka, H. (2006). Kreativitätstechniken und Methoden der Ideenbewertung. In Sommerlatte, T., Beyer, G., and Seidel, G., editors, *Innovationskultur und Ideenmanagement: Strategien und praktische Ansätze für mehr Wachstum*, pages 217–249. Symposion Publishing.

[Geschka, 2007] Geschka, H. (2007). Kreativitätstechniken. In Köhler, R., Küpper, H.-U., and Pfingsten, A., editors, *Handwörterbuch der Betriebswirtschaft*, pages 992–1005. Schäffer-Poeschel Verlag, Stuttgart, 6th edition.

[Geyer et al., 2010] Geyer, F., Klinkhammer, D., and Reiterer, H. (2010). Supporting creativity workshops with interactive tabletops and digital pen and paper. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10, pages 261–262, New York, NY, USA. ACM.

[Google Docs, 2012] Google Docs (2012). http://docs.google.com, Last Access 07/11/2012.

[Google Image Search API, 2012] Google Image Search API (2012). http://code.google.com/apis/imagesearch/, Last Access 07/11/2012.

[Groh, 2012] Groh, G. (2012). *Contextual Social Networking.* Habilitation, Institut für Informatik, Technische Universität München.

[Groh et al., 2010] Groh, G., Lehmann, A., Reimers, J., Frieß, M. R., and Schwarz, L. (2010). Detecting Social Situations from Interaction Geometry. In *Proceedings of the 2010 IEEE Second International Conference on Social Computing*, SOCIALCOM '10, pages 1–8, Washington, DC, USA. IEEE Computer Society.

[Gross and Koch, 2007] Gross, T. and Koch, M. (2007). *Computer-Supported Cooperative Work.* Oldenbourg.

[Guilford, 1950] Guilford, J. P. (1950). Creativity. *American Psychologist*, 5:444–454.

[Guilford, 1967] Guilford, J. P. (1967). *The nature of human intelligence.* McGraw - Hill, New York.

[Gutwin and Greenberg, 1995] Gutwin, C. and Greenberg, S. (1995). Support for Group Awareness in Real-Time Desktop Conferences. In *Proceedings of The Second New Zealand Computer Science Research Students' Conference*, pages 1–12.

[Ha et al., 2006] Ha, V., Inkpen, K. M., Whalen, T., and Mandryk, R. L. (2006). Direct Intentions: The Effects of Input Devices on Collaboration around a Tabletop Display. In *Proceedings of the First IEEE International Workshop on Horizontal Interactive Human-Computer Systems*, TABLETOP '06, pages 177–184, Washington, DC, USA. IEEE Computer Society.

[Hainsworth, 2004] Hainsworth, S. W. (2004). *Techniques for the Automated Analysis of Musical Audio*. PhD thesis, University of Cambridge, UK.

[Hall, 1963] Hall, E. T. (1963). A system for the notation of proxemic behavior. *American anthropologist*, 65(5):1003–1026.

[Hauschildt and Sören, 2007] Hauschildt, J. and Sören, S. (2007). *Innovationsmanagement*. Vahlen, 4 edition.

[Haykin and Chen, 2005] Haykin, S. and Chen, Z. (2005). The Cocktail Party Problem. *Neural Comput.*, 17(9):1875–1902.

[Hecker, 1996] Hecker, C. (1996). Physics, Part 1: The Next Frontier. *Game Developer Magazine*.

[Hecker, 1997a] Hecker, C. (1997a). Physics, Part 2: Angular Effects. *Game Developer Magazine*.

[Hecker, 1997b] Hecker, C. (1997b). Physics, Part 3: Collision Response. *Game Developer Magazine*.

[Helquist et al., 2007] Helquist, J. H., Santanen, E. L., and Kruse, J. (2007). Participant-driven GSS: Quality of Brainstorming and Allocation of Participant Resources. In *Proceedings of the 40th Annual Hawaii International Conference on System Sciences*, HICSS '07, pages 18–, Washington, DC, USA. IEEE Computer Society.

[Hessian Binary Web Service Protocol, Version 3.0.13, 2012] Hessian Binary Web Service Protocol, Version 3.0.13 (2012). Website. `http://hessian.caucho.com/`, Last Access 07/11/2012.

[Hevner et al., 2004] Hevner, A. R., March, S. T., Park, J., and Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1):75–106.

[Hilliges et al., 2007] Hilliges, O., Terrenghi, L., Boring, S., Kim, D., Richter, H., and Butz, A. (2007). Designing for collaborative creative problem solving. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, C&C '07, pages 137–146, New York, NY, USA. ACM.

[Hoegl and Gemuenden, 2001] Hoegl, M. and Gemuenden, H. G. (2001). Teamwork Quality and the Success of Innovative Projects: A Theoretical Concept and Empirical Evidence. *Organization Science*, 12(4):435–449.

[Holmström et al., 2009] Holmström, J., Ketokivi, M., and Hameri, A.-P. (2009). Bridging Practice and Theory: A Design Science Approach. *Decision Sciences*, 40(1):65–87.

[Honan, 2007] Honan, M. (2007). Apple unveils iPhone. `http://www.macworld.com/article/54769/2007/01/iphone.html`. Macworld, Last Acess 05/11/2011.

[Hunter and Maes, 2008] Hunter, S. and Maes, P. (2008). WordPlay: A Table-Top Interface for Collaborative Brainstorming and Decision Making. In *Proceedings of the 3rd IEEE Int. Workshop on Horizontal Interactive Human Computer Systems*, Amsterdam, the Netherlands.

[iOS Cocoa Touch Framework, 2012] iOS Cocoa Touch Framework (2012). `https://developer.apple.com/technologies/ios/cocoa-touch.html`, Last Access 04/01/2012.

[iQudo, 2010] iQudo (2010). Ideenfindung Studie. `http://www.iqudo.com/de/ueber_kreative_intelligenz/studie_ideenfindung_2010.html`, Last Access 07/11/2012.

[Isaksen, 1998] Isaksen, S. G. (1998). A Review of Brainstorming Research: Six Critical Issues for Inquiry. Technical report, Creative Problem Solving Group, Buffalo, New York.

[Johansen et al., 1991] Johansen, R., Sibbet, D., Benson, S., Martin, A., Mittman, R., and Saffo, P. (1991). *Leading Business Teams: How Teams Can Use Technology and Group Process Tools to Enhance Performance*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA.

[Jordà and Alonso, 2006] Jordà, S. and Alonso, M. (2006). Mary had a little scoreTable* or the reacTable* goes melodic. In *Proceedings of the 2006 conference on New interfaces for musical expression*, NIME '06, pages 208–211, Paris, France, France. IRCAM — Centre Pompidou.

[Jordà et al., 2006] Jordà, S., Kaltenbrunner, M., Geiger, G., and Alonso, M. (2006). The reacTable: a tangible tabletop musical instrument and collaborative workbench. In *SIGGRAPH '06: ACM SIGGRAPH 2006 Sketches*, page 91, New York, NY, USA. ACM.

[Kleinhans, 2009] Kleinhans, M. (2009). Development of an Application for the Collaborative Use of Creativity-techniques on a Multi-touch Table. Bachelor's thesis, Technische Universität München.

[Kleinhans, 2011] Kleinhans, M. (2011). Private Information Spaces for Co-located Collaborative Creativity Support Systems. Master's thesis, Technische Universität München.

[Klügel, 2009] Klügel, N. (2009). Development of an Environment for Collaborative Composition and Production of Music on a Multi-Touch Table. Diploma thesis, Technische Universität München.

[Klügel et al., 2011] Klügel, N., Frieß, M. R., Groh, G., and Echtler, F. (2011). An Approach to Collaborative Music Composition. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME 2011)*, pages 32–35, Oslo, Norway.

[Knapp and Hall, 1972] Knapp, M. and Hall, J. (1972). *Nonverbal Communication in Human Interaction*. Harcourt Brace College Publishers.

[Krcmar, 2005] Krcmar, H. (2005). *Informationsmanagement*. Springer, 4 edition.

[Kromrey, 2000] Kromrey, H. (2000). *Empirische Sozialforschung*. UTB, Stuttgart, 9 edition.

[Kruger et al., 2003] Kruger, R., Carpendale, S., Scott, S. D., and Greenberg, S. (2003). How people use orientation on tables: comprehension, coordination and communication. In *GROUP '03: Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, pages 369–378, New York, NY, USA. ACM.

[libTISCH, 2012] libTISCH (2012). `http://tisch.sourceforge.net/`, Last Access 07/11/2012.

[Likert, 1932] Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 22(140).

[Lott and Sommer, 1967] Lott, D. and Sommer, R. (1967). Seating arrangements and status. *Journal of Personality and Social Psychology*, 7(1):90–95.

[MacCrimmon and Wagner, 1994] MacCrimmon, K. R. and Wagner, C. (1994). Stimulating ideas through creativity software. *Management Science*, 40:1514–1532.

[Magerkurth and Prante, 2001] Magerkurth, C. and Prante, T. (2001). Metaplan für die Westentasche: Mobile Computerunterstützung für Kreativitätssitzungen. In *Mensch & Computer*.

[Majaro, 1988] Majaro, S. (1988). *The Creative Gap: Managing Ideas for Profit*. Longman, United Kingdom, 1st edition.

[Mamykina et al., 2002] Mamykina, L., Candy, L., and Edmonds, E. (2002). Collaborative creativity. *Commun. ACM*, 45:96–99.

[Massetti, 1996] Massetti, B. (1996). An empirical examination of the value of creativity support systems on idea generation. *MIS Quarterly*, 20:83–97.

[MAXQDA, 2012] MAXQDA (2012). `http://www.maxqda.de/`, Last Access 04/06/2012.

[Mayring, 2002] Mayring, P. (2002). *Einführung in die qualitative Sozialforschung*. Weinheim: Beltz, 5th edition.

[McCartney, 2002] McCartney, J. (2002). Rethinking the Computer Music Language: SuperCollider. *Comput. Music J.*, 26(4):61–68.

[Microsoft Surface, 2012] Microsoft Surface (2012). http://www.microsoft.com/surface, Last Access 05/31/2012.

[Mindjet, 2012] Mindjet (2012). MindManager 9. www.mindjet.com, Last Access 06/10/2012.

[Mindmeister, 2012] Mindmeister (2012). www.mindmeister.com, Last Access 06/10/2012.

[Müller, 2010] Müller, L. M. (2010). Leistungsmotivation beim kreativen Problemlösen. Diploma thesis, Technische Universität München.

[Morris et al., 2006] Morris, M. R., Paepcke, A., Winograd, T., and Stamberger, J. (2006). TeamTag: exploring centralized versus replicated controls for co-located tabletop groupware. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, CHI '06, pages 1273–1282, New York, NY, USA. ACM.

[Nacenta et al., 2007] Nacenta, M. A., Pinelle, D., Stuckel, D., and Gutwin, C. (2007). The effects of interaction technique on coordination in tabletop groupware. In *GI '07: Proceedings of Graphics Interface 2007*, pages 191–198, New York, NY, USA. ACM.

[Nachar, 2008] Nachar, N. (2008). The Mann ? Whitney U: A Test for Assessing Whether Two Independent Samples Come from the Same Distribution. *Tutorials in Quantitative Methods for Psychology*, 4(1):13–20.

[Netcraft, 2012] Netcraft (2012). Web Server Survey. http://news.netcraft.com/archives/category/web-server-survey/, Last Access 07/11/2012.

[Niemand and Bennet, 2002] Niemand, G. and Bennet, A. (2002). *Business Management: A value chain approach.* Van Schaik Publishers, Pretoria.

[Nunamaker et al., 1997] Nunamaker, J., Briggs, R. O., Mittleman, D. D., Vogel, D. R., and Balthazard, P. A. (1997). Lessons from a Dozen Years of Group Support Systems Research: A Discussion of Lab and Field Findings. *Journal of Management Information Systems*, 13(3):163–207.

[Nunamaker et al., 1991] Nunamaker, J. F., Dennis, A. R., Valacich, J. S., Vogel, D., and George, J. F. (1991). Electronic meeting systems to support group work. *Communications of the ACM - Special issue on computer graphics: state of the arts*, 34:40–61.

[Ocarina, 2012] Ocarina (2012). http://ocarina.smule.com/, Last Access 07/11/2012.

[Open Handset Alliance, 2007] Open Handset Alliance (2007). Industry Leaders Announce Open Platform for Mobile Devices. Press Release (2007-11-05). http://www.openhandsetalliance.com/press_110507.html, Last Access 07/11/2012.

[Open-I, 2012] Open-I (2012). http://www.open-i.org, Last Access 09/02/2012.

[OpenSound Control Home Page, 2012] OpenSound Control Home Page (2012). http://archive.cnmat.berkeley.edu/OpenSoundControl/, Last Access 08/17/2012.

[Osborn, 1957] Osborn, A. F. (1957). *Applied imagination: Principles and procedures of creative problem-solving.* C. Scribner's Sons; Rev. ed edition.

[Parnes, 1992] Parnes, S. J. (1992). *Source Book for Creative Problem Solving: A Fifty Year Digest of Proven Innovation Processes.* Creative Education Foundation.

[Prante et al., 2002] Prante, T., Magerkurth, C., and Streitz, N. (2002). Developing CSCW tools for idea finding -: empirical results and implications for design. In *Proceedings of the 2002 ACM conference on Computer supported cooperative work*, CSCW '02, pages 106–115, New York, NY, USA. ACM.

[Proctor, 2005] Proctor, T. (2005). *Creative problem solving for managers: developing skills for decision making and innovation.* Routledge, 2 edition.

[Puccio, 2006] Puccio, G. J. (2006). Creativity 101: An Introduction to Some Basic Concepts and the Field of Creativity Studies. The Informal Learning Review.

[Raskin, 2000] Raskin, J. (2000). *The humane interface: new directions for designing interactive systems.* ACM Press/Addison-Wesley Publishing Co., New York, NY, USA.

[recordMyDesktop, 2012] recordMyDesktop (2012). http://recordmydesktop.sourceforge.net, Last Access 07/11/2012.

[Rectable mobile, 2012] Rectable mobile (2012). http://www.reactable.com/products/mobile/, Last Access 07/11/2012.

[Reichwald and Piller, 2006] Reichwald, R. and Piller, F. (2006). *Interaktive Wertschöpfung. Open Innovation, Induvidualisierung und neue Formen der Arbeitsteilung.* Gabler, Cambridge.

[Reinhardt et al., 2010a] Reinhardt, M., Frieß, M. R., Groh, G., and Amberg, M. (2010a). Fostering Process and Context Support Through Social Networking Services on an Open Innovation Platform. In Hafkesbrink, J., Hoppe, H. U., and Schlichter, J., editors, *Schriften zu Kooperations- und Mediensystemen (Band 30) - Competence Management for Open Innovation*, volume 30, pages 169–190. EUL Verlag.

[Reinhardt et al., 2010b] Reinhardt, M., Frieß, M. R., Groh, G., Wiener, M., and Amberg, M. (2010b). Web 2.0 driven Open Innovation Networks - A Social Network Approach to Support the Innovation Context within Companies. In Schumann, M., Kolbe, L., Breitner, M., and Frerichs, A., editors, *Proceedings of the Multikonferenz Wirtschaftsinformatik (MKWI)*, pages 1177–1190, Göttingen.

[Reinhardt et al., 2010c] Reinhardt, M., Hetzenecker, J., Frieß, M. R., and Amberg, M. (2010c). Stiff Structures for Loose Folks - A Platform for an Open Innovation Community. In *Proceedings of the Forteenth Pacific Asia Conference on Information Systems (PACIS)*, pages 487–498, Taipei, Taiwan.

[Reinhardt et al., 2012] Reinhardt, M., Wiener, M., Frieß, M. R., Groh, G., and Amberg, M. (2012). Social Software Support for Collaborative Innovation Development in Organizations. *International Journal of Knowledge-Based Organizations (IJKBO). Special Issue on Corporate Open Innovation*, 2:56–76.

[Reinig et al., 2007] Reinig, B., Briggs, R., and Nunamaker, J. (2007). On the measurement of Ideation Quality. *Journal of Management Information Systems*, 23(4):143–161.

[Rekimoto, 1998] Rekimoto, J. (1998). A multiple device approach for supporting whiteboard-based interactions. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI '98, pages 344–351, New York, NY, USA. ACM Press/Addison-Wesley Publishing Co.

[Rhodes, 1961] Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan*, pages 305–310.

[Richmond and McCroskey, 1995] Richmond, V. and McCroskey, J. (1995). *Nonverbal Behaviors in interpersonal relations.* Allyn and Bacon.

[Rickars, 1999] Rickars, T. (1999). Brainstorming. In Runco, M. A. and Pritzker, S. R., editors, *Encyclopedia of Creativity*, pages 219–228. Academic Press, London.

[Ritchey, 1998] Ritchey, T. (1998). Fritz Zwicky, Morphologie and Policy Analysis. In *Proceedings of the 16th EURO Conference on Operational Analysis*, Brussels.

[Rodden et al., 2003] Rodden, T., Rogers, Y., Halloran, J., and Taylor, I. (2003). Designing novel interactional workspaces to support face to face consultations. In *CHI '03: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 57–64, New York, NY, USA. ACM.

[Rohrbach, 1969] Rohrbach, B. (1969). Kreativ nach Regeln - Methode 635, eine neue Technik zum Lösen von Problemen. *Absatzwirtschaft*, 12:73–75.

[Rummel, 1975] Rummel, R. (1975). *Understanding Conflict and War, Volume 2, The Conflict Helix.* Beverly Hills, California: Sage Publications, 1976.

[Runco et al., 2011] Runco, M. A., Millar, G., Acar, S., and Cramond, B. (2011). Torrance Tests of Creative Thinking as Predictors of Personal and Public Achievement: A Fifty Year Follow-Up. *Creativity Research Journal*, 22:243.

[Ruscio and Amabile, 1998] Ruscio, J., D. W. and Amabile, T. (1998). Looking Inside the Fishbowl of Creativity: Verbal and Behavioral Predictors of Creative Performance. *Creativity Research Journal*, 11:243.

[Sauter et al., 1994] Sauter, C., Mühlherr, T., and Teufel, S. (1994). Sozio-kulturelle Auswirkungen von Groupware. In Rauch, W., Strohmeier, F., Hiller, H., and Schlögl, C., editors, *Proc. 4 Intl. Symp. für Informationswissenschaft*, pages 517–526. Universitätsverlag Konstanz.

[Schöning et al., 2008] Schöning, J., Brandl, P., Daiber, F., Echtler, F., Hilliges, O., Hook, J., Löchtefeld, M., Motamedi, N., Muller, L., Olivier, P., Roth, T., and von Zadow, U. (2008). Multi-Touch Surfaces: A Technical Guide. techreport, Technische Universität München.

[Schooler and Meicher, 1994] Schooler, J. W. and Meicher, J. (1994). The Ineffability of Insight. In Steven M. Smith, T. B. W. and Finke, R. A., editors, *The creative cognition approach*, chapter 5, pages pp. 97–133. MIT Press, Cambridge, MA.

[Scott and Carpendale, 2006] Scott, S. D. and Carpendale, S. (2006). Investigating Tabletop Territoriality in Digital Tabletop Workspaces. In *Technical Report*, Calgary, AB, Canada. Department of Computer Science, University of Calgary.

[Scott et al., 2003] Scott, S. D., Grant, K. D., and Mandryk, R. L. (2003). System guidelines for co-located, collaborative work on a tabletop display. In *ECSCW'03: Proceedings of the eighth conference on European Conference on Computer Supported Cooperative Work*, pages 159–178, Norwell, MA, USA. Kluwer Academic Publishers.

[Scott et al., 2004] Scott, S. D., Sheelagh, M., Carpendale, T., and Inkpen, K. M. (2004). Territoriality in collaborative tabletop workspaces. In *CSCW '04: Proceedings of the 2004 ACM conference on Computer supported cooperative work*, pages 294–303, New York, NY, USA. ACM.

[Scritchfield, 1999] Scritchfield, M. L. (1999). The Creative Person, Product, Process and Press: The 4P's. http://www.buffalostate.edu/orgs/cbir/readingroom/html/Scritchfield-99.html.

[Shaughnessy, 1998] Shaughnessy, M. (December 1998). An Interview with E. Paul Torrance: About Creativity. *Educational Psychology Review*, 10:441–452(12).

[Shipton et al., 2006] Shipton, H., West, M. A., Dawson, J. F., Patterson, M., and Birdi, K. (2006). HRM as a predictor of innovation. *Human Resource Management Journal*, 16(1):3–27.

[Shneiderman, 1983] Shneiderman, B. (1983). Direct Manipulation: A Step Beyond Programming Languages. *Computer*, 16:57–69.

[Shneiderman, 2007] Shneiderman, B. (2007). Creativity support tools: accelerating discovery and innovation. *Commun. ACM*, 50:20–32.

[Shoemaker, 2000] Shoemaker, G. (2000). Supporting private information on public displays. In *CHI '00 extended abstracts on Human factors in computing systems*, CHI EA '00, pages 349–350, New York, NY, USA. ACM.

[SimpleMind Touch, 2012] SimpleMind Touch (2012). http://www.simpleapps.eu/simplemind/, Last Access 07/11/2012.

[Skrbl, 2012] Skrbl (2012). www.skrbl.com, Last Access 06/10/2012.

[Steiner, 2009] Steiner, G. (2009). The Concept of Open Creativity: Collaborative Creative Problem Solving for Innovation Generation - a Systems Approach. *Journal of Business and Management*, 15:5–33.

[Sternberg and Lubart, 1999] Sternberg, R. J. and Lubart, T. I. (1999). The Concept of Creativity: Prospects and Paradigms. In Sternberg, R. J., editor, *Handbook of Creativity*, pages pp.3–14. Cambridge University Press.

[Sternberg and O'Hare, 1996] Sternberg, R. J. and O'Hare, L. (1996). Creativity and intelligence. In Sternberg, R. J., editor, *Creativity handbook*, pages pp.251–272. Cambridge University Press, New York.

[Stewart et al., 1999] Stewart, J., Bederson, B. B., and Druin, A. (1999). Single display groupware: a model for co-present collaboration. In *CHI '99: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 286–293, New York, NY, USA. ACM.

[Streitz et al., 1999] Streitz, N. A., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., and Steinmetz, R. (1999). i-LAND: an interactive landscape for creativity and innovation. In *Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit*, CHI '99, pages 120–127, New York, NY, USA. ACM.

[Studio, 2012] Studio, O. (2012). `http://www.ohmstudio.com/`, Last Access 07/11/2012.

[Sullivan, 1896] Sullivan, L. (1896). The tall office building artistically considered. *Lippincott's Magazine*.

[SuperCollider, 2012] SuperCollider (2012). `http://supercollider.sourceforge.net/`, Last Access 08/16/2012.

[Tang et al., 2010] Tang, A., Pahud, M., Carpendale, S., and Buxton, B. (2010). VisTACO: visualizing tabletop collaboration. In *ACM International Conference on Interactive Tabletops and Surfaces*, ITS '10, pages 29–38, New York, NY, USA. ACM.

[Tang et al., 2006] Tang, A., Tory, M., Po, B., Neumann, P., and Carpendale, S. (2006). Collaborative coupling over tabletop displays. In *CHI '06: Proceedings of the SIGCHI conference on Human Factors in computing systems*, pages 1181–1190, New York, NY, USA. ACM.

[Tang, 1991] Tang, J. C. (1991). Findings from observational studies of collaborative work. *Int. J. Man-Mach. Stud.*, 34(2):143–160.

[Taylor et al., 1958] Taylor, D., Berry, P., and Block, C. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking? *Administrative Science Quarterly*, 6:22–47.

[Terken and Sturm, 2010] Terken, J. and Sturm, J. (2010). Multimodal support for social dynamics in co-located meetings. *Personal Ubiquitous Comput.*, 14:703–714.

[Terrenghi et al., 2006] Terrenghi, L., Fritsche, T., and Butz, A. (2006). The EnLighTable: Design of Affordances to Support Collaborative Creativity. In Butz, A., Fisher, B., Krüger, A., and Olivier, P., editors, *Smart Graphics*, volume 4073 of *Lecture Notes in Computer Science*, pages 206–217. Springer Berlin / Heidelberg.

[Terrenghi et al., 2008] Terrenghi, L., Fritsche, T., and Butz, A. (2008). Designing Environments for Collaborative Video Editing. In *Proceedings of the 4th International Conference on Intelligent Environments - IE08, IET.*

[The R Project for Statistical Computing, 2012] The R Project for Statistical Computing (2012). `http://www.r-project.org/`, Last Access 07/11/2012.

[Thinkature, 2011] Thinkature (2011). `www.thinkature.com`, Last Access 03/11/2011.

[Thinking Space, 2011] Thinking Space (2011). `http://www.thinkingspace.net/`, Last Access 05/11/2011.

[ThinkTank 2.0, 2012] ThinkTank 2.0 (2012). `www.groupsystems.com`, Last Access 06/10/2012.

[Thompson, 1973] Thompson, J. J. (1973). *Beyond words : nonverbal communication in the classroom [by] James J. Thompson.* Citation Press, New York,.

[Torrance, 1995] Torrance, E. (1995). *Why Fly?: A philosophy of creativity.* Ablex Publishing Corporation.

[Torrance and Sternberg, 1988] Torrance, E. P. and Sternberg, R. J. (1988). *The nature of creativity as manifest in its testing*, pages 43–75. Cambridge University Press.

[Toseland and Rivas, 2005] Toseland, R. W. and Rivas, R. F. (2005). *Introduction to Group Work Practice (with MyHelpingLab), An (5th Edition).* Allyn & Bacon, Inc., Needham Heights, MA, USA.

[Toynbee, 1964] Toynbee, A. (1964). Is America neglecting her creative minority? *Widening horizons in creativity*, pages 3–9.

[Törnqvist, 2004] Törnqvist, G. (2004). Creativity in Time and Space. *Geografiska Annaler: Series B, Human Geography*, 86(4).

[United States Patent Application 20120068957, 2012] United States Patent Application 20120068957 (2012). `http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PG01&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.html&r=1&f=G&l=50&s1=%2220120068957%22.PGNR.&OS=DN/20120068957&RS=DN/20120068957?fvrewsd`, Last Access 06/02/2012.

[Van de Ven, 1986] Van de Ven, A. (1986). Central Problems in the Management of Innovation. *Management Science*, 32:590–607.

[Vangundy, 1988] Vangundy, A. B. (1988). *Techniques of Structured Problem-Solving.* Springer Netherland, 1st edition.

[Vangundy, 1992] Vangundy, A. B. (1992). *Idea power*. Amacom, New York, 1st edition.

[Vinciarelli et al., 2008] Vinciarelli, A., Pantic, M., and Bourlard, H. (2008). Social Signal Processing: Survey of an Emerging Domain.

[Wallas, 1926] Wallas, G. (1926). *The art of thought*. C.A. Watts & Co. Ltd, London.

[Walther, 1997] Walther, J. B. (1997). Group and Interpersonal Effects in International Computer-Mediated Collaboration. *Human Communication Research*, 23(3).

[Weilhammer and Rabold, 2003] Weilhammer, K. and Rabold, S. (2003). Durational Aspects in Turn Taking. In *Proceedings of the International Conference on Phonetic Sciences*.

[Weiss et al., 2009] Weiss, M., Wagner, J., Jennings, R., Jansen, Y., Khoshabeh, R., Hollan, J. D., and Borchers, J. (2009). SLAPbook: tangible widgets on multi-touch tables in groupware environments. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, TEI '09, pages 297–300, New York, NY, USA. ACM.

[Wigdor and Wixon, 2011] Wigdor, D. and Wixon, D. (2011). *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*. Morgan Kaufmann, 1 edition.

[Wilson et al., 2008] Wilson, A. D., Izadi, S., Hilliges, O., Garcia-Mendoza, A., and Kirk, D. S. (2008). Bringing physics to the surface. In Cousins, S. B. and Beaudouin-Lafon, M., editors, *UIST*, pages 67–76. ACM.

[Woodman et al., 1993] Woodman, R. W., Sawyer, J. E., and Griffin, R. W. (1993). Toward a Theory of Organizational Creativity. *The Academy of Management Review*, 18(2):293–321.

[Wörndl and Frieß, 2012] Wörndl, W. and Frieß, M. R. (2012). Combining Decentralized Collaborative Filtering on PDAs with Multi-Touch Tabletops for Group Recommendation. In *International Conference on Collaboration Technologies and Systems (CTS 2012)*, pages 591 – 595.

[WWW Summary, 2012] WWW Summary (2012). Tim Berners-Lee. WorldWideWeb: Summary. `http://groups.google.com/group/alt.hypertext/msg/395f282a67a1916c?pli=1`, Last Access 07/11/2012.

[ZeptoPad, 2012] ZeptoPad (2012). `http://zeptopad.com/iphone/index.html`, Last Access 07/11/2012.

List of Figures

List of Tables

List of Abbreviations

AJAX Asynchronous JavaScript and XML
API application programming interface
CISE Computer and Information Science and Engineering
CLI Command Line Interface
CM Center of Mass
CSCW Computer Supported Cooperative Work
CSS Creativity Support System
DAW Digital Audio Workstation
DTO Data Transfer Object
EMS Electronic Meeting System
GCSS Group Creativity Support System
GSS Group Support System
GUI Graphical User Interface
HCI Human-Computer Interaction
HTTP Hypertext Transfer Protocol
ICT Information and Communications Technology
IS Information System
ISTC IdeaStream Tabletop Client
MDE Multi Display Environment
MVC Model View Controller
NUI Natural User Interface
OSC Open Sound Control
PDA Personal Digital Assistant
SDG Single Display Groupware
SDK Software Development Kit
TCP Transmission Control Protocol
TWQ Teamwork Quality Framework
UDP User Datagram Protocol
UI user interface
WIMP Windows Icons Menus Pointer
WWW World Wide Web
XML Extensible Markup Language
ZUI Zoomable User Interface