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**Hybrid Brainsketching –
Interaction Concepts for Sketching Activities Based on
Digital Pen & Paper and Interactive Visualizations**

by

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Konstanz, 6. Februar, 2012

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Kurzfassung

Diese Master Thesis befasst sich mit der Analyse, dem Design und der Evaluierung eines Digitalen Werkzeuges zur Unterstützung kollaborativer Brainsketching Sitzungen. Dabei wurde das Themengebiet rund um soziale Kreativität erschlossen, sowie zwei Benutzerrollen – die kreativen Arbeiter und den Moderator - mit in die Systemgestaltung mit einbezogen. Gestaltungsrichtlinien und Systemanforderungen wurden auf Basis von Benutzerbeobachtungen und entlang den Ergebnissen literarischen Untersuchen erstellt. Die daraus resultierenden Design-Richtlinien, speziell angepasst an Brainsketching-Aktivitäten, werden durch einen Prototyp implementiert und demonstriert. Dabei ist dieses System, das *hyb*-System (hybrid brainsketching), in kollaborativen Brainsketching-Szenarios einsatzfähig. Die Software wurde mit Hilfe des ZOIL-Frameworks und unter dem Einsatz der Anoto Technology (digitaler Stift und Papier) realisiert. Im Anschluss der Entwicklung wurde eine Fallstudie mit sieben Design-Studenten und zwei professionellen Moderatoren aus der Industrie durchgeführt, um sowohl die Schwächen als auch die Stärken des *hyb*-Systems herauszufinden. Dabei unterstützt das System die Vervielfältigung von Artefakten und Ideen, die Phasen der Ideenkommunikation sowie die Tätigkeiten des Moderators. Desweiteren werden auf Basis der Benutzerstudie auch Potentiale der computergestützten Sitzung, hinsichtlich der Förderung von kollektiven *Gruppier-* und *Clustering*-Aktivitäten der Gruppenergebnisse, ersichtlich.

Abstract

This master thesis research considers the analysis, the design and the evaluation of a digital tool, which aims at offering support for collaborative brainsketching sessions. The domain, the tasks and the activities that relate to social creativity have been studied and two user-roles have been considered during the phases of the system-design, namely the creative workers and the facilitator. Guidelines and requirements were either established by means of an observational user study or by means of theoretical investigations. The inferred design-implications, fit to the embodied practice of brainsketching activities, are then implemented by means of a demonstrative prototype – the *hyb*-system (hybrid brainsketching) - which is usable in collaborative brainsketching scenarios. The software has been developed by means of the ZOIL framework and Anoto's digital pen and paper technology. Subsequently, a case study was conducted with seven design students and with two professional moderators, in order to reveal the drawbacks and the strengths of the *hyb*-system. To conclude, the system offers support for divergent thinking (the duplication of and the work with design-artifacts by multiple persons at the same time) and for idea communication, as this system promotes the role of a co-moderator. The user study also points out the opportunities that emerge, when those meetings are augmented with computational-support. Finally, on the basis of the results of the user study, suggestions were made for leveraging *hyb's* potential by facilitating clustering-activities of the group's output.

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1 Introduction

In software development, design increasingly influences the disciplines of classical engineering (e.g. "Design Thinking" forms part of the study of computer science, taught by Stanford[1] or HPI[2]). Geyer (2012) summarized the design related literature and examined the nature of design with regards to engineering (Figure 1). Thereby, the iterative phases "exploration", "generation" and "evaluation" are the very core of design and engineering. In regards of the explorative activity, it is accompanied by analytical tasks for elaborating ideas and thoughts into different directions (divergence), followed by tasks of reflection, where ideas are being organized into groups for highlighting issues or bringing the ideas into relation with the initial subject – here, reduction and synthesis takes places in general (convergence). Based on the resulting ideas of the exploration, circles of generation and evaluation follow in order to create prototypes and the final software product. According to Figure 1, the early phases are rather relating to design, whereas the phases toward the end rather relate to engineering.

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[1] http://dschool.stanford.edu/

[2] Hasso-Plattner-Institute, Potsdam: http://www.hpi.uni-potsdam.de/news/beitrag/informationsflut-als-herauforderung-design-thinking-workshop.html?L=1&cHash=2b3584c9995b0ad4dedb1100a7061df9
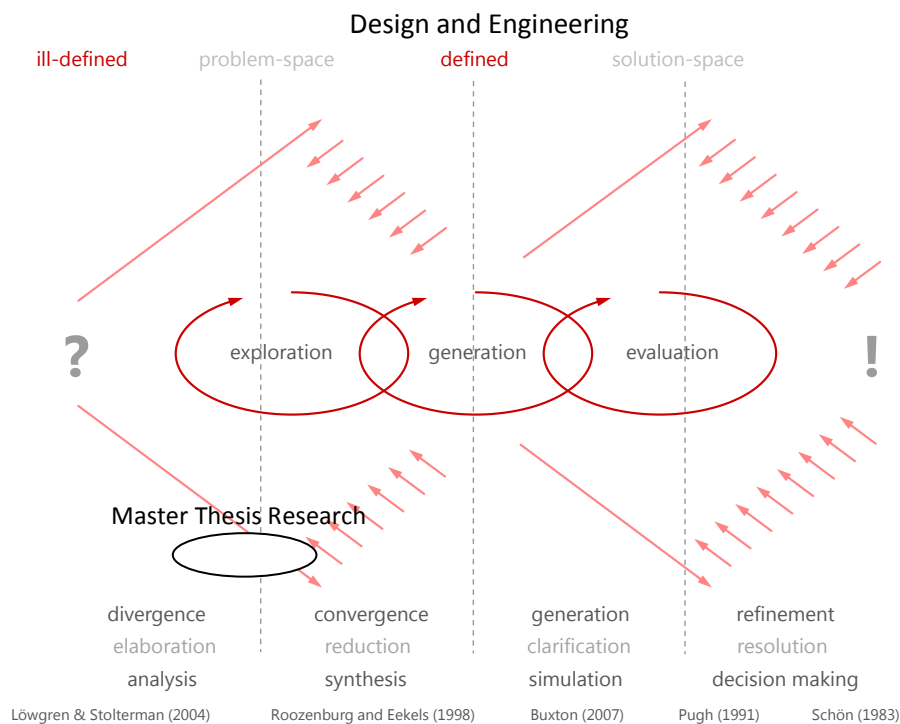
Figure 1. Workflow of design and engineering (source of image Geyer (2012)). This thesis rather relates to the phases were exploration takes place according to this diagram.

Since this master thesis research is concerned with supporting a sketching process digitally, this thesis thus relates to the phases of exploration and is to be put somewhere in between convergent and divergent activities (with slight tendencies to convergence) (see Figure 1, black circle). Thereby sketching, is a design methodology, which found its way into the field of computer science, as numerous informal and formal design techniques are increasingly developed and applied in early stages of design for supporting conceptual phases within classical engineering (Linsey et al., 2005). Sketching is fundamentally an informal drawing-technique and is used for quickly recording impressions, spontaneous minds and ideas through rough drawings performed by rapidly freehand motions. Therefore, traditional media like pen and paper are sufficient, which characterizes sketching as a low-cost method that enables easy accessibility of the design artifacts and the stimulation of collaboration accordingly. Subsequently, this master thesis research focuses on examining HCI[3] related challenges and issues that may come up by enhancing a creative sketching process with digital means. This thesis hence aims at mixing technology and social creativity by enriching sketching-related processes with computer power so that issues of the design technique (e.g. social negative factors) are minimized by the benefits of computer technology; without affecting important aspects of embodied practice[4]

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[3] Human-computer interaction

[4] Embodied practice: this term encompasses the physical interaction with objects or persons and is grounded in the theory of embodied cognition (Barsalou, 2008). The term embodied practice has been introduced by Geyer et al. (2011).

like verbal as well as non-verbal communication, synergy-effects and the native ideation[5] negatively. Thus for creating a digital sketching-supporting tool, this thesis research focuses not only upon the needs of the content-creating designers but also upon the needs of the session moderator, who guides and facilitates the group during the phases of a problem solving meeting.

1.1   Aim at Striving for Reality-Based Interaction

The purpose of the master thesis research is to facilitate and improve the creative group work and its moderation by the integration of computer technology. An overall guideline for this purpose has been introduced by Jacob et al. (2007). Thereby, the authors demonstrate the concept of "reality-based interaction", a notion that helps software engineers to find "gaps or opportunities for future development" (p. 1) of novel digital tools. This guideline gives an "understanding of both computers and interaction" (p. 1) and unifies new methods of interaction paradigms, as well as this guideline simply means the increasing use of real-world features when designing a human-computer interface. According to Jacob and his colleagues (2007), the interactions with the computer should become like the real world and they name "ubiquitous and pervasive computing, handheld interaction, multi-modal interaction" or "tangible computing" (p. 2) as examples for numerous "real-world" interactions. The authors suggest that designing computer interfaces in a more reality-based manner mimics reality and could thus reduce the mental effort using today's complex information systems, since "the user is already skilled in those aspects of the system" (p. 3). Furthermore, it could ease the learning, especially when it is only casually used, and it could minimize the information overload in order to improve performance in situations of time pressure.

However, the authors also assume that each "'unrealistic'" (p. 4) function or command is to be used in an artificial way, meaning that a computer system will hardly imitate the real-world. They state that more computer power reduces reality, but increases efficiency; less computer power may increase reality, but decreases efficiency. So, Jacob et al. (2007) point out a tradeoff between "power" versus "reality", whereby the term "power" encompasses the functionality and effectiveness of computer technology and the term "reality" means the "undigital" real world "outside of any form of computer interaction" (p. 2). According to this tradeoff, Jacob and his colleagues (2007) present a two axis diagram for structuring digital tools with respect to their ratio of reality-based features. Thus, linking the thesis to this tradeoff helps to illustrate the aim of this master research (see Figure 2).

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[5] Hereby, ideation means idea generation (Geyer et al., 2011)
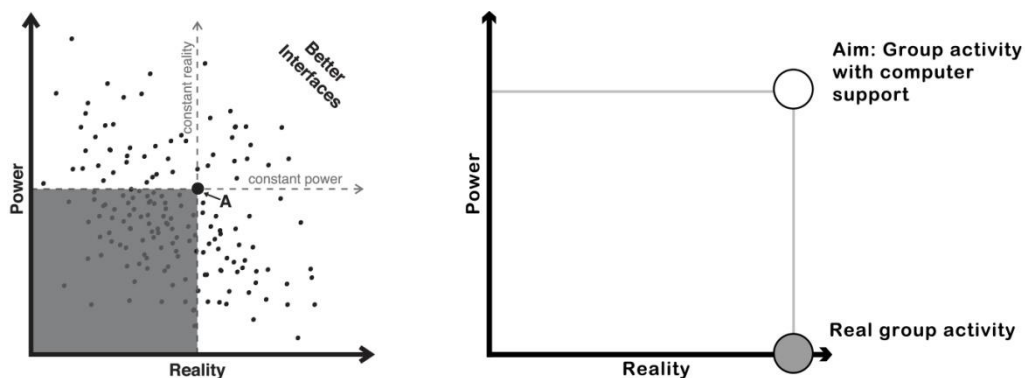
Figure 2. Image to the left: "Power vs. Reality Tradeoff" (Jacob et al. 2007, p. 4). Image to the right: This diagram illustrates the goal of this thesis: supporting the real world activity with functionality and efficiency without reducing reality.

Thereby, the grey circle in Figure 2 (right) illustrates real and unaltered group work. By contrast, the white circle in Figure 2 (right) illustrates the computer supported group activity (the aim of this thesis).

To conclude, it is suggested that designing digital tools upon the characteristics of reality with reality-based interaction styles could preserve the experiences and the affordance e.g. collaboration, face-to-face communication, or working with pen and paper, and could also exploit the benefits of computer technology for enhancing the efficiency and effectiveness of social creative activities at the same time[6].

1.2   Chapter Overview

Analysis. Therefore, this master thesis begins with an analysis of creative collaboration in order to reveal the benefits as well as the drawbacks of social group activities. This includes an exploration of the ways in which people work, what role design artifacts play and how the design environment affects the designer's practices. To better understand how human factors can impede creativity, e.g. the quality and the number of ideas, this chapter reveals three inhibitors that have been point out by other researchers. Informed by related studies, researchers also developed digital tools for supporting co-located or remote collaborative sketching activities, by means of stylus pen-based interaction and various electronic input and output devices. To restrict the matter of investigation this master thesis considers a particular sketching method, which is termed as brainsketching and which was promoted by van der Lugt (2002a). Some parts of this chapter are available in greater detail in the Master Seminar

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[6] (Budzinski, 2011a)

(Budzinski, 2011a).

Design. The aim of this chapter is to present the design criteria for the system and its features. Therefore, guidelines and requirements for the tool are grounded in theoretical investigations and they were informed by means of issues of reality that have been inferred by means of an observational user study. The resulting design criteria have been implemented by a system –termed as *hyb (hybrid brainsketching)* - which aims at facilitating the creative workers as well as the moderator within the phases of brainsketching. As a result, the paper-artifacts of the creative workers are enriched with additional functionalities (for printing, for highlighting, for rating ideas) and these functions are to be used by means of a digital pen (supporting the design session). The session facilitator has a display, separated from the group, and a set of functionalities that supports the value of analysis (supports the moderation). Some parts of this chapter have been described in greater detail in the documentation of the Masters Project (Budzinski, 2011b).

User Study. Finally, this chapter presents a user study for revealing the strengths and the drawbacks of the tool and the way which the tool affects the design process. Thus, two professional facilitators and two groups of design students (7 students in total) have been observed. Thereby, each group applied two brainsketching sessions, one with and one without computer support, and they had two different objectives to handle (within-subject design). The resulting data from the study (e.g. material gathered from questionnaires, focus groups, video-tapes) were then qualitatively analyzed.

Conclusion and Future Work. This chapter summarizes the thesis and offers suggestions and steps for further development of the system. Based on the results of the study, issues with the paper-based interface as well as computational power for supporting the value of clustering the design output are findings that have to be addressed in the future.

2 Analysis: Understanding the Domain, Tasks and the Characteristics of Social Creativity

The motivation for this initial analysis is to restrict the matter of investigation by considering collaborative sketching activities, their characteristics, strengths and shortcomings. Therefore, the following sections examine the nature of collaborative design practice such as the communication with colleagues; the creativity process, the ways in which people collaborate and the social influences on group performance. The design environment as well as design artifacts will be also explored in order to understand how the process of idea-sketching and the design environment e.g. the physical surroundings affect the social design activities (see chapter overview: Table 1, 2.1 & 2.2). Subsequently, the related work that evolved sketching supporting computer tools will be viewed through the lens of social and physical needs of collaborative creative meetings (Table 1, 2.3). Finally, this chapter concludes with an introduction of brainsketching – as a demonstrative sketching variant (Table 1, 2.5) - and the research questions that are to be addressed by this master thesis research.

Table 1. Chapter overview

2 Social Creativity		
2.1 Characteristics of Design Practice		2.3 The Social Factors
2.2 Sketching		
2.4 Digital Tools for Supporting Sketching		
2.5 Brainsketching		

2.1   The Characteristics of Design Practice

This section aims at offering insights into design and sketching activities with their underlying collaborative nature. Researchers that studied particularly the nature of design are Vyas (2009) and Vyas et al. (2009). They conducted broad investigations of physical design practices in order to give an understanding of how creative people explore, create, share, and use design artifacts, or what role the design environment plays for the coordination of the creative work. These findings reported by Vyas's investigations present knowledge and results from the latest design-related research and have been mainly taken into account for this chapter.

Observing Experts. By means of an ethnographic study (naturalistic observations as well as contextual interviews), Vyas and his colleagues (2009) and Vyas (2009) studied two design departments –and persons with design-expertise accordingly- over a period of several months. As a result, they reveal main characteristics of how designers externalize, coordinate, organize and communicate their thoughts.

2.1.1   Externalizing Thoughts

Idea externalization is the activity where thoughts and ideas are explored and externalized to various types of media and takes place at any point in time of the design process. Thereby, the designers construct physical artifacts in order to communicate the internalized thoughts by working with pen and paper (in early stages of the session) or by building physical objects made of modeling clay (in final stages of the session) (Figure 3 left & right). Vyas et al. (2009) concludes that using different types of materials for mediating ideas is an inherent part of "externalization".

Figure 3. Different types of media: on the left hand, sketches or on the right hand, clay forms (source of images Vyas et al. (2009 p. 8-9)).

2.1.2   Using the Physical Space within the Design Process

"Walls, tables, clipboards, and whiteboards are typical physical objects that surround designers and affect their work and their collaborative practices in a different manner" (Budzinski, 2011a, p. 4). The investigation by Vyas and his colleagues (2009) revealed that creative people usually tend to "elaborate their problems", meaning that they split issue into smaller bits that they resolve later on. Furthermore, they attach these bits, e.g. problems or solutions, to different and separated surfaces like bulletin-boards, tables or even walls. This behavior indicates that the designers engage the surroundings into the design process for creating an overview of project-related issues and for making their designed output accessible for other co-workers (Vyas et al., 2009). By means of a second investigation, Vyas (2009) further deduced four categories which the different surfaces can be classified as according to their purposes.

1. *A personal surface*.

2. A *shared surface*.

These kinds of surfaces are individually generated and used, and can be set up in a vertical or horizontal form ("as a mix of both" (Vyas, 2009, p. 2)).

"Personal surfaces appear as a portfolio for representing interests, achievements and goals of a designer and contains various materials and artifacts such as sketches, project associated information (time management, cooperative organization with other team members etc.), prototypes and inspirational data." (Budzinski, 2011a, p. 5)

The author points out that they favored to use vertical orientated surfaces because they allow for a quick overview of all artifacts as well as these surfaces serve as communication resources for bystanders (Figure 4a)

"These types of surfaces have the purpose of gathering and sharing inspirational related as well as design and project associated information to other team members in order to achieve 'common ground' in the group. Vyas (2009) observed that the designer preferred to use large notice boards, walls (within the design studio) and clipboards to supply a shared surface (Figure 4b)." (Budzinski, 2011a, p. 5)

3. A *project-specific surface*.

"These surfaces are created within a collaborative project by a group. As the name suggests, project-specific surfaces are placeholder for project related artifacts such as definition, design concepts (including sketches), to-do lists, goals, scheduling, time management (time line) and so on. These kinds of surfaces are used to hold group meetings (referring to design artifacts synchronously) or to leave individual information behind (presenting an artifact asynchronously). An important point hereby is that these surfaces are represented by 'movable whiteboards, wooden walls or tables' (Vyas, 2009, p.3) (Figure 4c)." (Budzinski, 2011a, p. 5)

4. A *live surface*.

"A live surface is utilized for short-living results inferred from intensive creative thinking work like brainstorming or sketching. Thus, these types of surfaces support co-located collaborative activities, which are temporarily conducted, and where the content is quickly as well as iteratively modifiable. The spatial orientation of these surfaces may be set either vertically or horizontally (Vyas, 2009) (Figure 4d)." (Budzinski, 2011a, p. 5)
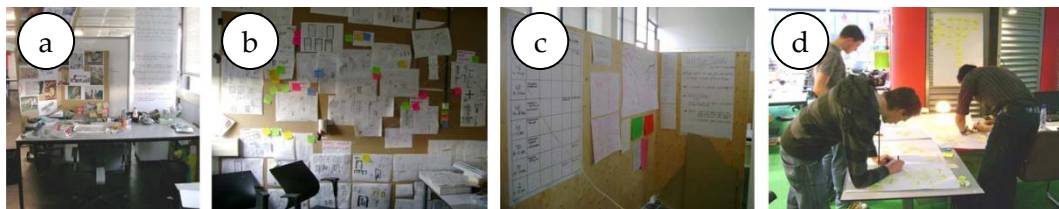
Figure 4. The four types of workspaces according to Vyas (2009): a) personal workspace b) shared surface, c) project-specific surface, d) live surface (source of images Vyas (2009, p. 2-4)).

Vyas (2009) distinguishes between four categories of surfaces and these four categories cannot be strictly distinguished. Nevertheless, this observational study highlights the essence and the ability of workspaces that have found varied purposes to support the work of a designer. In summary, these surfaces can be utilized asynchronous (communication at a different time) or synchronous (communication at the same time) by one person as well as by a co-located team, and these surfaces are to be used in order to organize and manage the project or to gain creative and inspirational information through gathered design artifacts. Overall, these environments improve the coordination of work.

2.1.3   Using the Body within the Design Process

During collaborative design activities, body and facial expressions helps to improve creativity and supports communication: "Designers creativity make use of their bodies while talking, while explaining a design sketch or referring to spatial arrangements within a design studio" (Vyas et al., 2009, p.13). Thereby, "methods such as role playing, body storming or design choreography in groups" (Vyas et al., 2009, p. 13) are commonly used for attracting the attention of others and for easing the communication of complex and dynamic ideas ("exploring interactive concepts", p. 14) (Figure 5). Generally, Vyas and his colleagues (2009) suggest that the body interaction supports collaboration in different ways:

a) Using the body helps to explain or to easily understand the affordance of a product since our body conveys both non-verbal emotions and active movements.
b) Using the body helps to decrease cognitive load while explaining highly complex issues or for mediating the context of a design task in a better way.
c) The body interaction enhances the verbal articulation beneficially and thus improves communication
d) Motion and the ability of walking around in the design environment improve design practices: "This was in fact an important rule-of-thumb in one of the design studios that we visited. One of the professors of the industrial design department frequently advised designers working in the studio to move around and don't just sit at the desks to generate creative ideas" (Vyas et al., 2009, p 14).

Figure 5. Using the body for mediating interactive system features (source of image Vyas et al. (2009, p. 13)).

The findings reported by Vyas (2009) and Vyas et al. (2009) highlight the characteristics of collaborative design practices ("externalization", "the role of the environment", "the role of the body"). As a result, "the correlation between the environment, the artifacts and the team members play a crucial role within the design process" (Budzinski, 2011a, p. 6). Thus, these factors should be taken into consideration when designing a digital tool for supporting physical design activities.

2.2   Externalization with Sketching

Externalization is considered as a design-related activity, where creative people try to explore and to find a solution for a problem (Vyas et al., 2009). There may be various techniques for externalizing thoughts, however this master thesis research only considers paper-based sketching, as sketching is seen as design method which is widely used for outlining mental images.

2.2.1   Sketching

Sketching is a design technique for outlining thoughts quickly without considering rules for appliance. Sketching is ubiquitous, which means in some sense that it is practical by merely using hands and by using at least a pen and a sheet of paper (low-cost) even without having professional drawing skills. This method can be applied individually or collectively and the resulting design artifacts can be considered as a purpose that can be erased as well as arbitrarily

modified and optimized (Buxton, 2007; Craft & Cairns, 2009). These findings
indicate also that these artifacts are portable and easy to handle. Both sketching
and viewing sketches inspires the actor to contribute to new ideas (ideas "'talk
back'", see Vyas et al., 2009 or "Sketching also enhances creativity by [...]
enabling cycles of generation and (re)interpretation", see Craft & Cairns (2009, p.
71)). Buxton (2007) has termed this attribute also as "Ambiguity", as sketches can
"be interpreted in different ways, and new relationships seen within them, even
by the person who drew them" (p. 111).

Overall, these characteristics confirm sketching as an appropriate design method
for creating first solutions in early and divergent stages of design (resuming
Figure 1), especially when problems and solutions are blurred (Johnson et al.,
2008). Thus, sketching is widely applied in various domains for various
purposes, e.g. by interaction designers, industrial designers, architects and
engineers, emphasizing that this technique is an inherent part of visual
communication (Craft & Cairns, 2009) and it should be considered as an "element
in the designer's toolbox" than a replacement of other design methods (Craft &
Cairns, 2009, p. 71) (see Figure 6).
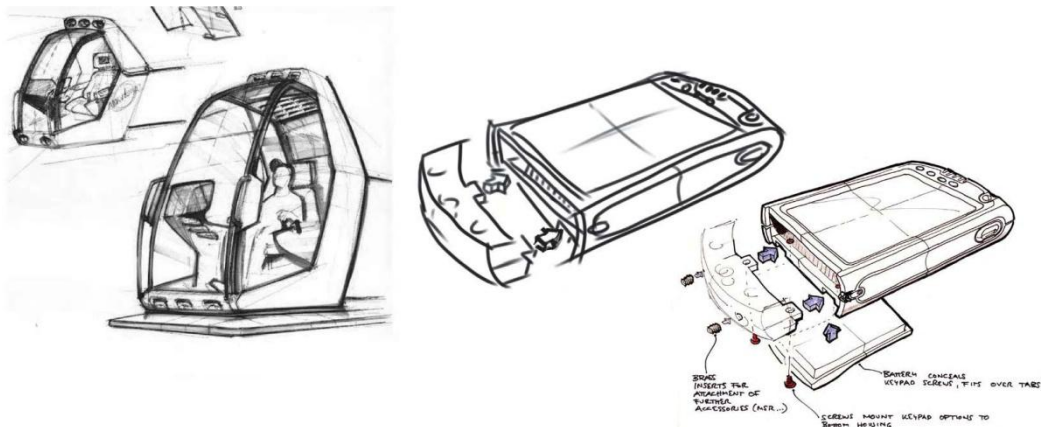
Figure 6. Example of sketches (source of images, Buxton (2007, p. 120, 122)).

2.2.2   Pen and Paper

Paper is an essential part of the early design process and it is often chosen by
professional designers (Cook & Bailey, 2005). Cook and Bailey (2005) studied
twelve professional designers by means of a contextual interview, in order to
understand the role physical tools e.g. pen and paper have in the early stage of
design in contrast to popular used computer tools e.g. "Photoshop" or
"Dreamweaver" (p.3) (these digital tools also termed as "informal tools" (p. 1)).
As a result, "they inferred that the design tasks have been better supported by
using traditional pen and paper in terms of idea communication and idea

acknowledgment ('soliciting feedback' (p.3)). The participants also reasoned that no additional cognitive effort is required when using paper and pen since 'paper is quicker and easier to use than a computer tool' and 'paper does not impose the extra layer of interpretation that a computer tool does' (Cook & Bailey, 2005, p. 5)" (Budzinski, 2011a, p. 8). Consequently, these traditional media (pen and paper) avoids unnecessary preoccupation with computer layouts, menus and buttons, and additionally paper preserves the affordances everyone has. The participants also report the portability, modifiability and the likeability of paper as benefits over computer tools and these attributes all in all contributes to the face-to-face collaboration.

Nevertheless, the authors also consider the power the computer tools have, and recommend to connect both approaches to fully meet the needs of designers (Cook & Bailey, 2005). They conclude that applying a "digital ink" (p. 7) interface (e.g. Anoto technology[7]) to the design process complements the work with physical tools most effectively, since this technology preserves the abilities of paper, but utilizes also digital benefits (Cook & Bailey, 2005).

2.3   The Social Factors

The nature of sketching encompasses individual as well as collaborative creative activities (Vyas et al., 2009), which means that inter-personal interactions (e.g. verbal as well as non-verbal communication) are a part of and affects the productivity of collective idea generation, even negatively. Thus, this section is concerned with investigating the social influences on the group's effectiveness and approaches the important question why group work affects creativity and innovation in a negative way.

Many researchers, especially social psychologists, studied idea generation meetings and they identified processes that are mainly responsible for the productivity loss in problem solving meetings (Diehl & Stroebe, 1990). This fact, that the presence of other people have effect on emotion, thoughts and creativeness, engaged also the interest of Warr and O'Neill (2005) to study the procedures of social creativity and to understand the nature of design. Therefore, they studied several empirical investigations that have been performed over the last 50 years (including the studies of Diehl & Stroebe), and they noted that these empirical investigations challenge the productivity of group performance in comparison to individual performance (individual working persons created more ideas with more quality). Consequently, Warr & O'Neill (2005) posed the question "are more heads better than one?" (p.122) on the one side. On the other

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[7] http://www.anoto.com/the-pen-2.aspx (last access 01.02.2012)

side, Warr & O'Neill (2005) also theorized that groups could have the potential
for creating more meaningful ideas, due to the fact that multiple persons can
share their knowledge. For instance, the group members can combine their ideas
and thoughts ("matrices of thought" (p.122)) which inspires the participants and
hence improves the creation of more novel ideas.

Figure 7 highlights this theoretical potential of group creativity and illustrates a
comparison between an individual and a group-related idea generation process.
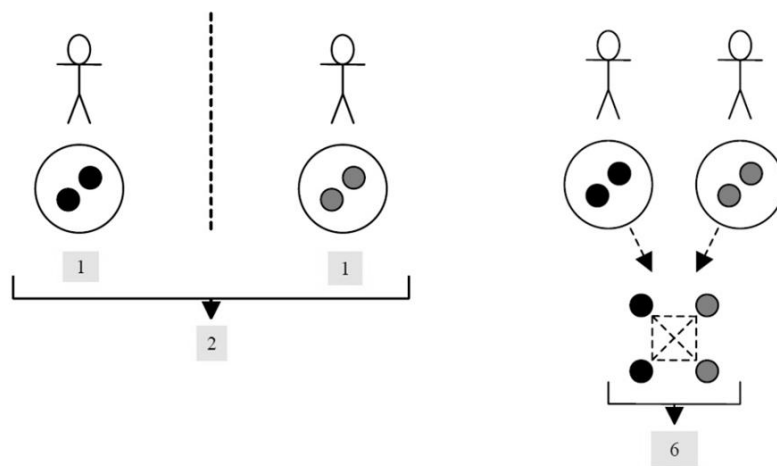
Figure 7. Individual idea generation (left) in comparison to the group related idea generation
(right) (source of image Warr & O'Neill (2005, p. 123, 124))

The scenario to the left of Figure 7 "demonstrates two persons working
independently on a creative activity, whereby each person has access to his
'matrix of thought' […] and each person has the ability to create one idea -
collating their productivity to a cumulative result of two ideas. The right scenario
in contrast demonstrates two persons working together, whereby each person
also has access to his 'matrix of thought'. The intra-group interaction however
facilitates the communication of their 'matrices of thought' to each other which
fosters a combination of their minds in various ways - with a cumulative
outcome of up to six ideas. Although there may be theoretical potential for social
creativity outperforming individual creativity, Warr and O'Neill (2005) refer to
empirical investigations that highlight the contrary due to the fact that thoughts,
feelings and creativity are affected by social influences of other team members"
(Budzinski, 2011a, p. 9, 10).

Consequently, Warr and O'Neill (2005) point out three major inhibitors that
impede the social idea generation process in order to explain why the group

work was being outperformed. These inhibitors are commonly known as "Production blocking, evaluation apprehension and free riding" (Warr & O'Neill, 2005, p. 124) and were once introduced by the research of Diehl and Stroebe (1990, p. 4): "In our 1987 paper we identified 'free riding', 'evaluation apprehension' and 'production blocking'". These factors are briefly summarized in the following sub-sections.

2.3.1 Production Blocking

"Production blocking is a phenomenon that commonly occurs when group members verbally explain their ideas to each other. This type of idea expression has been termed by Warr and O'Neill (2005) as an asynchronous-related interaction" (Budzinski, 2011a, p. 10) which is actually the crucial factor for production blocking. Thereby, asynchronous-related interaction means that only one person can articulate an idea at one time, which rules out the verbal idea expression of other team members. As a consequence, the other team members have to wait for other persons to finish speaking and during that time, they hold back their ideas until they forget them or they may suppress them because they feel that the ideas aren't relevant anymore (Diehl & Stroebe, 1990; Warr & O'Neill, 2005). Warr & O'Neill (2005) conclude: "Finally, if group members are prevented from expressing their ideas as they occur, they may be discouraged from producing further ideas." (p. 124).

Approaching Production Blocking. There are possibilities for mitigating these group factors. What Warr & O'Neill (2005) have pointed out, in order to address production blocking for example, is to use synchronous communication and "interaction techniques for expressing ideas, such as writing ideas and distributing them around the members of the group" (Warr & O'Neill, 2005, p. 124). Moreover, only articulating ideas is an uncommon behavior, as people naturally tend to use external storing medium for idea externalization, e.g. writing ideas down (Warr & O'Neill, 2005).

2.3.2 Evaluation Apprehension

"Evaluation apprehension relates to the phase where people are reviewing each other's outputs. This means that group members fear the judgment and criticism that may come up following the externalizing of one's ideas" (Budzinski, 2011a, p. 10). This in turn has a negative impact on the productivity, as the participants had created significantly fewer ideas. Warr and O'Neill (2005) further reported that the effect of evaluation apprehension can also be manipulated and intensified when designers with expertise are integrated in the review or by

increasing the identifiability between the creator and the output (Diehl & Stroebe, 1990; Warr & O'Neill, 2005).

Approaching Evaluation Apprehension. Writing ideas using pen and paper instead of articulating them anonymizes. This in turn lessens the identification between the ideas and its creators and thus lowers the assessment and the effect of evaluation apprehension accordingly (Warr & O'Neill, 2005).

2.3.3   Free Riding

Free riding "means that people do not completely contribute to the problem-solving process (such as the idea generation). In other words, some team members actually tend to become consciously inactive since pooling or cumulating the outputs of all group members avoids the identification of each one's performance and the performance of the 'free rider' accordingly" (Budzinski, 2011a, p. 10). Accordingly, Warr and O'Neill (2005) reveal that free riding can be reduced when poor performance of each individual is apparent to the team.

Identifiability   **Anonymity**

Reduces Free Riding   Reduces Evaluation
Increases Evaluation   Apprehension
Apprehension   Increases Free Riding
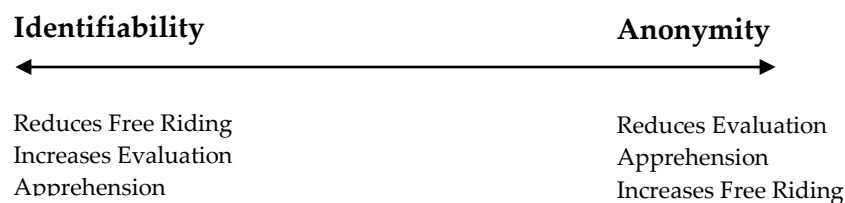
Figure 8. Tradeoff between free riding and evaluation apprehension.

Thereby, the two inhibitors "evaluation apprehension" and "free riding" disclose a tradeoff between removing "identification from ideas in order to mitigate evaluation apprehension" and highlighting "identifiability in groups" in order to reduce free riding (Warr & O'Neill 2005, p.125) (see Figure 8). Unfortunately, Warr and O'Neill (2005) further report that there is no clue which one of these two inhibitors has more negative impact on creativity. However, this could have been helpful for weighting between those social influences.

Approaching Free Riding and Evaluation Apprehension. In order to minimize both social influences at the same time, the team members have to use different colored pens (Warr & O'Neill, 2005; Linsey et al., 2005). Thereby, for minimizing the effects of evaluation apprehension and free riding (what Linsey et al. (2005) has termed as "social loafing" (p.2)), the authors used different colored-pens and engaged an experimenter as a moderator into the design session. Thereby, "the

various colors make it difficult for other team members to match the color to its owner which highlights anonymity. Temporarily, the participants have however still in mind, that the experimenter can 'identify the source of each idea' (Linsey et al. 2005, p.4) which actually prevents free riding" (Budzinski, 2011a, p. 12).

To conclude, the findings that have been offered here by Warr & O'Neill (2005) give an account of how social influences can inhibit the social interaction between team members, and this in turn hinders achieving common knowledge in a group. Thus, production blocking, evaluation apprehension and free riding are essential issues for various collaborative idea generation activities and have hence to be taken into consideration when designing a digital tool for sketching-related group sessions.

2.4   Digital Tools for Supporting Sketching

This section reveals what kind of digital tools, for supporting the sketching activity, are already existent from the related HCI research. The goal hereby is to explore the ways in which the collaborative sketching activity has been supported and whether the researchers consider the nature of design (according to Vyas et al., 2009; Vyas, 2009) and the influences of other persons (according to Diehl & Stroebe, 1990; Warr & O'Neill, 2005) during the conceptual phases of their systems.

i-LAND. "The first example is called 'i-LAND' an environment that supports collaborative workspaces in which information spaces such as displays are blended with the real physical environment to perform interactive walls, tables and even chairs" (Budzinski, 2011a, p. 12). This example, developed by Streitz et al. (1999), should simply be considered as a vision of the future workspace that supports cooperative and flexible team activities using features of augmented reality and ubiquitous computing[8]. Thereby, they integrated a set of interactive computer devices, termed as "roomware components", into the physical environment for supporting social activities e.g. presentations or the group-based organization of digital information on vertical digital surfaces ("'interactive electronic wall'" (Streitz et al., 1999, p. 120)). The "i-LAND" system also contains horizontal interactive displays attached to mobile chairs or integrated into tables for allowing the group-based annotation (also sketching) of digital information e.g. by stylus input (Figure 9).

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[8] The notion of ubiquitous computing was promoted by Mark Weiser (Weiser, 1991).
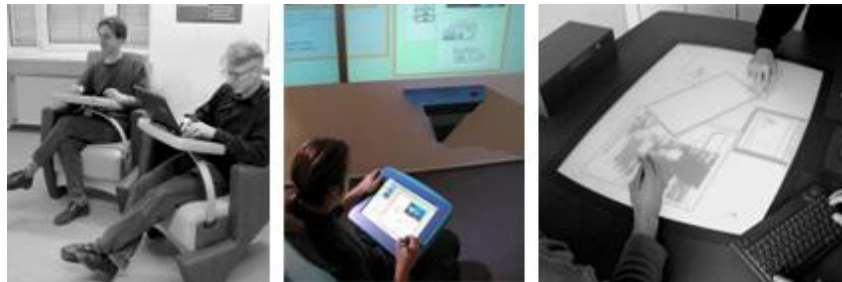
Figure 9. The vision of i-LAND (to the left), remote annotation by means of pen-based input (to the middle) and the interactive table (to the right) (source of images Streitz et al. (1999, p. 124, 125)).

Calico. An example for a more sketching-related tool is called "Calico" and has been developed by Mangano et al. (2010). This digital tool has the purpose to support software engineers during the conceptual phases of a software design process. Thereby, the authors analyzed the ways in which software engineers are practicing sketching and secondly, they created the tool requirements upon their findings. As a result, they revealed that software engineers tend to work on vertical whiteboards and they tend to "shift their focus frequently amongst different design problems e.g. 'switching from user interface design to internal data structure design, to architectural issues, and back to user interface design' (Mangano et al., 2010, p. 25)" (Budzinski, 2011a, p. 13). They also drew "low detail models" e.g. arrows, boxes etc, and they mixed notions e.g. models of the user interface and their underlying data-backend. Consequently, "Calico" supports those characteristics by providing an interactive whiteboard and a system for allowing stylus-based input. Thereby, the system facilitates the crosswise distribution of sketches to multiple digital canvases (see Figure 10a) and it provides elements that captures "emerging notations" and groups "strokes and sketches and makes them moveable, stackable, and relatable" (Mangano et al., 2010, p. 25) (see Figure 10b & c).
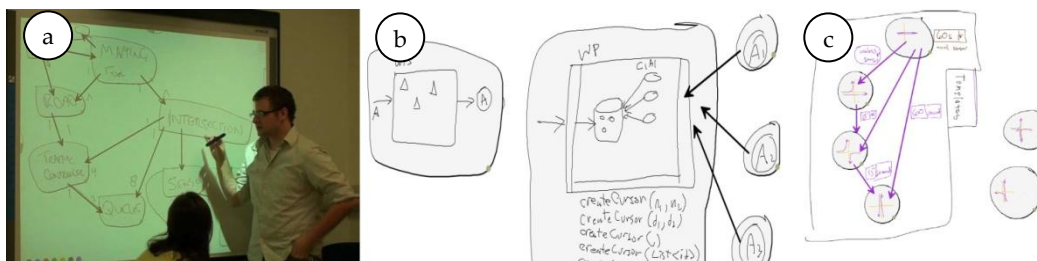
Figure 10. Design behaviors supported by Calico according to Mangano et al. (2010): "(a) Shifting Focus, (b) Low Detail Models, and (c) Mix of Notations" (p.25). Source of images (Mangano et al. 2010, p. 26 - 30).

MCSketcher. In contrast, the next related work demonstrates a system, which supports mobile pen-based collaborative sketching sessions. This system is termed as "MCSketcher" and has been developed by Zurita et al. (2008). The

authors argue their research in mobile sketching due to a) the use of mobile devices has crucially increased in everyday life, and b) the rapid interconnection between the devices helps to mimic co-located collaboration e.g. sharing thoughts and exchanging ideas.

In order to take part in a collaborative peer-to-peer session, the "MCSketcher" application must be installed on each handheld device before. In doing so, the interconnection between the clients takes place simultaneously and the clients are automatically synchronized. During the sketching activity, all strokes that have been drawn or all pictures that have been taken get immediately distributed to all other clients, meaning that the interconnected clients share the same view. Subsequently, the creative outputs become directly visible and accessible for all interconnected designers (see Figure 11). This synchronization mechanism can also be avoided if needed. To conclude, with this system, the creative people rather work upon a logical shared surface, implemented by synchronized interactions and views, than upon a real physical shared surface as it was realized by Mangano et al. (2010) with "Calico" or by Streitz et al. (1999) with "i-LAND".
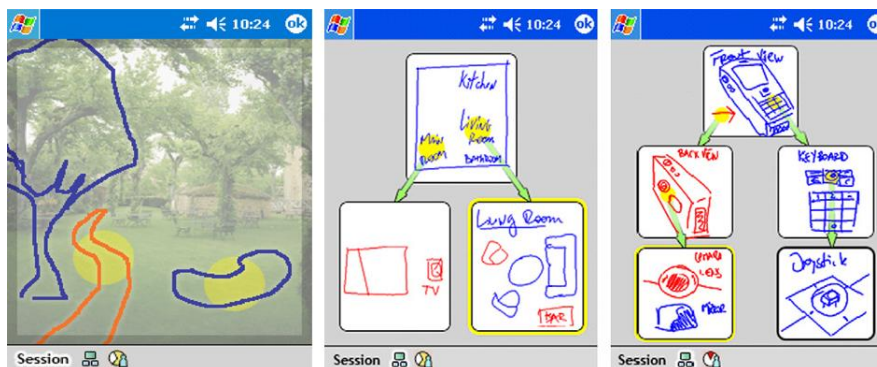
Figure 11. The images at the left hand side illustrate the shared view and current sketching activities. The image on the right illustrates an overview of the design session and its design artifacts. Source of images Zurita et al. (2008, p. 343).

TEAM STORM. "Those two approaches of handheld mobile devices and physical surfaces have been already combined by Hailpern et al. (2007) in order to provide 'working with multiple ideas in parallel or collaboration' (p. 193). They present an 'interaction model' (p.193) that is completely implemented in terms of a groupware system called 'TEAM STORM'" (Budzinski, 2011a, p. 15). Therefore, the authors created a set of requirements through the review of related theories of creativity and collaboration, followed by own impressions obtained by observing creative group work in practice. This guideline considers also the three social inhibitors of co-located group work (Diehl & Stroebe (1990); Warr & O'Neill (2005)).

A key feature of this system is the utilization of interactive maps, "mentioned to be used as landscapes for organizing, reflecting/modifying and communicating designs and visual thoughts" (Budzinski, 2011a, p. 15). Another feature is the "combination of both private devices that realize a 'personal workspace' (p. 197) for editing ideas, and public devices that realize a 'group workspace' (p. 197) for communicating and sharing designs" (Budzinski, 2011a, p. 15) (see Figure 12). Besides having the ability to create new ideas (sketching with a stylus pen), users can select sketches out of the group workspace into the individual workspace in order to work with them: "The design is copied (not moved) to the local workspace" (p. 199).
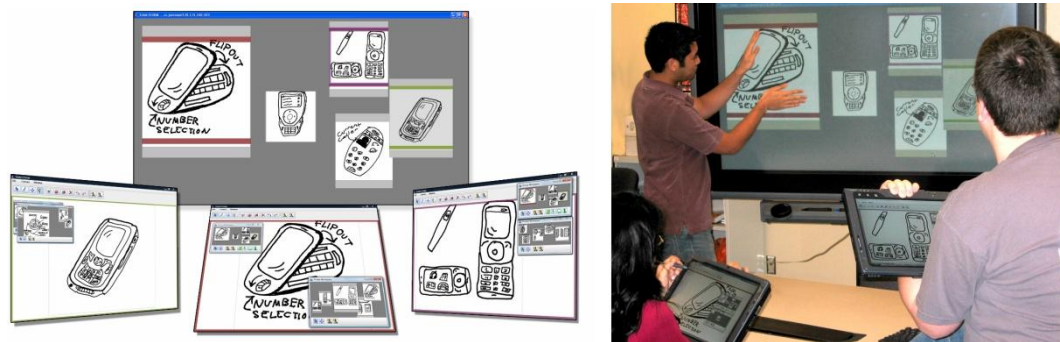
Figure 12. Illustration of the system (left) and the scenario (right). Tablets represent the personal workspaces and the large display represents the shared group workspace which both "allow designers to sketch on the same or different designs in parallel" (source of image and quotation Hailpern et al. (2007), p. 193, 196).

PaperSketch. The related work by Weibel et al. (2011) focus upon enhancing the work with ordinary pen and paper for creating a "suitable interface to better support the nature of sketching" (p. 9). With the "tendency toward synchronous collaboration with geographically separated people" (p. 4), the authors consider the remote and synchronous group-based idea generation. Therefore, Weibel et al. (2011) conducted an interview with creative people such as "designers, architects and engineers" (p. 3) in order to get an understanding of both the domain of sketching and the nature of collaboration. According to their findings, Weibel et al. (2011) implemented "PaperSketch", a prototype for supporting remote collaborative sketching activities that are to be conducted with digital pen and paper and Skype. In doing so, the participants share a common view on the design space; and the information exchange between the participants is implemented by drawing with the pen on the paper (the drawn information are synchronized) (see Figure 13). As a result, "PaperSketch" demonstrates a hybrid solution of "power" and "reality", meaning that the pen and paper technology helps to preserve the physical practice but enables additionally digital support (e.g. with modifiability, remote accessibility and dynamical updateability).
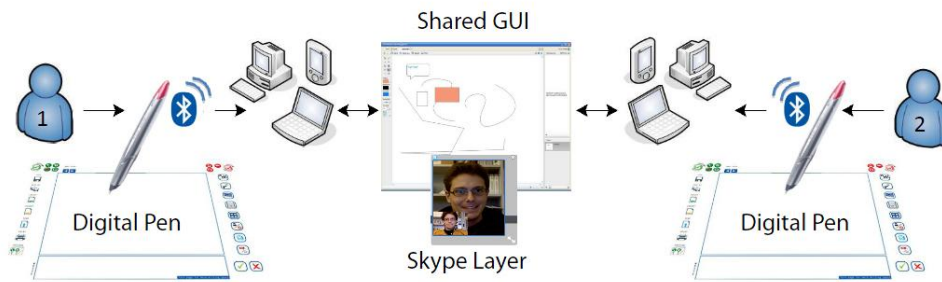
Figure 13. Scenario of use: PaperSketch by Weibel et al. (2011, p. 5).

2.4.1   Reviewing the Related Research

Replace Physical Environment. In order to support the phases of exploration and idea externalization the researches of the related work mainly applied stylus-based pen modalities e.g. the handheld devices (Zurita et al. 2008; Hailpern et al., 2007) or the electronic whiteboards (Mangano et al., 2010). Vyas (2009) inferred that designers principally use both horizontal and vertical workplaces (a "live surface") for conducting rapid collaborative idea generation. Accordingly the researchers of the related work replicated these surfaces with digital and interactive walls in order to mimic those real-world scenarios.

Disregard Social Factors. Resuming the social factors that inhibit creativity, they "weren't considered in-depth by the related research. For example Hailpern et al. (2007) referred only marginally to production blocking, evaluation apprehension and free riding whereas the other authors completely disregarded those phenomenons". (Budzinski, 2011a, p. 17)

Imprecise Research Focus. The related work "that have been presented here had principally focused on creating a tool which improves creativity, collaboration and supports the whole design process e.g. 'TEAM STORM' by Hailpern et al. (2007) or 'MCSketcher' by Zurita et al. (2008). Although drawing and sketching has been considered as an inherent part of the related research, the activity 'sketching' in principle however wasn't exactly defined which led to a plethora of functions" the computer tool has to provide (Budzinski, 2011a, p. 17). The related work also didn't take the role of the moderation into consideration.

Thus, this master thesis research restricts the matter of investigation by using a sketching activity with a precise workflow, which also allows for integrating a facilitator (in contrast to the related work). It is assumed that a rule-based sketching activity can be fundamentally supported with computer technology, as a defined procedure allows for customizing system features exactly on issues and tasks. Therefore, an appropriated sketching technique has been chosen for this

master thesis research that is called *brainsketching*. This design technique has been developed by Remko van der Lugt (2002a) and will be briefly introduced in the following section.

2.5   Brainsketching: A rule-based creative problem solving process

Brainsketching is a collaborative design method applied for refining first design solutions in the early design process by a group (as illustrated in Figure 1). It is generally practiced with pen and paper collectively on a shared vertical or horizontal surface, for instance on table or on a whiteboard. Brainsketching enhances traditional drawing activities due to the fact that annotations can be added such as texts, comments or other information that help to clarify or elaborate the sketch. For this section, the researches of van der Lugt (2002a; 2002b; and 2005) have been taken into account for providing insights into this technique. Thereby, he practiced this method with the utilization of a professional facilitator.

2.5.1   Practicing Brainsketching

The brainsketching activity, according to van der Lugt (2002a), encompasses four phases the participants have to work through (see Figure 14). However, van der Lugt (2002a) didn't specify an exact number of participants:

- *"Phase 1 – Creating.* Each group member individually sketches ideas, e.g. on sheets of papers, on flipcharts etc.
- *Phase 2 – Sharing and Continuing of Sketching*. After a few minutes, the team members pass the sheets of paper to other team members, e.g. by rotating clockwise; by changing their location on the occasion of drawing on flipcharts; by gathering all ideas at one place whereby each participant can freely chose a sketch. The ideas, created by others actually serve as a source of inspiration. New emerging ideas or annotations can be either build upon the ideas of others (adaption) or can be drawn on new sheets. This phase should be carried out at least more than once. Between each round of shifting, the participants should briefly discuss their ideas.
- *Phase 3 - Gathering and Presenting*. After a few rounds, the produced sheets are to be gathered (attached on a surface, whiteboard etc.) and presented, in order to facilitate an understanding of each other's sketches. The presentation of each sketch (either by a facilitator or by the participants) may lead to new ideas; and if so, the next step would be the creating

phase again for idea creation, re-interpretation or refinement. A facilitator (if existent) emphasizes on the re-interpretation of other ideas between each round. The sketches, collected on the public surface additionally serve as inspiration.

- *Phase 4 – Rating.* Each sketch is to be rated according to its relevance, e.g. by means of markers. Those sketches with the highest score can be utilized in further modeling techniques (embedding the sketched ideas into a story-board, creating prototypes of clay, or creating a low-fidelity UI according to the most important sketches)" (Budzinski, 2011a, p. 18).
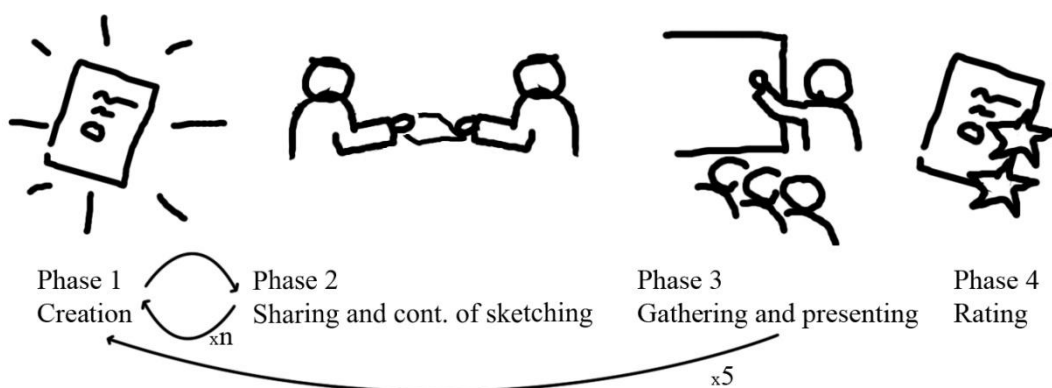
Figure 14. The four phases of brainsketching according to van der Lugt (2002a).

The Characteristic of Brainsketching. To point out the drawbacks and strengths of this designing methodology, van der Lugt (2002a; 2002b; 2005) studied and compared the processes of both brainsketching and brainstorming with four experimental meetings and with 20 skilled product designers. Each session has been moderated by a professional moderator and the participant hat to handle the objective: "How to make travelling by car fun for children?" (van der Lugt 2002a, p. 46). Therefore, van der Lugt (2002a; 2002b; 2005) analyzed brainsketching and brainstorming with *linkography* in order to give evidence of how design artifacts are build upon and relate to each other.

As a result, van der Lugt (2002a) pointed out that brainsketching is more suitable for idea refinement (*idea development* (van der Lugt, 2002a, p.47)) then for massive idea creation (*idea differentiation* (van der Lugt, 2002a, p. 47)). Moreover, the participants were also inspired by previous generated ideas that have been attached to a shared surface e.g. to a whiteboard (in phase 3). Accordingly, within brainsketching, the participants rather build upon their own ideas as they do in brainstorming (higher self-link index & less inter-personal links (van der Lugt (2002a)), which also indicates that the designers significantly less built upon the ideas of others in some way (Budzinski, 2011b).

Early Fixation. Additionally, van der Lugt (2002a) points out one more issue, particularly for brainsketching, which has to be taken into account especially when unskilled participants are engaged within the creative meeting. Van der Lugt (2002a) noted that untrained participants tend to fixate on the very first ideas, even considering brainsketching's rotational-based distribution idea. These ideas are like a frame, which restricts orientation and modification. But working with previous ideas actually should inspire the participants to create ideas towards completely new directions or to elaborate the problem in different ways. Van der Lugt (2002a) suggests two possible motivations for early fixation:

1) Setting up a novel idea requires more effort rather than modifying an earlier sketch.
2) Participants with no design background tend to judge each other's ideas instead of reflecting on them.

The author concludes that participants should rather interpret the sketches reasonably in order to obtain new thoughts and he emphasizes three rules that have to be taken into account for approaching the effect of early fixation when applying brainsketching with untrained persons.

1. First of all, a group should start with a "Paper warming-up activity" (van der Lugt, 2002a, p. 53), to reduce the apprehension of drawing and sketching of thoughts. This activity also confirms writing (words), if a participant is not able to communicate his idea by drawing.
2. "Emphasizing interpretation and exploration of ideas, rather than evaluation of ideas" (van der Lugt, 2002a, p. 53). This means the participants should disregard the quality of the sketches (e.g. well drawn sketches by a skilled person), and they should rather ask, how to explore and to modify ideas in order to gain new meanings. A crucial rule of thumb hereby is that participants shouldn't evaluate their own sketches or the sketches of others in a critical manner.
3. "Invite making new drawings, rather than drawing on the existing one" (van der Lugt, 2002a, p. 53), is a rule that adds weight to generating new sketches and thus confirms the distinction of ideas (without creating replicas). In contrast to sketch creation, van der Lugt (2002a) mentions that adding features to existent sketches fosters the development of ideas in terms of refining them.

Thereby, it is assumed to engage a professional facilitator during the design process, who can a) provide creative guidance, b) contributes to minimize the negative social factors and c) encourages the creative workers to generate more novel ideas.

2.6   Concluding the Analysis

The reason for this thesis chapter was to analyze the characteristics of collaborative design sessions. This analysis began with an exploration of the design practices in order to give an understanding of how professional designers work in their physical environment (Vyas, 2009; Vyas et al., 2009).

Pen and Paper. Vyas et al. (2009) inferred important inter-personal interactions such as idea exploration, idea illustration and idea communication ("externalization") and they reported that the environment is directly engaged into the design process. According to the findings of Cook and Bailey (2005) and Weibel et al. (2011), professional designers appreciate to work with ordinary pen and paper in the early stage of design. Thus, the "first conclusion is that a computer tool must preserve the affordances that pen and paper have in order to meet the needs of creative workers (Cook & Bailey, 2005; Weibel et al., 2011)" (Budzinski, 2011a, p. 21).

Reality-Based Environment. Vyas et al. (2009) further revealed that the designers often use the surroundings in order to collect, manage and elaborate the design artifacts. It is assumed that replicating this physical surfaces with digital interactive displays, using multi-touch devices or tangible user interfaces, allows for direct and easy access to the digital objects with naturally touch and finger gestures. Subsequently, the "second conclusion is that more reality-based technology […] is to be taken into account in order to implement the creative workspace" (Budzinski, 2011a, p. 21).

Social Factors. The authors Diehle & Stroebe (1990) and Warr & O'Neill (2005) highlighted "less effectiveness of group work compared with single performance due to the fact that thoughts, feelings and creativity are affected by social influences of other people. These crucial factors however haven't been explicitly considered in-depth by the related work" (Budzinski, 2011a, p. 21). Therefore, the third conclusion is that the social inhibitors of group work strongly have to be addressed.

Brainsketching. In contrast to the related research, it is assumed that applying digital tools to and customizing interaction models for a defined and ruled-based sketching workflow may increase the overall effectiveness of the session. Hence, the fourth conclusion for this master thesis research is to apply computer support to a phase-structured sketching activity (brainsketching).

By taking these conclusions into consideration for the design of the digital tool, it is suggested that the system is likely to provide a balance between power and

reality and will thus meet to the needs of the participants and the session moderator within brainsketching (adding power without reducing features of reality (Jacob et al., 2007), see Figure 2). Consequently, this leads to the following two research questions:

> *RQ1: Does the integration of reality-based computer devices – designed with respect to the social influences - enable additional functionality for the participants but preserve the basic workflow of brainsketching and embodied practice at the same time?*

> *RQ2: How does the integration of the reality-based computer devices – designed with respect to the social influences - affect the moderation of brainsketching sessions?*

Therefore, the following chapter of the master thesis research accordingly will focus on those research questions by exploring possible interaction concepts and digital solutions, customized for augmenting embodied practice by means of reality-based   computer   support   when   practicing   brainsketching[9].

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[9] Some parts of this chapter have been described in greater detail in the Masters Seminar (Budzinski, 2011a) and were being summarized and modified.

3 Design: Computational Support for Brainsketching

This chapter considers the design of the digital tool by means of a "top-down" approach. Therefore, it begins with a brief introduction of the final workspace-setting in order to offer an overview of the way in which the tool is being applied and how the tool actually works, followed by a detailed description of the design criteria and their conceptual development. These criteria are well-founded on literal and on observational investigations with respect to two different user roles - the creative workers and the moderator.

3.1   An Overview of the Digital Design Environment

Figure 15 illustrates the final workspace-setting for both the creative workers that generate ideas (on the left-hand side) and for a facilitator who can rapidly shift the focus from his analytical tool to the group and vice versa (on the right-hand side as illustrated in Figure 15a). Therefore the interactive display, meaning the digital tool for the facilitator, is located near the group workspace (see Figure 15b). This digital tool is programmed to record and to represent the drawn information of the creative workers by means of an interactive tree-visualization, which supports the value of analysis. With it, the facilitator is able to browse through the design space in order to detect design-fixations according to van der Lugt (2002a), and he or she is able to detect the contributions of every creative worker (e.g. *who is doing what*) for identifying free riders (Diehl & Stroebe, 1990). The display is turned to the back side so that the participants can't view their recorded data from the session, since this would probably cause evaluation apprehensions and may distract the participants from accomplishing their tasks. The features of the facilitator's tool are described in section 3.3 (p. 33).

The workspace of the creative workers, in contrast to the workspace of the facilitator, consists of a traditional table for preserving embodied practice of

ideation (Figure 15, table); it consists also of a vertical non-interactive display, which offers support for dynamic design-visualizations and hence facilitates the value of presentation (see Figure 15c). Moreover, there is also a printer available so that the designers are able to duplicate sketches (Figure 15d). Thereby, working with duplicates should encourage the creative workers in reusing and extending sketches more carelessly. In doing so, digital pens are applied that allow for live digitalization of the design information and for augmenting the physical paper-artifacts with computer buttons (by means of colored areas on the paper itself (see close-up Figure 15e)). The computational support for the creative workers is considered in section 3.4 (p. 43).

Consequently, the following sub-sections give insights into the conceptual development of this digital tool and its functionalities, beginning with the needs when dealing with social creativity in general (next sub-section 3.2 (p.28)).
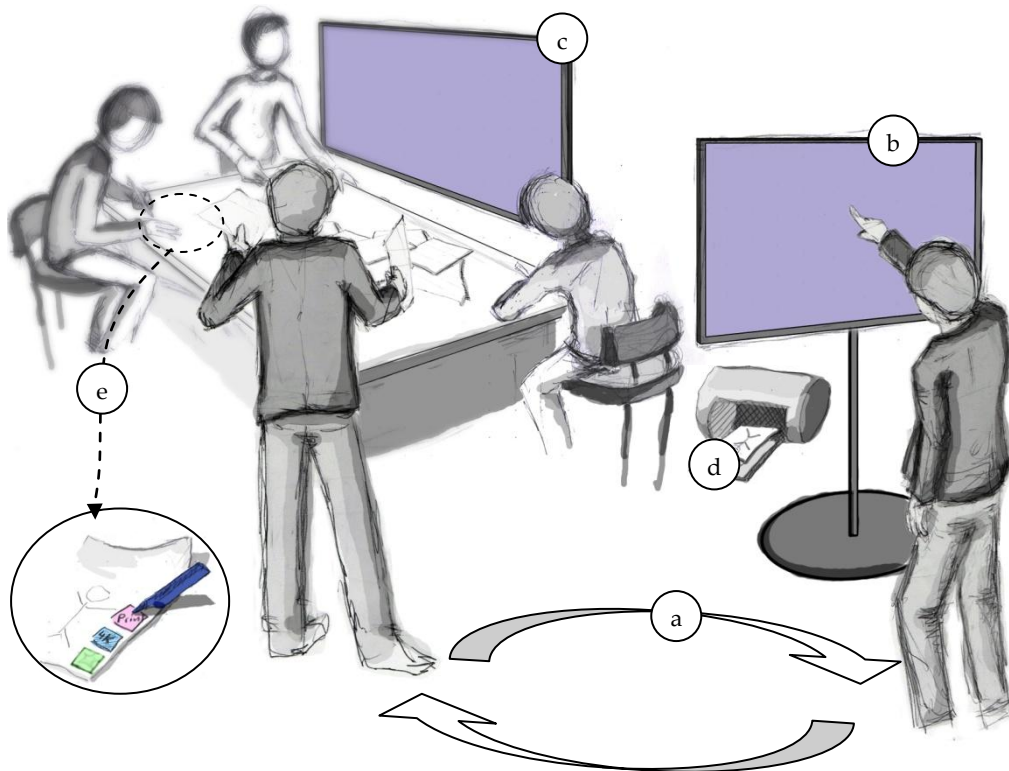
Figure 15. The basic layout of the brainsketching sessions enhanced with the reality-based computer devices.

3.2 The Role of the Social Communication for the Digital Workspace

When investigating the related research, one can identify limitations and issues

of collaboration and of creativity and consider them as aspects that may benefit from digital solutions. This encompasses the *social influences* (Diehl & Stroebe, 1990; Warr & O'Neill, 2005) e.g. *production blocking, evaluation apprehension* and *free riding* and the *early fixation* phenomenon, mentioned by van der Lugt (2002a). Nevertheless, before employing technology, the researchers Warr & O'Neill (2005) made suggestions that a wisely chosen design technique itself can also contribute to minimize these inhibitors of creativeness. So viewing brainsketching through the lens of their conclusions, this design technique also partly helps to overcome the productivity loss, caused through the negative social influences, as visual or verbal idea communication (writing, drawing, talking), and idea distribution takes place simultaneously. Moreover, drawing upon the claims of van der Lugt (2002a), fixation-effects or the presence of free riders can be addressed by means of a creativity facilitator, who emphasizes evaluation and encourages the motivation of the creative workers as well (Table 2).

Although expressing and organizing ideas this way approaches these aspects of social communication in some way, there are assumptions indicating that supporting the creative workers and the moderation with digital means would make this social creative process more effective (using computer power, Jacob et al., 2007). Subsequently, for bringing insights into how this digital workspace should appear, the above-mentioned *four issues* of social creativity are to be considered as the basic needs for the system's design. In the following, suggestions are made of how those issues are to be supported by technology (see also overview, Table 3).

Issue1 - Production Blocking. The primary workflow of brainsketching should not be changed in order to prevent – in particular - *production blocking* when applying computer technology, meaning that the access to and the work with traditional media are to be preserved (therefore reality-based devices are to be employed (Jacob et al., 2007)) (see Table 3, Production Blocking).

Issue 2 - Evaluation Apprehension. This behavior was studied on the basis of brainstorming-similar techniques, wherein people primarily write their ideas on separated notes. However, the notion of brainsketching poses a new interpretation of evaluation apprehension in the context of sketching, as sketches (in contrast to brainstorming) are frequently passed to other group-members. This may increase the apprehension to draw irreversible changes on somebody other's design artifact, especially when unskilled persons with inhibitors are participating (van der Lugt, 2002a). As a result, this confirms the assumption of a *modification apprehension* as a proper sub-category of evaluation apprehension. Therefore, it is thought that digitalizing design artifacts and enabling participants to work with sketch duplicates, if needed, can contribute to bypass the fear of

making irreversible modifications and fosters a more carelessly reuse of the ideas (see Table 3, Evaluation Apprehension).

Free Riding. The phases within brainsketching where the creative workers present their generated sketches and solutions enable idea reflection but helps also participants to identify poor performance of other team members (this lessens social loafing). However, it is suggested that involving a professional facilitator into the design process may impede the effect of *free riding* in a more confident manner, as a moderator can motivate participants to idea contribution. A computer system can improve this moderation task by coloring the strokes of a digitalized sketch with respect to its creators (similar to Linsey et al. (2005) using colored pens). This visualizes the productivity of every participant to the facilitator, who can react on poor performance (Table 3, Free Riding).

Early Fixation. An idea fixation generally hinders participants from exploring novel solutions. Therefore, van der Lugt (2002a) emphasizes warm up-activities or he advises that participants should interpret and explore instead of critically evaluating ideas. In addition to that, computational power can provide an appropriated illustration of the productivity of the entire design-session that my help a session integrated moderator to detect *early fixations* and enables him or her to emphasize sketches of interest for refinement (see Table 3, Early Fixation).

As a result, these four issues and their approaches are illustrated in Table 3 (here, Table 3 complements Table 2). It is suggested that those digital improvements help to decrease the impact of the social factors, help to prevent from early fixations and help to foster a better integration of each participant into the design process. Thereby, it is assumed that *issue 1* and *issue 2* mostly relate to the creative workers whereas *issue 3* and *issue 4* rather relate to the facilitator. Subsequently, the next section presents the digital support for the *creative workers* (facing *issue 1* and *issue 2*), followed by the section with a detailed description of the features that affect how the *facilitator* is to be supported (facing *issue 3* and *issue 4*).

Table 2. Overview of how brainsketching may be helpful for overcoming the inhibitors of group work (table similar to Budzinski (2011a, p. 22))

Issue	Warr & O'Neill (2005), Linsey et al. (2005)			Van der Lugt (2002a)
	Production Blocking	Evaluation Apprehension	Free Riding	Early Fixation
Approaches by the Literature to Address those Issues	Using **synchronous communication** Using "interaction techniques for expressing ideas, such as **writing** ideas and **distributing** them around the members of the group" (Warr & O'Neill, 2005 p. 124)	**Reducing** identification Annotating (writing or drawing) ideas instead of articulating them also **anonymizes** and reduces identification	**Increasing** identification Providing **feedback assessing** each individual call upon **responsibility**	"**warming-up** activity" "Emphasizing **interpretation** and **exploration** of Ideas" "Invite making **new drawings**" (p. 53)
Contributions by the Brainsketching Activity	• Facilitates synchronous idea communication between phase 1 and phase 2 (participants can talk to each other) • Facilitates idea writing and drawing in phase 1 • Facilitates idea distribution in phase 2	• Phases 1 facilitates annotation and sketching what lessens identification	• Activity provides feedback and assessment of each individual between phase 1 and phase 2, since the participants can talk to each other • Increases identification • Integration of a facilitator who can give feedback and who call upon responsibility	• Activity must be guided according to the above-mentioned points by means of a facilitator

Table 3. Overview of the issues and the corresponding approaches. The goal is to support the creative workers by addressing the social influences; and to support the facilitator by providing a solution for detecting early fixation (source of table, Budzinski (2011b, p. 8)).

	Warr & O'Neill (2005), Linsey et al. (2005)			Van der Lugt (2002a)
Issue	Production Blocking	Evaluation Apprehension	Free Riding	Early Fixation
Approaches by the Literature to Address those Issues	Using **synchronous communication** Using "interaction techniques for expressing ideas, such as **writing** ideas and **distributing** them around the members of the group" (Warr & O'Neill, 2005 p.124)	**Reducing** identification Annotating (writing or drawing) ideas instead of articulating them also **anonymizes** and reduces identification	**Increasing** identification Providing **feedback assessing** each individual call upon **responsibility**	"**warming-up** activity" "Emphasizing **interpretation** and **exploration** of Ideas" "Invite making **new drawings"** (p. 53)
Contributions by the Brainsketching Activity	Theoretically addressed by the design technique	Almost addressed by the design technique, since verbal articulation fosters apprehensions	Almost addressable by integrating a facilitator who guides the process by means of the above mentioned aspects	Theoretically addressable by integrating a facilitator
Possible Improvements	**Designing the system according to the RBI paradigm** Preserving the affordances of idea writing, drawing and the nature of creative group work on vertical / horizontal design surfaces	**Digitalizing Ideas** Working with digital copies may reduce inhibitors to draw on other's sketches. This also eases the reuse of a sketch.	**Tracking & Illustrating** Tracking the pen ID and illustrating the person-related contributions. This feature enables the facilitator to identify the productivity of each person	**Illustrating the Idea generation and the productivity of the entire design-session** This feature enables the facilitator to detect fixations (early fixations). This function is also usable for highlighting sketches of interest (for further refinement)

3.3   Digital Support for the Creative Workers

Referring once more to the needs from the latter section, it is clear that they highlight two crucial issues that have to be taken into account for supporting the creative workers within the brainsketching activity. Therefore, any applied technology should not force the creative workers to change their basic design workflow in order to address production blocking (*Issue 1*), and it is suggested that there is a need for idea replication, in order to facilitate the reuse of a sketch and to prevent possible modification apprehensions (*Issue 2*). Thus, the next step is to conduct an observational study of students who apply brainsketching in order to get an understanding of the participant's experiences and the ways in which they work in reality (physical practice). The findings of this explorative observation will then be linked to the initial issues (production blocking, evaluation apprehension) for pointing out how those issues are to be implemented concretely.

3.3.1   User Observation for Investigating Physical Practice

There were four groups of undergraduate as well as graduate students observed within a brainsketching meeting in the context of an HCI course - *Usability Engineering Design* - at the University of Konstanz in summer 2010. The groups consisted of between four and six persons ($N = 15$) and no facilitator was involved. A bulletin board as well as colored pens and sheets (A4 sized) were supplied and the design task included the creation of an information and entertainment system for the car. This course-project was in cooperation with the research center of a German car company (VW), meaning that the participants were highly motivated. The participants were introduced into the design technique (brainsketching) through the course lecturer and they studied the technique a week before with the help of the brainsketching articles by van der Lugt (2002a). This brainsketching process was applied on top of affinity diagramming[10], which had been conducted in the week before by the same students. This means that the brainsketching activity was used to refine the creative output of the affinity diagramming and the output was collected and attached to a bulletin-board, allocated near the group's workspace (workspace illustrated in Figure 16). Overall, the brainsketching sessions lasted for about 1.5 hours and have been videotaped. The videotapes were then analyzed in an explorative way, with paying particular attention to the main activities *ideation*,

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[10] A brainstorming-like design technique, mentioned to generate and cluster a large amount of ideas with post-its. See also the related work of Geyer et al. (2011).

distribution, *communication*, and *rating*, with foci on distinctive phenomenon in order to get an impression of the basic tasks and issues when practicing brainsketching.

Figure 16. Collaborative brainsketching session, conducted during a HCI course at the University of Konstanz.

3.3.2   Observing the Design Environment

Based on the analysis, the students created personal workspaces intended for individual information preparation and information management e.g. they used the table throughout the entire brainsketching session mainly as place for individual idea creation (see Figure 17, left), idea browsing (see Figure 17, right), group-based idea reflection and idea discussion. This finding is in line with the results reported by Vyas et al. (2009) and Vyas (2009). They revealed that vertical surfaces are a means for coordinating the work within the creative context (by creating *personal surfaces* as well as *live surfaces*, see section 2.1.2). This conclusion also confirms the findings revealed by Geyer et al. (2011) who applied affinity diagramming and conducted a behavioral user-study with interaction design students. In doing so, the observed students "primarily worked in individual workspaces on the table" as well as "each participant spent on average 60% of the time creating content and 56% on sorting notes within an individual workspace on the table" (Geyer et al. 2011, p. 168 (4)).

- *Implication 1 – Table as Workspace*: The participants extensively used the table as tool for idea externalization and organization. Thus, the first design decision is to keep an ordinary table still as physical workspace (in other words, there is no reason for replicating the table with a horizontal digital workspace e.g. a Microsoft Surface).

Figure 17. Ideation (left) and Idea management (right) within personal spaces.

3.3.3 Observing the User Behavior within Idea Distribution, Gathering and Presentation

The observed participants across the groups acted similarly while the idea distribution took place. They tended to *explain and present* the ideas immediately to *all* participants before they shared their design content with other team members (so as a result, they blurred phase 2 and phase 3). During distribution, the students shared their ideas by gathering the paper-artifacts at the center of the table in order to emphasize that these ideas could be used for further development (see Figure 18, right) and the other participants subsequently selected the interesting ideas. To conclude, the phases of distribution are performed by cumulating the ideas and they are constantly accompanied by discussions.

Within the idea discussion, the students extensively made use of deictic references like holding, folding and rotating the sketches, pointing with the finger on aspects of interest and making gestures for illustrating interactive contents (Figure 18, left). They mainly use also their body and skills as a means for supporting the idea communication and for controlling the attention of other team members (this in line with the findings of Vyas (2009)). However, limitations of visual access were identified as the participants often blocked the group member's view of their paper-artifact, so that bystanders in particular couldn't see anything of the sketch. "This probably inhibits visual communication and may reduce the understanding of important design aspects as well" (Budzinski, 2011b, p. 10). Moreover, the participant didn't use the bulletin board for presentation.

- *Implication 2 – Group Display:* It is assumed that a digital display, applied into the design process, likely supports the value of presentation (equal

visual access) and allows for dynamic visualizations. For instance, this display could be used for collecting digitalized virtual sketches (replicating the bulletin board) and it could be used for highlighting virtual sketches for discussion (by increasing the size).

- *Implication 3 - Digital Pen and Paper:* Using digital pens allows for digitalizing and recording the drawn information, similar to Weibel et al. (2011) and enables also the definition of interactive fields and computer functions on the paper itself (e.g. a function for sending this sketch to the display).
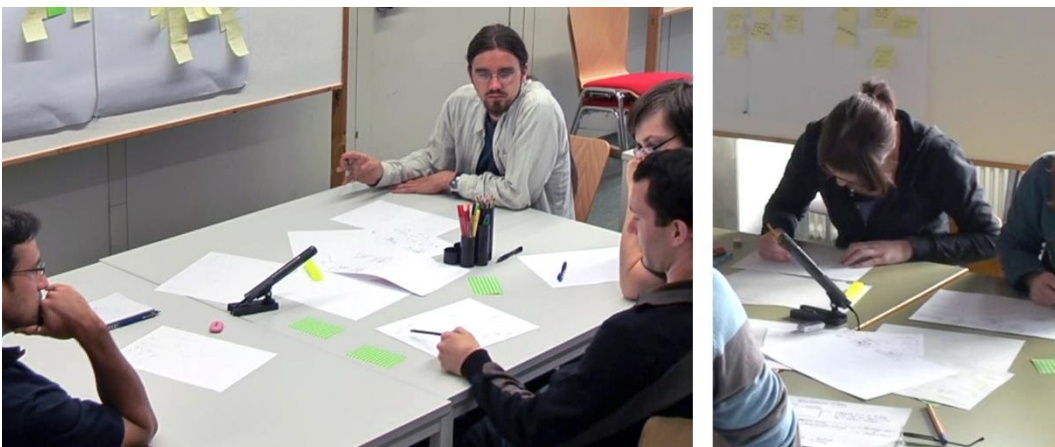
Figure 18. Participants often used deictic references (left) and they collected their output at the table's centre (right).

3.3.4   Observing the Rating-Activity

At the end of the brainsketching session the participants had to rate the ideas by means of ordinary green glue spots. In doing so, the participants generally *comment on* their *decisions* at the moment of rating for making their judgment comprehensible to all team members. One student said for instance: "*I like the 'joy of use and interoperability' idea*" and put a green glue spot onto the sketch. Thereby, the phases of rating mainly took place on the table across all observed groups (see Figure 19). Afterwards, the group attached the sketches with the most glue spots to the bulletin board in order to apply these ideas to later design stages.

- *Implication 4 – Idea Differentiation*: In order to improve the visibility of high relevant design information amongst all displayed ideas at the display, the ideas with the most ratings should behave accordingly e.g. by *size* or by *virtual glue spots*.

Figure 19. The participants use mainly the table for idea rating.

Summarizing the decisions derived from the analysis and viewing them through the lens of "the power vs. the reality tradeoff" (the RBI paradigm), the design *implication 1* (*Table as Workspace*) strives mainly to preserve the basic affordances of reality without adding computational power to the group work.

Implication 2 (*Group Display*) replicates a physical medium and helps to enrich the design process with dynamic visualizations for enhancing equal visual access of the design artifacts. This feature is not possible in reality and adds power to the interface.

Implication 3 (*Digital Pen and Paper*) strives for integrating digital features into the group work without losing the affordances of paper in design practice by adding interactive fields to the paper-artifact. This feature preserves reality but enables power at the same time.

Regarding *implication 4* (*Idea Differentiation*), it eases the differentiation amongst relevant artifacts and hence adds power to the interface in a way which is also not possible in reality. Those implications are applied as criteria (in addition to the social factors) for designing the workspace and the features of the digital tool (see Figure 20).
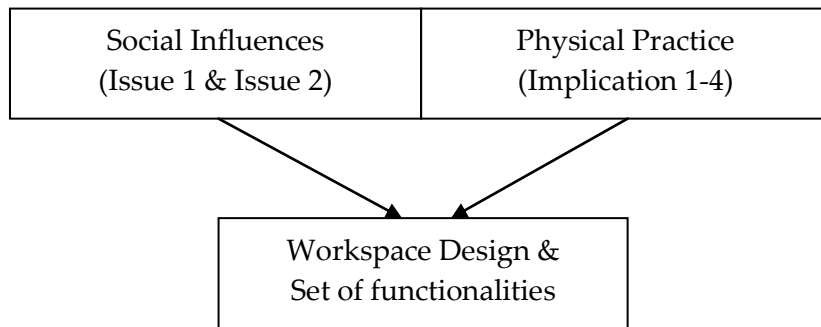
Figure 20. The workspace and the functionalities for the creative workers are grounded in the theory of social influences and in physical practice.

3.3.5   Workspace Design for the Creative Workers
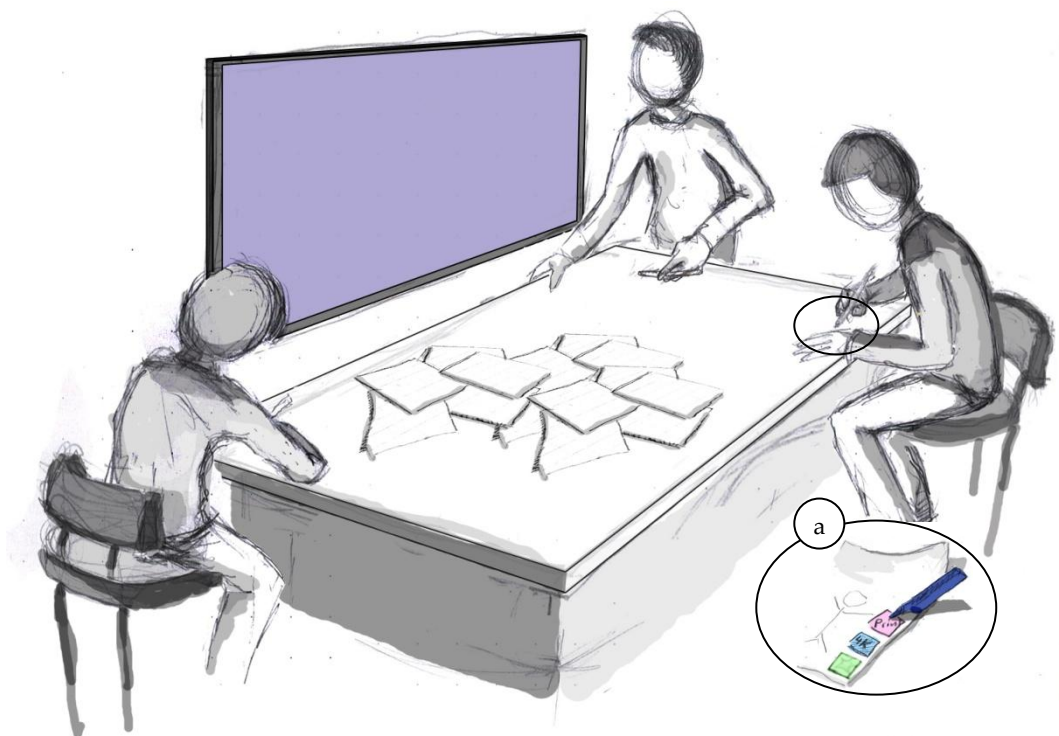
Figure 21. The final workspace-setting for the creative workers.

With regards to the design implications 1 and 3, the participant's final workspace consists of an ordinary table and the creative workers still utilize traditional paper for informal design activities (Figure 21). By using digital pens, this allows for augmenting the creative process with technology for the very first time, since the drawn information becomes digitalized and hence accessible for a computer. However, the paper-artifacts contain pre-printed areas with the purpose to

illustrate the human-computer interface by means of interactive fields (fields appear as computer buttons, see Figure 21a), and the digital pen slightly differs from an ordinary pen in terms of the surface and its physical characteristics (e.g. thickness, state-light). In order to execute functions, the creative workers have to draw a single dot (at least) in one of these areas, meaning that using pen and paper as a digital interface should minimize cognitive load and should ease the use of the computer-functions accordingly (a paper-based interaction technique).

Regarding implication 2, the workspace is supplemented with a digital surface for facilitating an overview of all generated (and recorded) sketches and thus fosters inspiration and creativity, since every idea can be mapped onto the vertical surface (Figure 22, left). Furthermore, this digital vertical surface also supports the idea communication by providing easily visual access to the idea for bystanders. At the same time, the presenters can still use (as preferred) the paper artifact with their hands and fingers for mediating their thoughts and for supporting argumentation. (Figure 22, right).
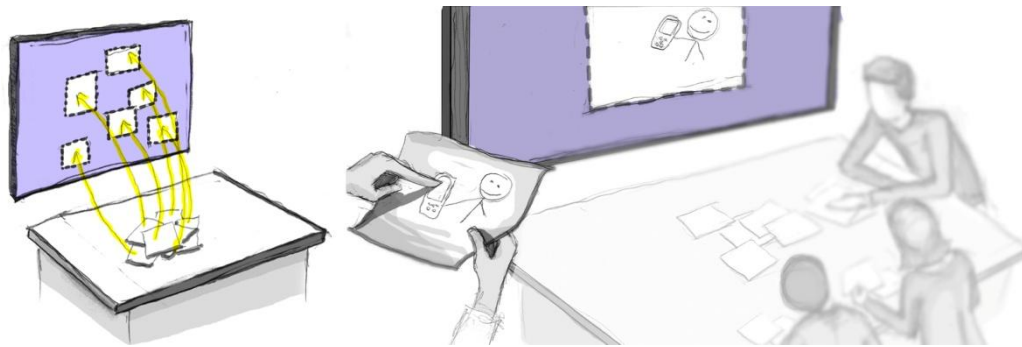
Figure 22. Image to the left: The underlying idea is that each sketch gets digitally mapped to the display for providing a better overview of all generated design artifacts. Image to the right: The underlying idea is to support the communication within the session by the display. The presenter, in this example, points unconsciously on the mobile phone while he emphasizes a special feature on the base of the physical sketch. The other creative workers with impaired visibility to the sketch can however consider the idea at the peripheral display and can thus better follow the discussion.

Based on the workspace setting and the paper-based interaction technique, additional functionalities can be designed that augment the basic workflow of ideation, idea communication and idea rating. Therefore, functions for *idea replication,* for *idea highlighting* and for *idea rating* have been integrated.

3.3.6   Idea Replication

As reported in section 3.2 (p. 28), there is an identified issue that impedes the social creativity, namely evaluation apprehension. It is assumed, that a fear of making irreversible modifications emerges in the context of sketching as a sub-

kind of evaluation apprehension. This possible fear has been termed as *modification apprehension* for this master thesis research. It is thus suggested, that if the creative workers are able to duplicate ideas, this eases the reuse of the sketch and should all in all prevent such modification apprehensions.

In doing so, if a person wants to duplicate, he or she can send the sketch to the printer by drawing (e.g. a dot) into the interactive area as demonstrated by Figure 23.
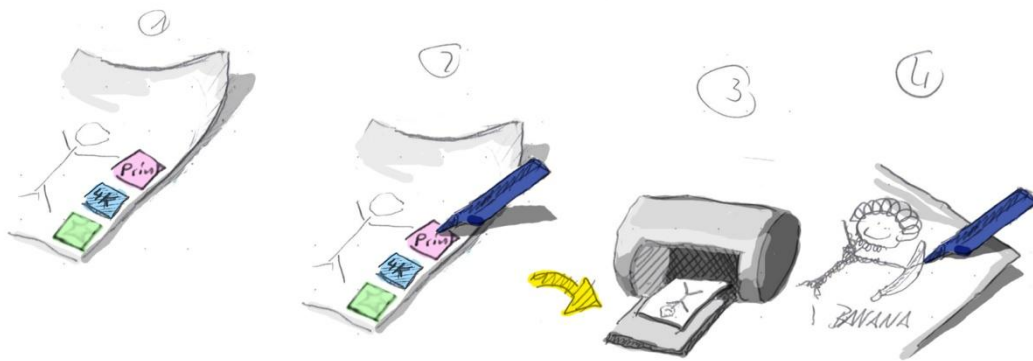
Figure 23. The Process of a print job. The paper has an interactive area for providing a quick replication of the corresponding sketch. In this scenario, the creative worker modifies and supplements the desired sketch by changing the person to an ape. However, the source of this idea remains unaffected.

Although interacting with a computer-system requires visual, physical (vibration) or auditory system-reaction for informing the user that his input was handled successfully, there is no direct system-feedback when the pen enters into the interactive area of the paper (besides noises the printer produce 20 seconds later due to the printing process). Thus, a printing-preview is to be provided at the peripheral display, in order to meet the need of a quick visual system-response (see Figure 24). As a result, if a participant draws into the interactive area of the printing-function, this automatically depicts a thumbnail of the to-be-printed page at the bottom of the display, in order to inform the user about the received printing action. The user then has to wait, until the printing job is finally completed.
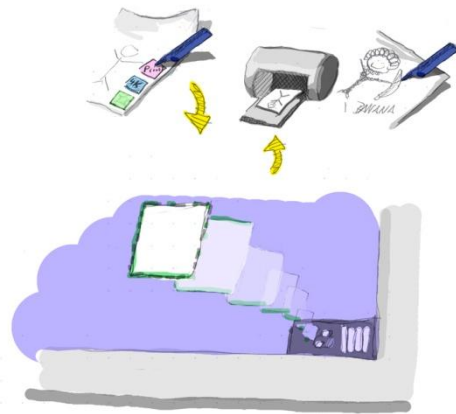
Figure 24. The peripheral display is also used for providing rapid visual system-feedback, in order to inform the user that the print job has been successfully received

3.3.7   Idea Highlighting

Within phases of discussion, the creative workers can highlight a sketch, using the display, for supporting idea communication and for inspiring other team members. In doing so, the creative worker can send an idea (the stick figure) to the display by drawing with the digital pen a dot into the blue area on the paper (see Figure 25).
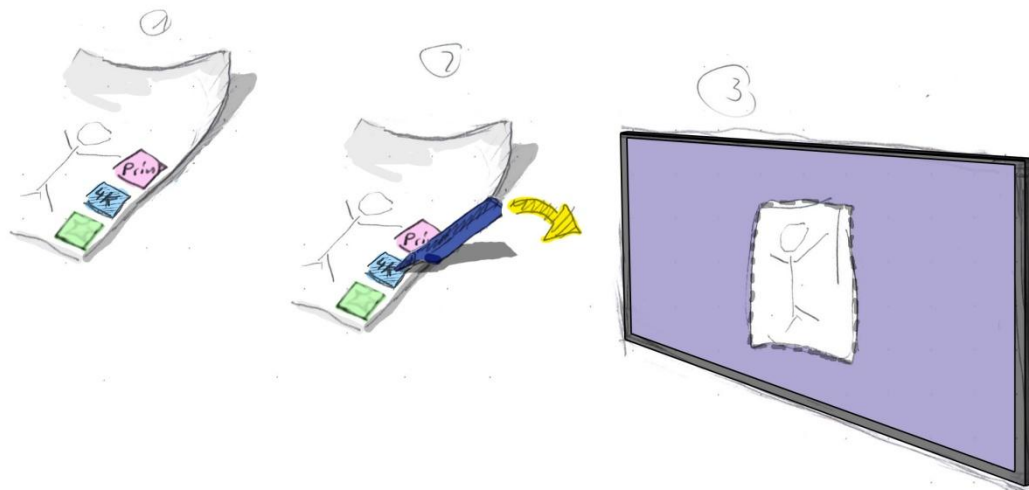
Figure 25. Interactive paper. The design artifact provides several functions, the creative worker can use. Here, the creative worker sends a sketch to the display.

Furthermore, an idea will remain on the display once it was sent to it. Subsequently, every sent sketch incrementally fills the available display-space with design information so that the display accordingly replicates a bulletin board and acts likewise as a surface for inspiration (see Figure 26).
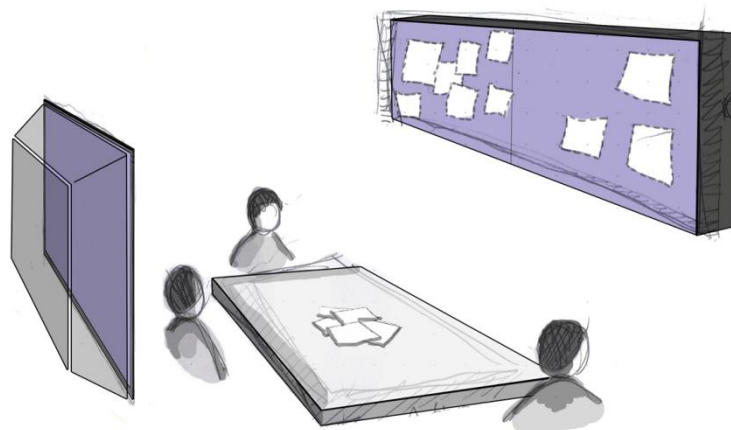
Figure 26. Every highlighted sketch remains on the display. This, the digital design environment serves as places for inspiration by replicating the bulletin board.

This highlighting functionality is an example of how technology (digital pen & paper and a peripheral display) can augment the phases of discussion as to the limitations of visual access.

3.3.8   Idea Rating

It is assumed that augmenting the rating-activity with computational power improves the visibility of high relevant design information at the digital surface (implication 4). However, it is a challenge to make the rating visible for both, the physical and the digital world: Reflecting upon the findings of the observational study in section 3.3.4 (p. 36), the participants mainly rated the design output on the table with green glue spots. But, putting glue spots on paper doesn't inform the computer-system that a creative worker has given a score to a sketch. Thus, an appropriate solution would be to do the rating also with help of the interactive area e.g. by drawing primitive geometries like a circle with a diameter of 1 cm, see Figure 27).
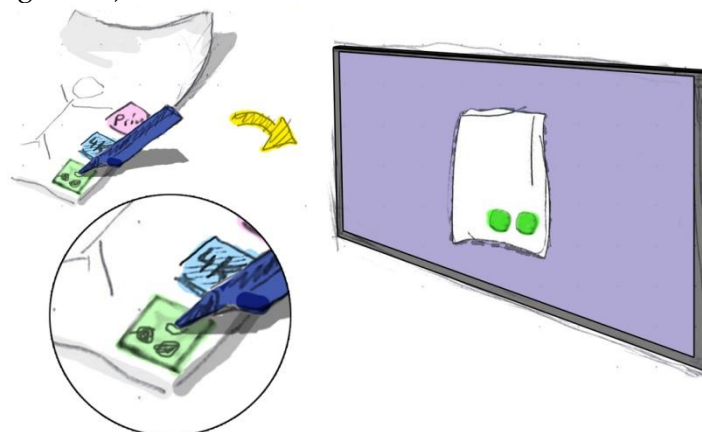
Figure 27. Rating a sketch with means of an interactive area.

By drawing a circle, this actually informs the system that a participant has increased the value of this sketch by one. The system can henceforth react with an appropriate visualization (e.g. adding a virtual green glue spot to the digital sketch) on the one hand. On the other hand, this small circle on the paper itself is immediately apparent to a person and indicates that this artifact has been rated (the drawn geometry replicates the green glue spots on the paper).

3.4   Digital Support for the Moderator

The last section presented digital solutions that both facilitate creative people within the main phases of brainsketching and fit to their physical and embodied practice e.g. the native ideation & idea communication by using physical tools (pen, paper, table). This section by contrast demonstrates computational power for supporting the value of moderation, as it is assumed that a moderator fundamentally approaches the last two issues: *Issue 3 -Free Riding*, which occurs when people become lazy during the session and don't participate to the idea generation meeting and *Issue 4 -Early Fixation*, which occurs when creative workers disregard other creative output. In order to overcome free riding the authors Warr & O'Neill (2005) argue that fostering "social stimulation" (p. 125) and "increasing accountability for individual performance" (p.125) likely encourages the motivation of the participants. Concerning early fixation, the facilitator should follow the rules that have been set by van der Lugt (2002a), in order to promote the group to reflect upon other ideas.

However, the way in which the tasks of a moderator can be computationally supported is yet unexplored. It is suggested that the digital tool could support the tasks of moderation by providing a set of analytically features. For instance recording and tracking the idea generation, and illustrating the productivity of the entire design-session enable the analysis of the person-related design contributions (*Issue 3 - Free Riding*) as well as the effectiveness of the group work, even the identification of design fixations (*Issue 4 - Early Fixations*). Thus, the next step is to clarify the capabilities and the limitations of the moderators' tool e.g. the functionality and the interaction techniques.

3.4.1   Inspiration for the Moderators' Tool by the EBS

For gaining inspiration in regards to how the moderator could be supported exactly, the related work of Valancich et al. (1994) has been taken into account, which provides insights into digital support for collaborative idea generation. In doing so, the authors presented the "Electronic Brainstorming System" (EBS), which helps to overcome "the productivity loss of interacting groups" (p. 452)

with respect to the negative influences of social communication (production blocking, evaluation apprehension, free riding).

Therefore, the authors conducted three experiments for comparing real groups with nominal groups[11]. As a result, Valancich et al. (1994) stated that "groups using a computer-based idea generation system outperformed equivalent nominal groups in idea-generation tasks" (p. 448) due to the "elimination" of production blocking. Thereby, the core concept of this system concentrates primarily on file sharing: "Each participant types a brief idea or comment in response to a theme question and then sends the file to a shared pool, getting in return another, randomly drawn file containing the theme question and any comments it may have already attracted. The participant appends a further comment, returns the file to the pool, receives another randomly drawn file and so on"[12] (p. 452).

Hence, the mechanism of the EBS principally receives, collects and distributes ideas randomly to the creative workers so that the management of the design information is realized fully machine-controlled (see Figure 28, left). However, the EBS eliminates inter-personal communication and synergy effects of groups (important benefit of group work, van der Lugt (2002a)), and this system also hardly replicates the role of a professional moderator. Nevertheless, the basic functionalities of the EBS could augment the workspace of a creativity facilitator in terms of idea organization and analysis. Subsequently, the facilitator who uses this tool is aware of each generated design content, this system enables reflection during divergent phases and the moderator can emphasize sketches that are to be further developed and by whom (see Figure 28, right).

Thus, the moderator's tool must provide three features: *receiving ideas*, *idea visualization* (for enabling awareness of the group-related productivity) and *returning ideas*.

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[11] Nominal groups: Pooled output of individuals that work alone; Real Groups: Pooled output of individuals that work collaboratively (Valancich et al., 1994).

[12] The students were placed around a two-tiered room arbitrarily (one tier for each group). Thereby, the "nominal group members had the same EBS like the real groups, however without the possibility to share files with others" (Budzinski, 2011b, p. 12).
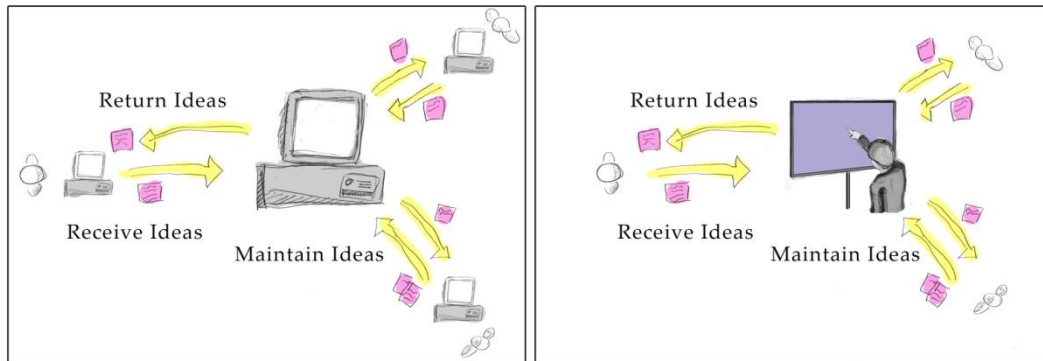
Figure 28. The EBS (left-hand side) is being replicated by a facilitator (right-hand side). This point out the basic functionalities of the moderator's tool: Receiving ideas from the group, pooling and displaying ideas and returning ideas back to the group.

Receiving Ideas. With the Electronic Brainstorming System, every participant has to send the idea to the system exclusively by keyboard input. Applying this procedure to the brainsketching activity, the participants would have to send every sketch to the moderator's system by using a function.

- *Implication 1 - Sending by Drawing*: Subsequently, a conclusion is to transfer a sketch to the moderator's system once the digital pen touched the paper. Thereby, "this process takes place simultaneously; contributes to the automation of the idea transmission; and it has no effect on the creative workflow, since the participants don't have to pay attention using this functionality" (Budzinski, 2011b, p. 13).

Design Visualization. A source of inspiration for visualizing the entire design process was offered by Buxton (2007), as he depicted the nature of design by means of a tree (Figure 29, left). He states that: "Design is about exploring and comparing the relative merits of alternatives. There is not just one path, and at any given time and for any given question, there may be numerous different alternatives being considered, only one of which will eventually find itself in the product" (Buxton, 2007, p. 388). Drawing upon Buxton's line of thought implies, that a tree enables the representation of "various alternatives that were explored in the process" (p. 387) with regard to the time. As a result, it is suggested that "the characteristics of this tree-view correlate with the development of a single idea, as brainsketching fosters circles of distribution and differentiation of thoughts" (Budzinski, 2011b, p. 14). Thus, by displaying and linking each modification of a sketch in form of a new node automatically, this depicts the *outgrowth* and the *evolution* of an idea in form of a tree.

However, the more effective the idea generation meeting, the more space for displaying outgrowing trees (ideas) is required. An approach for visualizing a large mount in parallel has been presented by Lamping et al. (1995). They

presented a manipulation technique, denoted as *hyperbolic browser*. This browser smoothly blends focus and content with the intention "for visualizing and manipulating large hierarchies" (Lamping et al., 1995). In doing so, they map each tree on a circular hyperbolic 2-d plane, which enables a context overview. This browser also offers a magnifier at the center of the hyperbolic space for creating a detailed view (see Figure 29, right). Accordingly, this layout augmented with a magnifying effect indicates a circular vanish-point perspective, "so that those nodes toward the center enlarge while the nodes toward the edge shrink until they completely fade off. Additionally, by using elementary manipulation techniques, e.g. by clicking on a node of interest or by dragging points of interest to a new position (using a computer mouse for instance or touch), this allows basic interaction styles for changing the focus of the tree-view according to the user's intention" (Budzinski, 2011b, p. 14).

- *Implication 2 - The Tree-View*: Having the ability to share ideas and to print copies, this allows for creating different variants of an idea in a yet unexplored way. Therewith, it is suggested that ideas grows similar to a tree: "the depth of the tree subsequently reveals the idea's degree of refinement and the width of the tree reveals how many different alternatives of the idea were being created already" (Budzinski, 2011b, p. 15).
- *Implication 3 - The Hyperbolic Tree Browser:* The hyperbolic plane - and all trees upon it - enables a visualization that scales live and with respect to dynamical growing data. Additionally, this plane transforms to the input of user by means of a dynamic distortion, so that those regions approaching "the center become magnified, while regions that were in the center shrink as they are moved toward the edge" (Lamping et al., 1995). As a consequence, "it is assumed, when applying the hyperbolic browser technique with its underlying concept of a circular, scalable and interactive visualization to the context of design, this may allow for awareness of the overall productivity and may contribute to identify design fixations" (Budzinski, 2011b, p. 15).
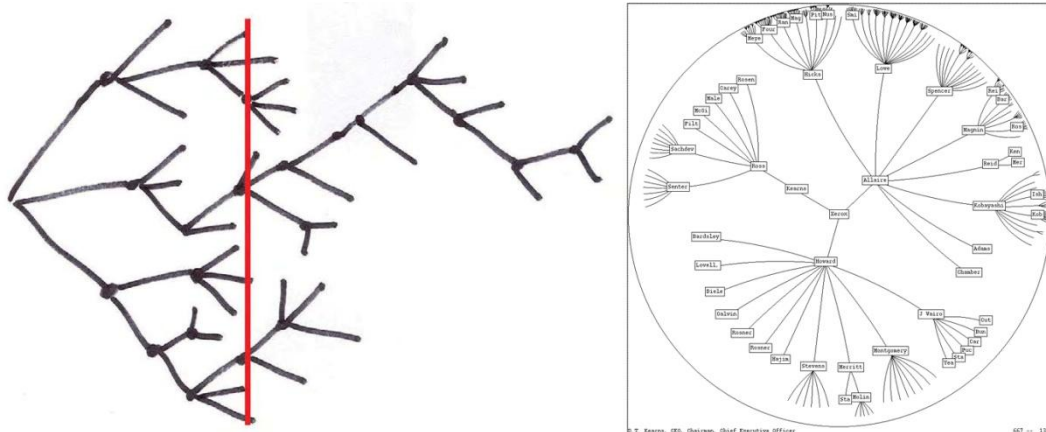
Figure 29. The figure to the left illustrates the explorative nature of design for comparing alternatives by Buxton (2007, p.388). The figure to the right displays the hyperbolic tree by Lamping et al. (1995).

Returning Ideas. This feature indicates that the virtual ideas, adjusted according to the hyperbolic distortion, get enriched with functionalities and makes them interactive. Subsequently, the facilitator can highlight interesting ideas at the groups display or he or she can combine and print out digital sketches for providing creative stimuli.

- *Implication 4 - Interactive Virtual Sketches*: It is a control mechanism required, in order to provide access to the design input, meaning that the facilitator can also work with the digital artifacts within his digital workspace (his display).

3.4.2   Inspiration for the Moderators' Tool from Participation in a Creativity Workshop

Up until now, the features of the moderator's tool have been literarily derived from Valancich et al. (1994). In addition to that, an informal participating observation of a creativity workshop was conducted at the Customer Research Centre, Daimler AG, in Böblingen. Thereby, the primary focus was put on the creative group work and on moderation practices as well[13]. Within this creativity workshop, multiple groups and multiple moderators participated, with one moderator per group. According to the observations, the moderators encouraged the motivation of the participants in idea generation by using different brainstorming-like and sketching-like techniques on the base of various types of media e.g. bulletin-boards, pens, markers, post-its and paper (A4 sized and

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[13] It was disallowed carrying recording equipment. Thus, the session could not be videotaped, besides some photos taken by the organizer of this creativity workshop (e.g. Figure 30).

greater). The environment was embedded into the design workflow, as participants partly worked individually on horizontal surfaces (e.g. tables, see Figure 30, left) as well as collaboratively on vertical social surfaces (e.g. bulletin-boards, whiteboards, see Figure 30, right). In addition to the visual communication, the moderators also led discussions in parallel in order to gain insights into the participant's design decisions and their opinions. As a result, the moderator plays a crucial role in mediating tasks, in promoting the group's performance and in organizing only relevant output, meaning that this finding highly confirms the aim to develop digital support for the moderation of creative tasks.

In return, one moderator[14] visited the HCI Group in Konstanz with the intention to shape the interaction concepts for the digital moderator tool. In the context of his visiting he received an introduction to the system, including the computational support for the creative workers as well as the above-named set of functions for the moderator. Generally, he strongly appreciated the support the moderator obtained, especially the analytical features, and he also praised the fact that the paper-artifacts were augmented with interactive areas. Additionally, he suggests that the hyperbolic tree has the potential to highlight fixations of group and individual-related productivity. He also mentioned that the hyperbolic tree must reveal - to somebody who moderates - what idea is currently being used by somebody and the tree must reveal the nature of the ideas (what idea in the tree is a duplicate and what idea is a source idea). As a result, this statement leads to the last implication:

- *Implication 5 - Advanced Tree-Awareness*: This implication aims at augmenting the hyperbolic tree by emphasizing the group's current activity. Therefore, each physical sketch that is currently being used by a participant should be signalized within the hyperbolic tree e.g. by *glowing*. Furthermore, nodes and branches that are duplicates must be distinguishable from its source ideas e.g. by *color*. Thus, by mapping the drawing actions as well as the quality of the sketches onto the hyperbolic tree, this enables a history of actions and could improve the basic orientation in the hyperbolic tree

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[14] This moderator also manages and organizes the creativity workshops and this moderator took also part in the user study described in section 4 (p.55)
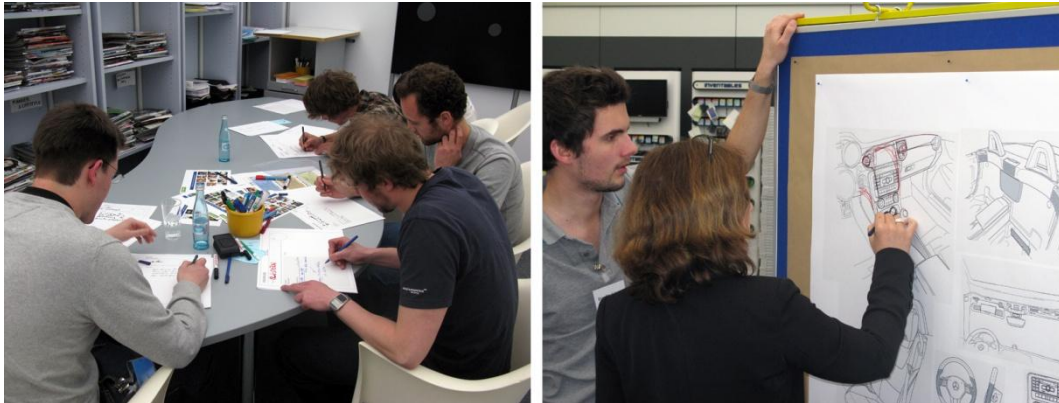
Figure 30. Participating observation of a creativity workshop at the Customer Research Center, Daimler AG, in Böblingen, Germany.

To conclude, the tasks of the facilitator are primary to be supported by means of a digital tool with analytical features. Thereby, linking the derived five *implications 1 to 5* for the system' design to the RBI paradigm and its "power vs. reality tradeoff", it is suggested that every implication adds power to the interface in a way that is not possible in reality. Thus, the challenge is to implement these features for augmenting the moderation, but without influencing the facilitators' workflow negatively (those implications are also used as criteria for designing the workspace and the features of the digital tool, in addition to the social factors (see Figure 31)).
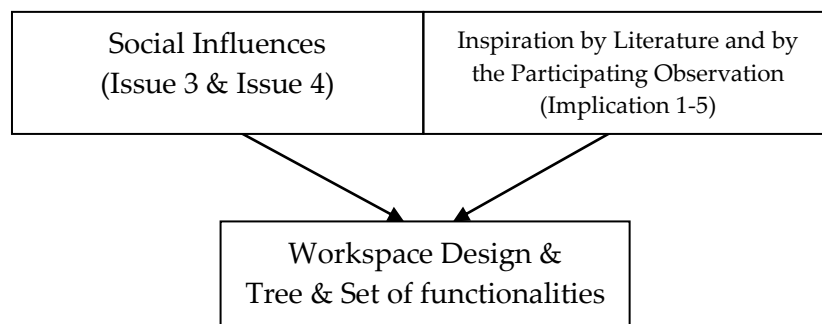
Figure 31. The workspace and the functionalities for the moderator are grounded in the theory of social influences and they were informed by the EBS and a participation observation.

3.4.3   Workspace Design for the Facilitator

The first design decision was to integrate a vertical display near the workspace of the group, so that the facilitator is able to quickly shift the focus of his attention between the group and the system. This decision implies easy accessibility of the system as well as its utilization on demand and has hence most priority. The second design decision was to turn the display to the back side for blocking the

creative worker's view of the moderator's screen. Thereby, it is suggested to minimize possible evaluation apprehensions. The resulting brainsketching setting, composed with the digital workspaces is illustrated in Figure 15 at the beginning of this chapter.

3.4.4   Hyperbolic Tree

The core concept of this tool is to provide computational power for supporting the analysis of the creative output. According to the design implication 1, 2, 3 and 5, every created sketch is being directly sent to the moderator's tool and is being adjusted according to the hyperbolic space (see hyperbolic tree in Figure 32a). Thereby, every physical sheet on the creative worker's table has a virtual corresponding sketch, attached as node to the tree's root. The other outgrowing nodes are created and attached due to modifications and printings. Here, glowing nodes indicate that the corresponding physical artifact is currently being used by a person (Figure 32a1). The yellow-framed nodes belong to the source idea (Figure 32a2) and the purple-framed nodes indicate duplicates (Figure 32a3). Figure 32b and Figure 32c demonstrates the hyperbolic tree after the user navigated through the tree. The sketches at the centre are magnified and the sketches near the edge are scaled-down. The source ideas with strongly growing branches point out that this idea has been extensively used, which indicates also a design fixation.
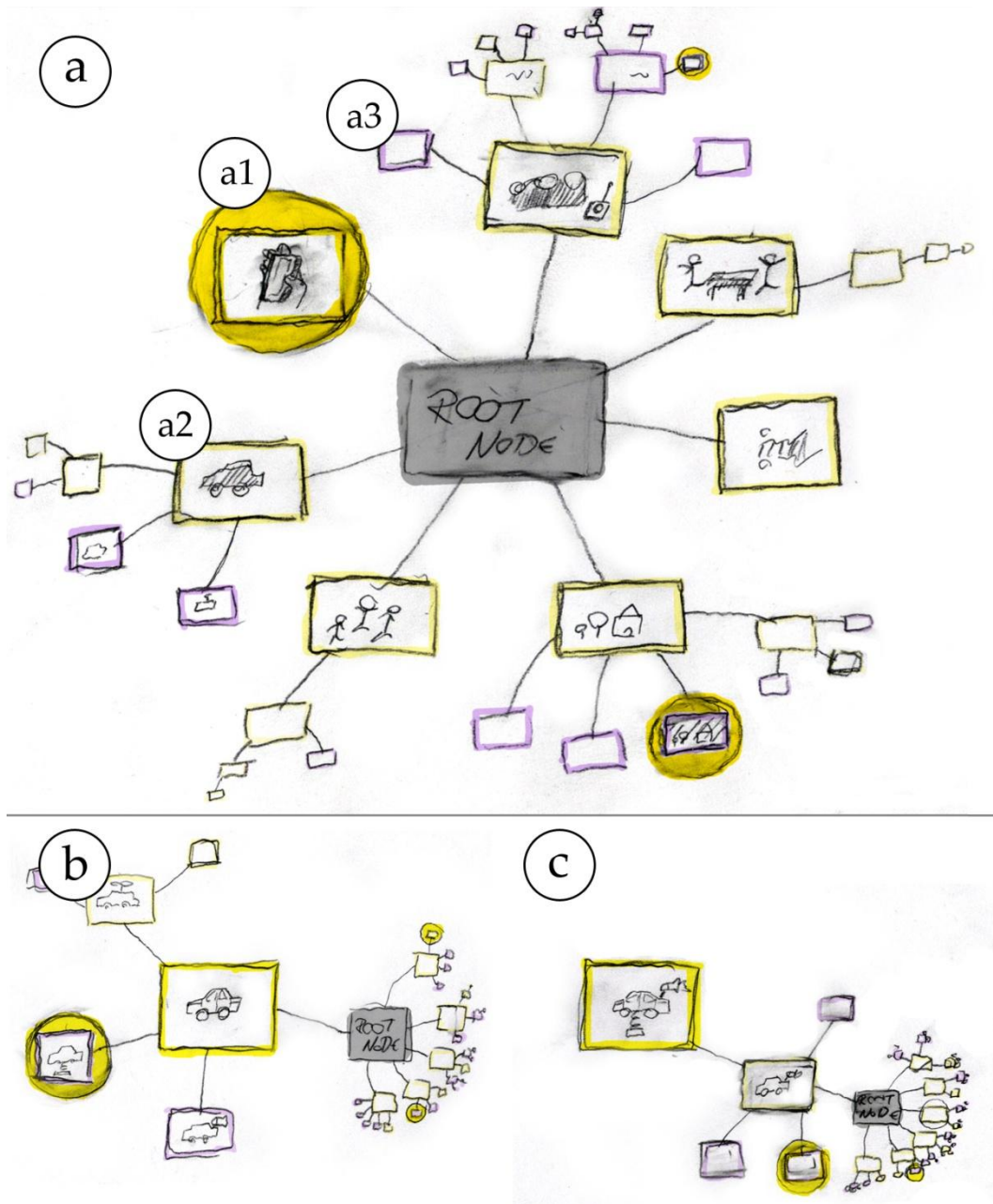
Figure 32. Hyperbolic Tree applied to the context of brainsketching.

In doing so, a new node is generated by every modification of the physical sketch due to another person. Figure 33 reveals how correlations between the virtual and the physical sketches are made. The sketches above illustrate physical sheets on the table. The sketches beneath represent the corresponding virtual sketches at the moderator's display. Every colored pen represents a different person (person red, person green, person purple), meaning that three different creative workers make supplementations bit by bit.

This mechanism enables a sketching-history automatically in one direction; and if a person prints a copy of a sketch, branches will emerge by means of new variants (Figure 34).
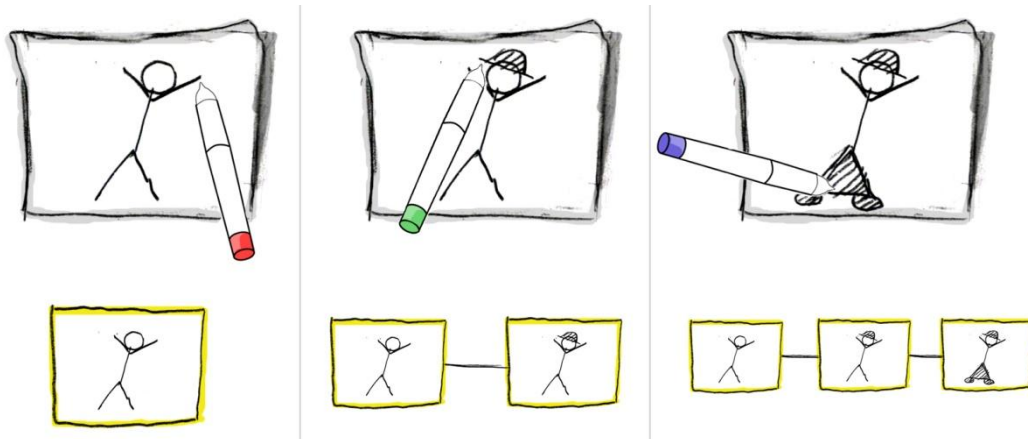
Figure 33. Correlations between the physical and the virtual artifacts.
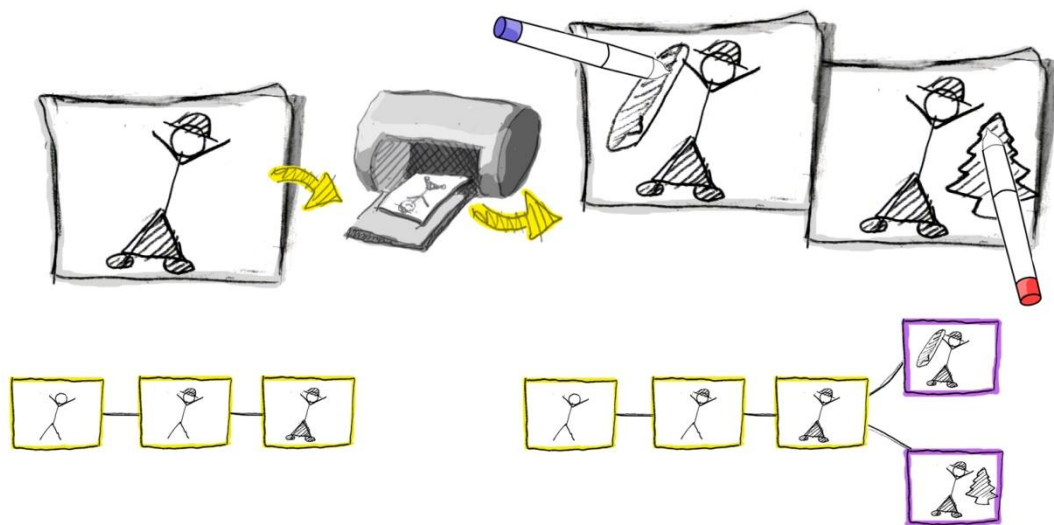
Figure 34. Making tree branches by duplicating a sketch.

3.4.5   Interactive Virtual Sketches

Considering design implication 4, the virtual design-artifacts (tree-nodes) are enriched with additional functionalities (see Figure 35a) in order to provide a manipulation mechanism for the facilitator. For instance, he can combine and print out sketches (Figure 35b), or he can send sketches to the group's display (Figure 35c), giving the group design-input; or he can keep track of each individual's design contribution by means of person-related pen color (Figure

35d). The following modifications by the creative workers e.g. comments, questions or drawings are then received by the system again and transformed according to the hyperbolic tree, making the designers performance visible for the facilitator by means of new tree-nodes.
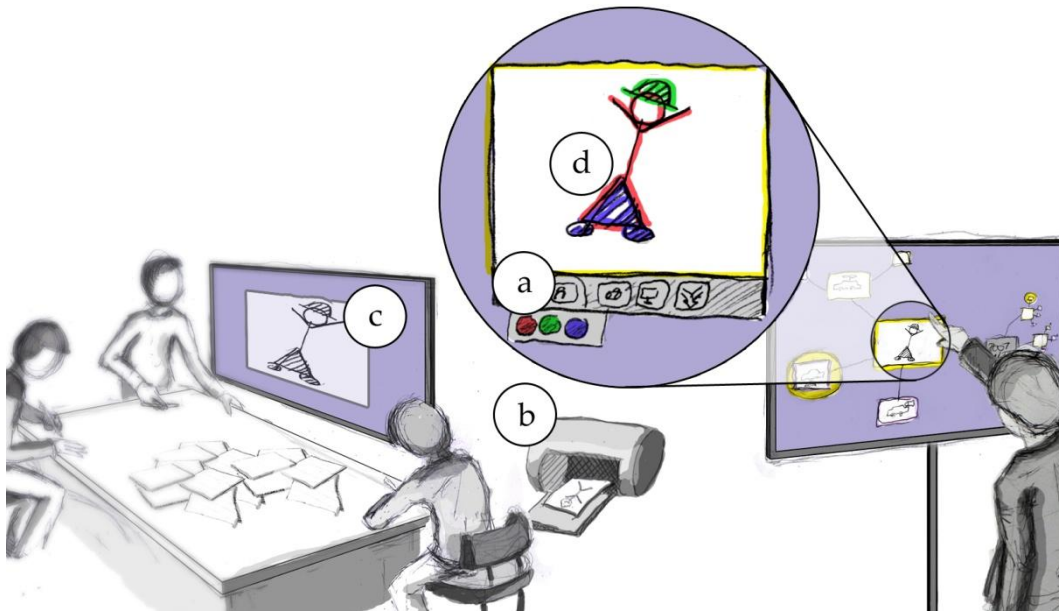
Figure 35. Interactive virtual sketch.

3.5   Concluding the System Design

The point of interest here in this section was to clarify the way in which the brainsketching session can be digitally supported and augmented with respect to the negative social influences. In doing so, the first step encompassed a behavioral analysis of the physical practice. For instance, the students used their environment and the paper-artifacts as design tools, they extensively used deictic gestures within communication, they collected the sketches at the center of the table and they rejected the bulletin board. Overall, these findings helped to shape and to customize the design of the creative worker's digital workspace.

To offer support for the facilitator, inspiration has been taken from the "Electronic Brainstorming System" by Valancich et al. (1994) and by means of a participatory observation, since there were no data available about moderation practices (videotapes, audio recording etc…). Thereby, the moderator's system aims at offering services for live data recording, a computer-controlled organization of the design artifacts (hyperbolic tree) and analysis (additional functionalities e.g. coloring the strokes according to its creator). Therefore, Table

4 provides an overview of the solutions that have been introduced in this section together with their benefits. As a result, the approach of creating a system closely upon the practices and characteristics of reality blends the digital and the physical world and is thus termed as *Hybrid Brainsketching (hyb)* for this master thesis research.

Thereby, the resulting concepts have been implemented by means of a system, which is usable in collaborative brainsketching sessions (*hyb-system*). The software was developed with the ZOIL framework[15] and the digitalization of the sketches was accomplished by means of the Anoto digital pen and paper technology[16]. A detailed description of the software development e.g. components, classes and an overview of the client-server architecture is available in the documentation of the Masters Project (Budzinski, 2011b) (See Appendix C DVD Content). An overview of the final system and its functionalities is available in Appendix B Overview of the hyb-System.

The next step is to conduct an investigation in to whether the system has the potential to facilitate the brainsketching activity without affecting the workflow negatively. Therefore, an exploratory case study will be applied in order reveal the way in which the *hyb*-system influences the behavior of the participants (creative workers). Additionally, this qualitative approach includes also an observation of the facilitator and his activities within brainsketching (which has not been addressed yet by the related research) and investigates whether the *hyb*-system offers support for the moderation. The results of the study are then linked to the research questions that have been posed at the end of section 2.6 (p. 25)[17].

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[15] Documents of the ZOIL project, see Jetter et al. (2008) or Zöllner et al. (2011)

[16] http://www.anoto.com/

[17] Some parts of this chapter have been already described in the Documentation of the Masters Project (Budzinski, 2011b) and were being summarized and modified.

Table 4. This table presents the final concepts that are to be implemented for addressing the four identified issues of social creativity (see also Budzinski (2011b, p. 17)).

	Warr & O'Neill (2005), Linsey et al. (2005)			Van der Lugt (2002a)
Issue	Production Blocking	Evaluation Apprehension	Free Riding	Early Fixation
…	…	…	…	…
Possible Improvements	**Designing the system according to the RBI paradigm** Preserving the affordance of traditional media and the basic workflow of brainsketching	**Digitalizing Ideas** Working with digital copies may reduce inhibitors to draw on other's sketches. This also eases the reuse of a sketch.	**Tracking & Illustrating** Tracking the pen ID and illustrating the person-related Idea generation. This feature enables the facilitator to identify the productivity of each person	**Illustrating the Idea generation and the productivity of the entire design-session** This feature enables the facilitator to detect fixations (early fixations). This function is also usable for highlighting sketches of interest (for further refinement)
Implications To Implement	- Using an ordinary table as physical workspace for preserving the nature of individual and collaborative actions (personal as well as public areas) - Using Anoto's digital pen & paper technology for facilitating computational power (computer functions) and for preserving the work with ordinary pen and paper - Using a peripheral vertical display (non-interactive), which can be used, if needed, for creating a wall of inspiration, for supporting discussion and for improving deictic references.	- Providing a printing-function that enables the duplication of a sketch - Using the ordinary paper as interface between the physical world and the digital world, by defining interactive areas on the paper and the digital pen as input device - coloring the interactive areas in order to make the computer functions visible for the user -using the digital display for providing a visual feedback of the computer functions (let the user know, that the pen-input was successfully handled)	- representing the **evolution** of a single idea as a tree -illustrating the development of a sketch by means of a new node so that branches emerge -the branches subsequently indicate the degree of refinement of the corresponding idea and hence illustrates fixation effects - using the **hyperbolic tree browser** for providing a dynamic scalable and interactive overview of numerous trees on the landscape - **Fixations** are identifiable by an extensive outgrowth of a tree - The **number of trees** represents the **number of ideas** - Providing **panning** for allowing the navigation through the tree - Providing functions that allows the facilitator to **highlight the contributions** of a person, to **print** a sketch, to **send** a sketch to the group display and to **combine** sketches	

4 User Study: Measuring the Effects of the System

For this master thesis research, a case study was employed in order to explore the role the technology plays within brainsketching and how it affects the basic workflow of the design technique as well as the user behavior. Particularly, the point of interest here is to figure out whether the initial requirements of Table 4 were successfully achieved, meaning whether the system and its reality-based technique approach was appropriately designed and successfully implemented. A "case study" approach has been chosen for validating the system's features and to observe its influences on the design-workflow, since case studies are suited for a) empirical investigations with smaller groups of participants and b) this approach is an "in-depth" study for "gathering requirements and evaluating interfaces" (Lazar et al., 2010, p.144), with respect to a real life context like in this case to social creativity. The gathered material is then qualitatively analyzed and the results are linked to the initial research questions.

4.1   Method and Study Design

This sub-section addresses the apparatus of the investigation in order to make the empirical procedure for other researchers comprehensible. Bringing insights into the procedure enables the replication of data-set and hence fosters reliability as well as the triangulation of the inferred results by other studies.

Again, the aim of this research is to give an understanding of how the provided variety of functions supports the users accomplishing their tasks (creative workers and the facilitator) and to point out how the additional functionality affects the workflow of the design technique. Therefore, the participants should have practiced brainsketching with traditional media at least once before, so that they are able to identify differences, to recognize difficulties and to perform a comparison when the design technique was augmented with computer technology. This implies two treatments for the study design, namely

1. A study (session) conducted *without* computational sketching support, as control condition
2. A study (session) conducted *with* computational sketching support.

This apparatus describes the basic study layout for this master thesis research and is generally known as "within-subject design", meaning that "the same group of subjects serves in more than one treatment"[18] in the same meeting. To achieve a coherent understanding of the technologies impact on the workflow, this above-mentioned within-subject design was applied to two meetings, with one group of different participants per meeting.

Both groups consisted of advanced designers (Master students, Creative Direction) from the *University of Applied Science* in Pforzheim[19], whereby four students were involved in the first meeting and three students were involved in the second meeting (seven students in total, 6 female, $\varnothing$ 27 years). The first meeting was moderated with one facilitator and the second meeting was moderated with two facilitators, since one facilitator wasn't able to handle both the group and the *hyb*-system (the moderator support) at the same time. Both moderators are employed at the Daimler AG, Böblingen and work for the *Customer Research Center* as professional facilitators (2 male, $\varnothing$ 41.5 years, $\varnothing$ 4 years professional expertise).

During warming-up activities at the beginning of the study, the participants and the facilitator were introduced to the design technique – brainsketching - at the beginning of the first session (treatment without technology) and to the system's functionalities at the beginning of the second session (treatment with technology). The facilitators furthermore were given a handout, which describes the functionalities and their purposes in detail. Every session lasted for about one hour with a break of about 30 minutes in order to minimize fatigue.

Two different objectives were given by the facilitators from the Customer Research Centre - one per treatment. The participants were asked to generate ideas according to the following objectives.

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[18] http://web.mst.edu/~psyworld/within_subjects.htm
[19] http://www.hs-pforzheim.de/DE-DE/GESTALTUNG/MASTER/MA-CREATIVE-DIRECTION/MACD/Seiten/Inhaltseite.aspx

- Objective one (Ob1): "How to get somebody to tidy up the dishes after a meeting took place"[20]
- Objective two (Ob2): "What is the possibility that one's own coffee cup is used more than once in the same meeting"[21].

The order of the objective was alternated, so that the participants of the first meeting had to handle Ob1 with the treatment "*non-technology*" and Ob2 with the treatment "*with technology*"; and the participants of the second meeting had firstly to handle Ob2 with the treatment "*non-technology*" and then Ob1with the treatment "*with technology*" in order to minimize order effects as to the quantity of the group performance (overview of study design illustrated in Table 5).

Table 5. Study Design

	Study 1 **(Group 1)**	Study 2 **(Group 2)**
Treatment 1 Without technology support	Objective 1	Objective 2
Treatment 2 With technology support	Objective 2	Objective 1

The objectives were illustrated on a projection screen and thus were always viewable by the participants. The ideation took place on an interactive table covered with a plate of wood – specially built by the carpenters and mechanics of the university - so that the vertical workspace is usable as an ordinary table. The problem solving process was also composed with an ordinary bulletin-board to the left of the table. The moderator tool – a touch screen with a diameter of 54" – was placed to the right of the table with the back-side to the creative workers in order to impede the visibility of the screen (due to possible evaluation apprehension) (overview of the setting illustrated in Figure 36).

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[20] Original sentence in German: „Wie bringt man Menschen dazu ihr Geschirr nach einer Veranstaltung freiwillig wieder aufzuräumen"

[21] Original sentence in German: „Welche Möglichkeiten gibt es zu erreichen, dass in einer Veranstaltung die eigene Kaffeetasse nicht nur einmal genutzt wird."
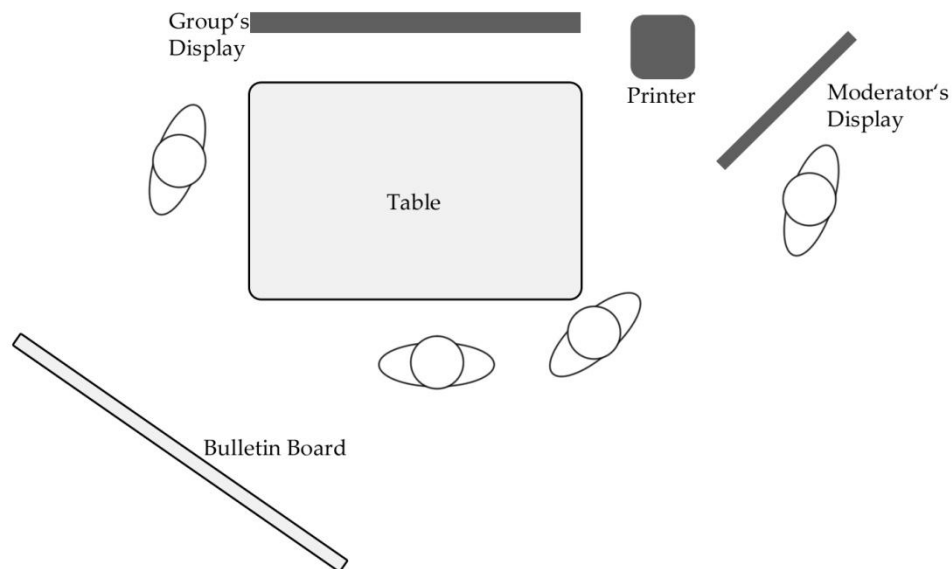
Figure 36. Setting of the user study.

At the end of both sessions, the participants took part in a questionnaire about the applicability of the paper-based functionalities (rating scale from 1 – I strongly agree to 7 – I strongly disagree) followed by a focus group – based on a semi-structured interview - in order to gain a clearer picture of the system, its strengths and its drawbacks according to the statements of the participants (qualitative data)[22]. The fact that the participants have expertise in design and in moderation furthermore adds weight to their statements and fosters the reliability of the results accordingly and argues for an employment of a focus group at the end of the study. Furthermore, every session has been videotaped for additional analysis.

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[22] The questionnaires are also available in Appendix A Evaluation Documents

4.1.1   Pre-Test and Implications for the Final Study

In order to check the reliability of the system and to clarify whether the *hyb-system* works at all in collaborative design scenarios – since operating delays and system errors cannot be ruled out at last – a pre-test has been conducted with students that have no design-skills (see Figure 37 right). The pre-study also was valuable to observe the behavior of the participants and the ways that they are practicing brainsketching. For example it was observed how they drew, discussed and distributed ideas or whether they had any inhibitions to draw on somebody else idea, what paper-based functions were most used and for what purpose. Considering the fact that the participants of the pre-test have no expertise in design also helps to gain a deeper understanding of the system's general applicability in interdisciplinary teamwork.

For this pre-test, five students participated (2 female, $\varnothing$ 30.4 years) and they were divided into two groups (three persons in the first group and two persons in the second group, since one person didn't attend). The students had two objectives to handle for the problem solving process and these two objectives have been altered according to the treatment – a brainsketching session - *with* or *without* technology support.

- Objective one (Ob1): "An early-warning system for when somebody is sitting incorrectly"[23]
- Objective two (Ob2): "Steering wheel goodbye - New forms of automotive control"[24]

The sessions weren't creatively moderated (besides some proper instructions given by the experimenter to change between the phases e.g. from ideation to distribution after 10 minutes) and the students got a detailed introduction of both the design technique and the paper-based functions.

As brainsketching should be conducted on top of an explorative design technique like brainstorming (van der Lugt, 2002a), the students got inspiration by means of virtual post-its, projected onto a projection screen over the entire session with keywords relating to the issues (e.g.) (see Figure 37 left).

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[23] Original sentence in German: "Frühwarnsystem für falsches sitzen"

[24] Original sentence in German: "Lenkrad ade – Neue Methoden der Fahrzeugsteuerung"
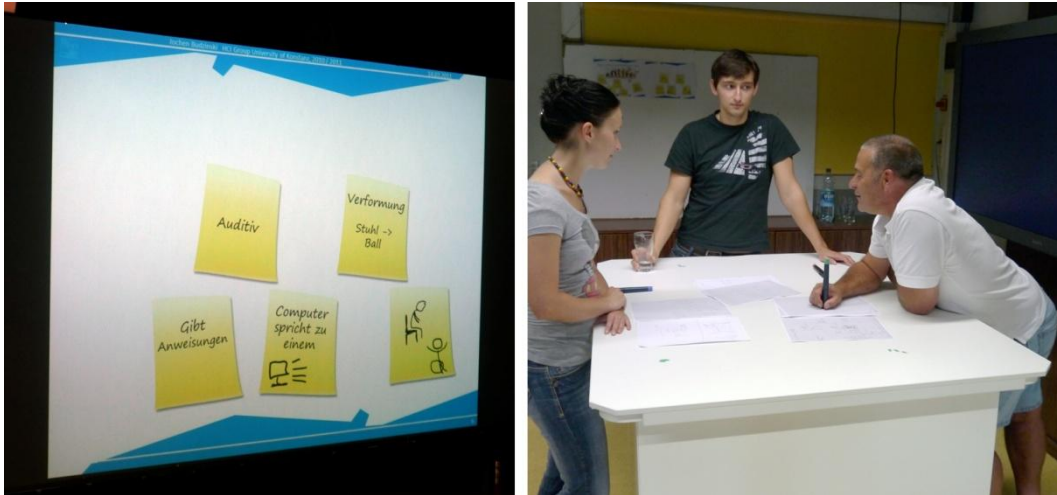
Figure 37. The pre-test: a study with non-professional students.

Based on the questionnaire and the focus group at the end of the session, some of the participants had difficulties drawing on the ideas of others and they didn't know when to use the paper-based functions. During the phases of ideation and distribution, the participants were rather quiet and cautious. The findings of the pre-test led to the following implications for the *final study*:

- *Implication 1 – Intensive Icebreaker Session*: The current research projects of the HCI research group (e.g. *AffinityTable* by Geyer et al., 2011) and its technology (multi-touch, digital pen and paper) should be demonstrated to the participants from Pforzheim and Böblingen. This allows for the participants to get to know each other and to reduce both social barriers between experimenter and participants and creative inhibitions more effectively. Additionally, this minimizes "wow-effects" and they become familiar with the design environment.
- *Implication 2 – Advanced Self-Exploration*: In addition to the warming-up activity (drawing & using the paper-based functions), the design students should furthermore explore the possibilities of these functions and should reflect upon their purpose for minimizing inhibitions using them.

4.2   Method of Analysis

This section addresses the methodological approach of analysis in order to make the examination of the findings and results comprehensible for other researches. As mentioned in section before, this case study contains various forms of recorded communication e.g. questionnaires, transcripts of the focus group or transcribed observations of the video tapes that hence produces different forms of content and argues for the employment of a qualitative content analysis (Mayring, 2000). The basic idea of the analytical procedure is thereby to use the

qualitative materials (protocols / texts, video, audio) on top of the quantitative results (questionnaire). This is because taking the so called "latent" (p. 2) content or contextual aspects into consideration in addition to the quantitative findings as linking quantitative and qualitative output helps to reach a deeper understanding of the results e.g. the meaning of text messages (Mayring, 2010).

To make inferences from the gathered material, a methodological approach according to Mayring's qualitative content analysis (Mayring, 2000; 2010; Mayring & Brunner, 2007) has been used. In particularly it has been *adapted* for this master thesis research in order to apply a systematical step by step analysis appropriate to the subject matter[25]: "It is a method used for the analysis of fixed elements of communication (e.g. text). Based on a set of category, the method prescribes a systematic, rule- and theory-based procedure measured by performance criteria. The qualitative part of this method consists of the development of categories as well as the content-based and systematic allocation of categories to elements of the text." (Paraphrased to Mayring & Brunner, 2007, p.4)

The procedure for examining the data, which was gathered by the case study, fundamentally follows the common analytical steps as stated by Mayring (2010) and is illustrated in the flowchart below (see Figure 38). This flowchart (Figure 38) slightly differs from Mayring's (2010) original procedure in terms of the sequence of some steps. For example *Step 1 – Direction of analysis –* was initially allocated near the end of this process, since qualitative content analysis is also useful to generate hypothesis or research questions (this step is now at the beginning, as the RQs are already known). Nevertheless, drawing upon the claims of Mayring & Brunner (2007) it is generally important that the procedure is disclosed to and comprehensible for other researchers in order to reach validity and reliability of the qualitative results.

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[25] The analysis of qualitative content is actually rooted in the domain of the communication research and had its beginning in the early 20th century in the USA. This scientific approach allows for studying and quantifying the characteristics of mass media and mass communication e.g. by statistically analyzing word or theme frequency (Mayring, 2000). Hence, this approach has been often termed as *quantitative* content analysis. Leaders of this approach are e.g. Krippendorff (Krippendorff, 2004) or Neuendorf (Neuendorf, 2002). The *qualitative* content analysis in contrast, was developed in the middle of the 20th century due to the critics of "rash quantification" without regarding the semantic meaning of the qualitative content (Mayring, 2000, p. 2). Philipp Mayring developed "a bundle of techniques for systematic text analysis" (p.1) 20 years ago in Germany and he is one of the leaders of the qualitative approach and hence is an important reference in this master thesis research.
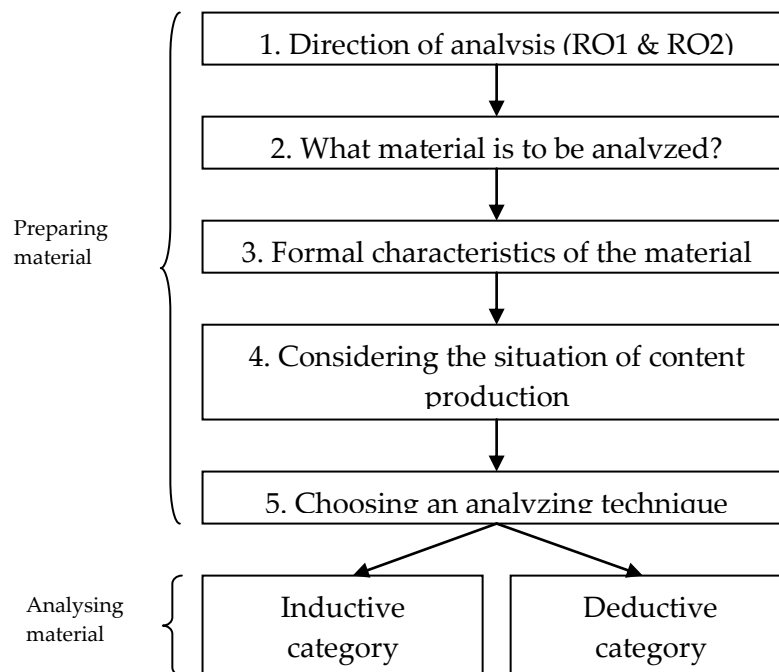
Figure 38. This flowchart illustrates how the qualitative analysis is carried out for this master thesis research (according to Mayring (2010)).

Regarding Step 2 & step 3

These two steps - *What material is to be analyzed & Formal characteristics of the material* – are closely related to each other and encompass the definition of the units that are to be analyzed, as they clarify what content will be actually examined (Mayring, 2010, p. 52-53). For this analysis, the following materials are to be analyzed.

- *questionnaires* (pre-, post-) with quantitative as well as qualitative results (text),
- *audio material of the interviews* of the focus group that were transcribed (text),
- *logged data* e.g. the design artifacts (drawings),
- *video material*, which shows the user behavior. The behavioral characteristics, if relevant to the RQ, were then transcribed (e.g. "person A pointed with the finger on the screen")

The author recommends also using sampling-strategies in order to examine only a subset of the content. This is especially so when the set of data is overwhelming e.g. considering only every n^{th} interview of all recorded interviews or choose the interview randomly. However, the set of data is reasonable for this analysis and hence no data-sampling strategy is required.

Regarding Step 4

The next step - *Considering the situation of content production* – furthermore tells a researcher to denote who took part and to consider the circumstances under which they produced the material e.g. the emotional behavior, the situation or the cognitive performance of the participants (Mayring, 2010, p. 53) e.g.

- In this case study, *two* groups of graduated design students (*seven* students in total) and *two* facilitators with professional expertise participated and were observed. They have *two* design-tasks to accomplish with respect to the treatment *with* or *without* computer support (this step is already described in greater detail in section 4.1).
- They took part voluntarily.
- They often they laughed and they had fun during the sessions using the technology.
- The design students knew each other very well and they briefly met the two moderators before.

Especially the latter one is important, since some results indeed are explainable due to the fact that they knew each other before.

Regarding Step 5

This step – *Choosing an analyzing technique* – finally concerns the analysis itself, whereas the other four steps before rather support a researcher to prepare the content for the analysis. Mayring (2000) distinguish amongst two approaches: *inductive category development* and *deductive category application*.

The latter one (deductive cat. application) "works with prior formulated, theoretical derived aspects of analysis, bringing them in connection with the text. The qualitative step of analysis consists in a methodological controlled assignment of the category to a passage of text" (Mayring, 2000, p. 4). It is used to classify or structure text passages according to a pre-defined scale of categories ("high self confidence – middle self confidence – low self confidence" (Mayring, 2000, p.4)) and enables also quantification. This approach is however not suitable for this analysis, as no categories are yet available.

The former approach (inductive cat. development) enables by contrast the summarization of text, by formulating "categories, as near as possible to the material" (Mayring, 2000, p.3). Thereby, "the material is worked through and categories are tentative and step by step deduced" (Mayring, 2000, p4) according to a criterion derived by the research question. In other words, this approach helps to examine meaningful behavioral characteristics of the participants, e.g. "*why*" and "*how*" they used the provided set of functionality. This is performed

by reducing relevant text passages (e.g. transcribed video / audio statements) gradually to their essential messages that are then to be termed as categories (e.g. words or small sentences).

Summed up, the gathered material should be analyzed with respect to the research questions. This means that the two different user roles, the general applicability of the system, the functionalities and user behavior are to be taken into account. The following table (Table 6) illustrates the final defined criterion, which has been applied to the material for examining and for formulating categories inductively (e.g. transcribed text passages of the interview or video-scenes are to be analyzed as to the printing-function, the highlighting-function and so on).

Table 6. This table represents the criterion for inductive qualitative content analysis.

Creative Workers	Facilitator	Material
Workspace-design (design phases, table, pen & paper)	Workspace-design (design phases, table, pen & paper, moderator tool)	Questionnaire
Printing-function (paper)	Printing-function (tree)	Transcribed statements / interview
Highlighting-function (paper)	Highlighting-function (tree)	
Rating-function (paper)	Rating-function (paper)	Design artifacts
-	Interactive tree visualization (tree)	
-	Color-to-person identification (tree)	Video / transcribed behavior
-	Sketch-combine-function (tree)	

4.3   Evaluating the Computational Support for the Creative Workers

This section reveals the results of the tool's impact on the workflow of the design technique and the general applicability of the provided functions as well. The results are then linked to the initial research question in section 4.5 (p. 83).

4.3.1   Results Creative Workers: Workspace-Design

Based on the video tapes, the participant created, sorted and organized the

design content within individual workspaces during the phases of idea generation (across both conditions)(see Figure 39b). Thereby, as part of his intention to contribute to the performance, the facilitator encouraged the participant in producing ideas as much as possible, as he fostered the participants to verbally express their thoughts at the same time (see Figure 39a & c). This is especially important in order to reach a common understanding of every produced idea. As shown within the observational user study in section 3.3.3 (p. 35) the phases of idea generation and idea discussion were blurred at some point and the creative workers also pooled the ideas at the center of the table to emphasize that the generated output is ready for re-interpretation. Subsequently, there were no sketches attached to the supplied bulletin board during the problem solving meeting, meaning that the creative workers rejected this vertical surface. Every design phase, including rating (Figure 39d), was being conducted upon the table (across the both conditions - no-technology vs. technology)).
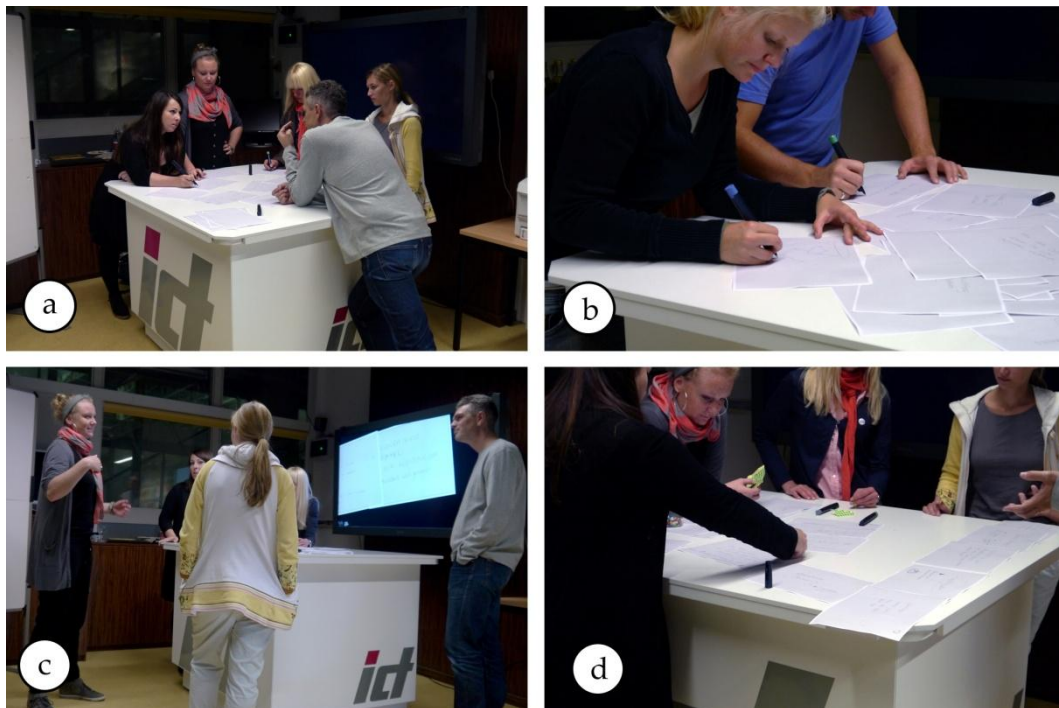
Figure 39. The facilitator and the group collaborate creatively (a). Individual ideation within the personal workspace and idea collection at the center of the table (b). Communication of ideas by using the body (c) and idea-rating is being conducted on the table (d).

Furthermore, it has been noticed that the participants used the table as storage place in order to put down personal objects. For instance a notebook, mobile phones or cups were put onto the table (in this case the cup and the glass were both also matter of subject) (see Figure 40). This finding is a clue for the profound role the physical environment plays within design practice, since the students utilized their workspace individually for creative purposes. However, the

participants also criticized the small size of the table and the uniform colored Anoto pens that aren't usable as markers for highlighting special design aspects on the paper.
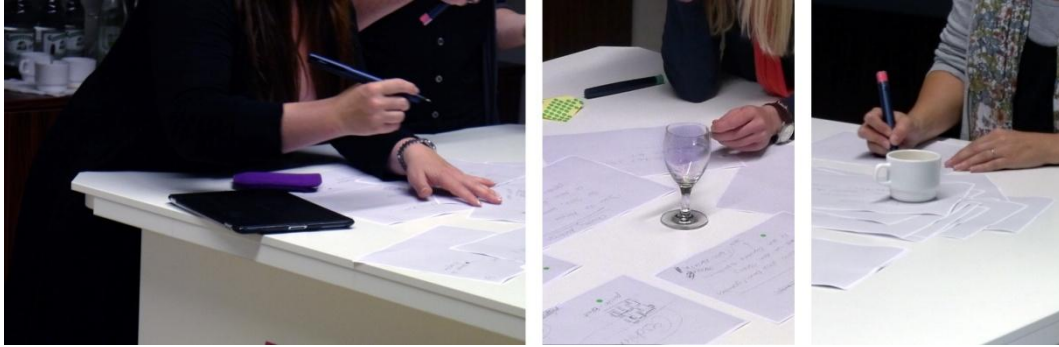
Figure 40. The participant used the table to put down personal objects (left) as well as other physical things like glasses or cups (image middle & right).

4.3.2   Results: Interactive Paper with Additional Functionalities
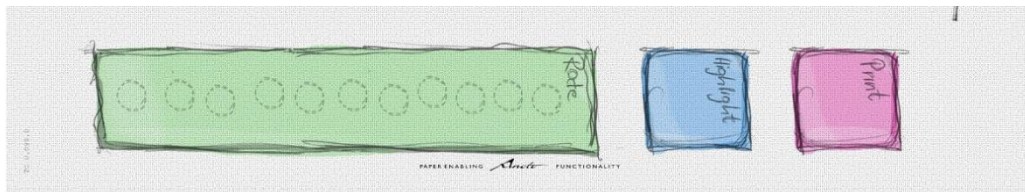
Figure 41. Set of functionality for the creative workers.

In both conditions, the participants used Anoto's digital pen and paper technology for idea creation. The results of the questionnaires and the interviews of the focus group reveal that the participants (N = 7) highly appreciated the work with pen and paper on an ordinary table ($M = 1.86$, $SD = 1.01$) (see Figure 42[26]). This confirms the finding of Cook & Bailey (2005) that experienced designers in particular like to use these physical tools (pen & paper) for informal activities.

In order to use the additional functionalities, the paper was complemented with interactive regions that are to be used by the digital pen (see Figure 41). According to the questionnaire, the participants liked it that the physical paper was enhanced with computer power ($M = 2, SD = 1.73$, see Figure 43) and they liked utilizing the digital pen as an input-device for executing the paper's functions. Furthermore, they strongly agreed that these functions were easy to

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[26] The items of the questionnaire have been translated from German to English

use ($M = 2.43, SD = 1.61$, see Figure 44) and their implications were easy to understand ($M = 1.43, SD = 1.13$ see Figure 45).
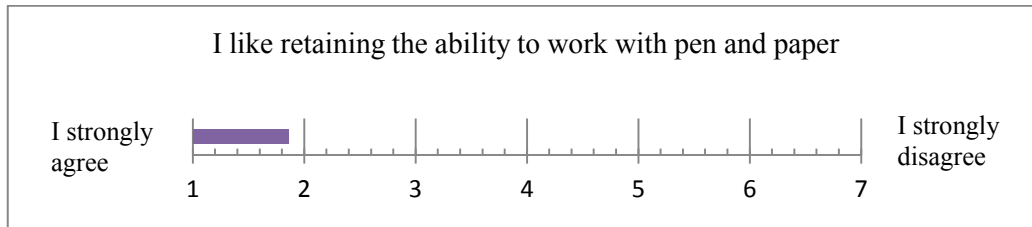
Figure 42. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants apparently appreciated pen and paper for creative work.
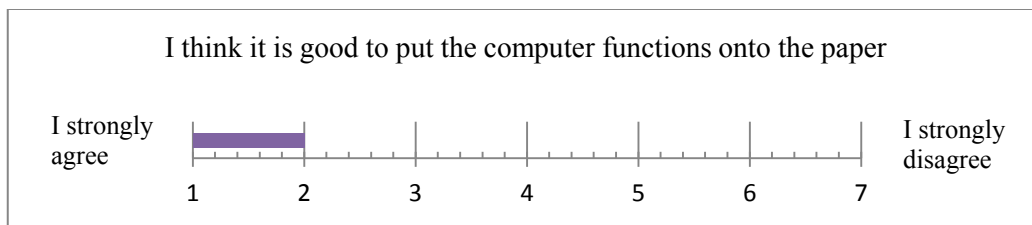
Figure 43. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants appreciated that the physical paper was enhanced with computational power.
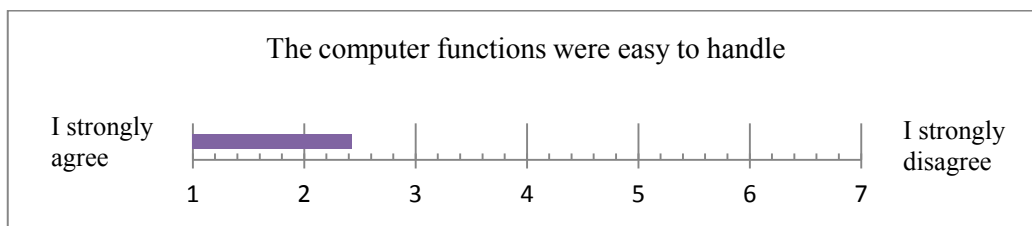
Figure 44. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants could easily use the functions.
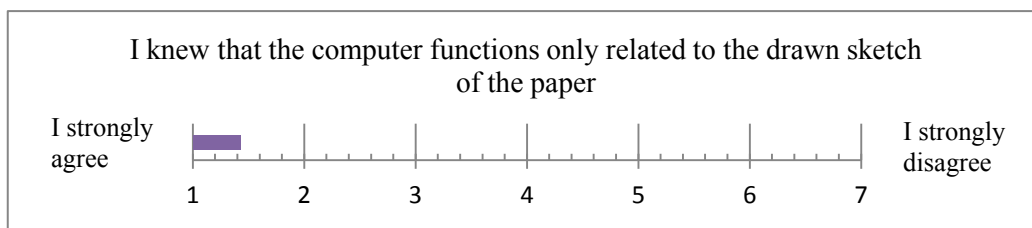
Figure 45. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants easily understood that the functions on the physical sketch only affect the corresponding digital sketch.

4.3.3   Results: Printing-function

The printing-function was intentionally provided for overcoming proper *modification apprehensions*. Thus, this investigation should clarify the meaning of this function, how often it has been used by the participants and why the participants used it. Referring to the results of the questionnaire, the design

students generally liked to be able to duplicate physical sketches during the design process ($N = 5, M = 1$, $SD = 0$, see Figure 46) and they strongly agreed that it was easy to duplicate a sketch. This means that it was easy to execute a print-command on the basis of the digital pen and the paper-based interaction technique ($N = 5$, $M = 1.43$, $SD = 0.79$, see Figure 47).

I think it is good to have the ability to print sketches

I strongly agree ... I strongly disagree

1   2   3   4   5   6   7
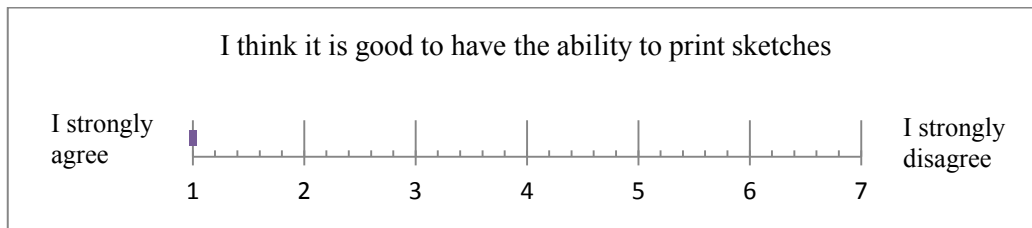
Figure 46. Strongly agree = 1 to strongly disagree = 7. This figure shows an overall consensus that the participants appreciated to have a function for printing.

It was easy to print / duplicate a sketch

I strongly agree ... I strongly disagree

1   2   3   4   5   6   7
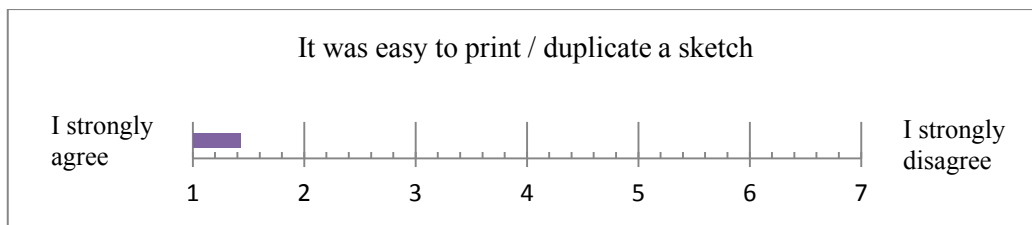
Figure 47. Strongly agree = 1 to strongly disagree = 7. This figure shows that the pen-paper interaction style augments reality appropriate for sketching activities.

However, the printing-function wasn't used to the extent as expected, since only 9 of 52[27] sketches were duplicated across both computer supported brainsketching sessions (2 in the first, 7 in the second study). There are two prober reasons for this finding.

Firstly, the participants hadn't had any fears of performing irreversible changes. Referring to the results of the questionnaire, the participants rated that they had generally no difficulties modifying somebody other's idea ($M = 6.86, SD = 0.38$), regardless of crucial modifications ($M = 6.86$, $SD = 0.38$) or only slight modifications ($M = 6.23$, $SD = 1.25$). One participant furthermore explained that participants knew each other for a long time and this may explain why they were highly motivated to draw on the sketches of others.

Secondly, it is also argued that the facilitator additionally kept the phases of distribution low, meaning that he rather forced the group to undertake massive idea generation as opposed to encouraging them to refine ideas. Thus, the participants didn't take the ideas of others strongly into consideration, implying that they rarely sketched on the ideas of others. Additionally, the participants

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[27] Thereby 15 sketches were being created in the first and 38 sketches were being created in the second study.

supplemented the ideas often by adding words, implying that the participants didn't violate the design content crucially. It is hence likely that it wasn't worth it for them to print a copy (in order to preserve the original sketch) for such insignificant supplementations. One participant confirmed this suggestion and reported that from his point of view, printing generally is a waste of natural resources and he thus never used this function within the session. The facilitator furthermore was concerned that the sheets were to be printed weren't readily available and gave the advice to speed up this process, especially when important thoughts have to be rapidly externalized (the printing-operation lasted for about 30 – 40 seconds). As a result, the design students had almost no modification apprehensions and they were forced not to do many modifications at all (and if so, they rather wrote down their thoughts). Those mentioned reasons may explain why the printing-function wasn't used to the extent as expected on the one hand.

On the other hand, the participants have mainly duplicated ideas based on the instructions of the facilitator when concerning the question of why the printing-function was used all. An excerpt from a conversation between the facilitator and a participant during the focus group brings insights.

- Facilitator: *"So, I just wanted to try this function because it promotes branches of the design content. Then, two persons can work at the same time into two different directions."*
- One participant added later on*: "And Erik [name of the facilitator] pressed always on printing, so then I forgot about this function."* [28]

This excerpt clarifies that the facilitator mostly made use of this function and he pushed the creative workers to print duplicates. Based on his statement, he used this functionality for creating multiple variations of one idea by different participants (and the participants and facilitator also added that there should be also a method for merging once split ideas into one artifact). One participant for instance, also reasoned that she used the printing-function to back up her favorite paper sketch and to take this backup copy back home.

In addition to the participant's statements (creative workers & facilitator), the duplicated sketches and the ways in which they were actually modified have been considered as well. For instance, four duplications have been used to make negations by scratching out certain design aspects (of an elaborated idea). As shown in Figure 48, the sketches a & b illustrate the source idea and the sketches a1 & b1 represent the duplicated sketches with certain design aspects that were being scratched out. This finding highlights that it is likely that the design

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[28] Every statement within this thesis was paraphrased from German to English.

students used the function to print duplicates unconsciously for conducting crucial modifications and it helps them to express their rejection of a design proposal.
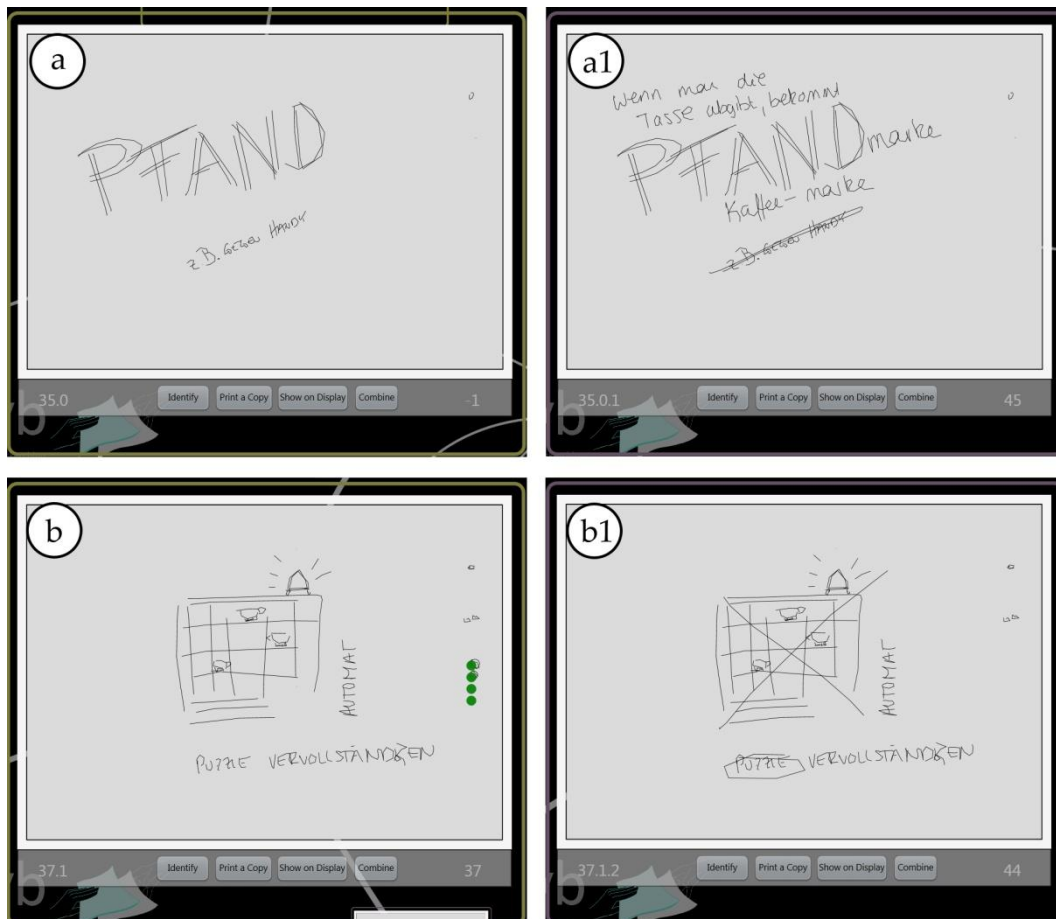
Figure 48. This figure illustrates that the duplicates (right-hand side) were being crucially modified, since the participants scratch out particular design aspects.

4.3.4   Results: Highlighting-function

The highlighting-function was intentionally offered to support the communication of the design output within the phases of discussion. Furthermore the display should also serve as a "wall of inspiration" by gathering and displaying every highlighted idea. In doing so, the participants rated this functionality (highlighting-function and the display) generally as helpful for presenting their ideas ($M = 2$, $SD = 1.33$, see Figure 49). During discussion, *five* participants commented that they gave their attention to the physical sketch and *two* participants rated they gave their attention to the digital sketch on the display, which means that the creative workers preferred to use the physical sketch (with deictic references) to explain their thoughts (this finding is in line

with the behavior of the observed interaction design students in section 3.3.3 (p. 35)). The creative workers also strongly agreed that it was easy to highlight a sketch digitally on the peripheral display, meaning that the function was easy to use with the pen & paper interaction technique ($M = 1.71$, $SD = 1.25$, see Figure 50). Additionally they liked the ability to highlight a sketch as needed (the design students could freely decide to use this function or not) ($M = 1.86$, $SD = 1.57$, see Figure 51).
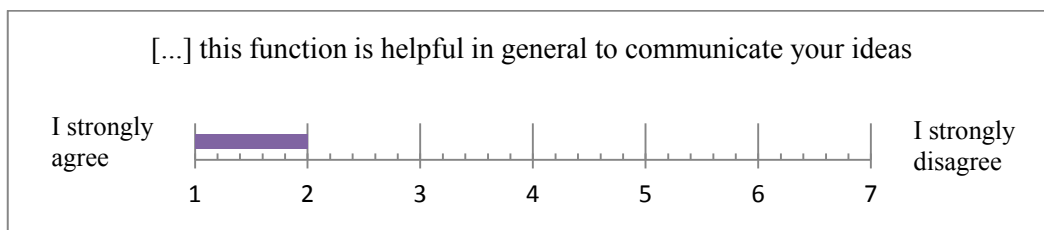
Figure 49. Strongly agree = 1 to strongly disagree = 7. This figure shows that this functionality supported the participants within the phases of presentation.
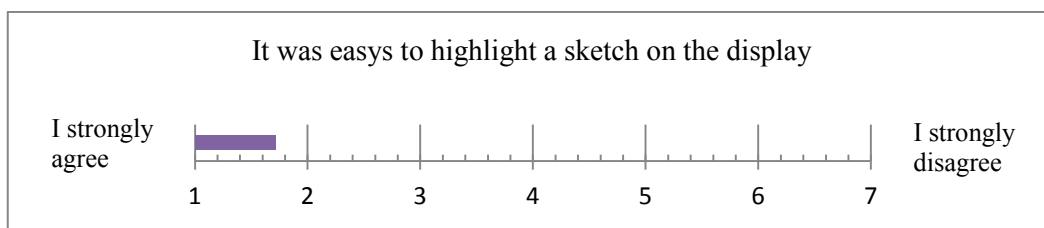
Figure 50. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants could easily use this function.

Figure 51. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants liked it that they were able to freely decide to use this function.

Based on the analysis of the videotapes, the participants mostly highlighted their sketches, as expected, in order to emphasize their thoughts or to make recent modifications of an idea more comprehensible for the other participants. Thereby, before they began to talk, the participants who had executed the function looked at the display and watched the animation of how the idea gets moved to the center of the digital surface and enlarged. One participant for example received an order by the facilitator to make annotations upon an existing idea: *"write down the word 'puzzle' upon this idea and 'completion'"*. She wrote those words down and afterwards she highlighted this artifact on the display to demonstrate that she accomplished her task: *"now it is on the first one*

[meaning the original idea]" and she pointed with her finger to the display. Another participant reported that this highlighting-function is helpful to explain details of the idea that are hidden for people who are on the opposite side of the table:

> – *If I talk to you and you want to show me something on your sketch, it would be very difficult for me to read it when the sheet is upside down. And therefore you can project this [meaning the sketch] onto the display*"

Figure 52 exemplifies this statement. The group discussed the value of an idea (during the phase of rating) and the person with the blue shirt verbally expressed his thoughts about the notion of "malicious joy". Therefore, he used the physical design artifact (containing this word) in front of him as a means for presentation (Figure 52a). The participant at the table's corner then leaned forward to reach the interactive areas of the physical sketch and she highlighted this idea on the display (Figure 52b). The other participants (including the facilitator) then shifted the focus of their attention to the display while the presenter still looked at the paper-sketch in front of him (Figure 52c). In another situation, the facilitator also highlighted a specific sketch in order to emphasize this idea for further development.
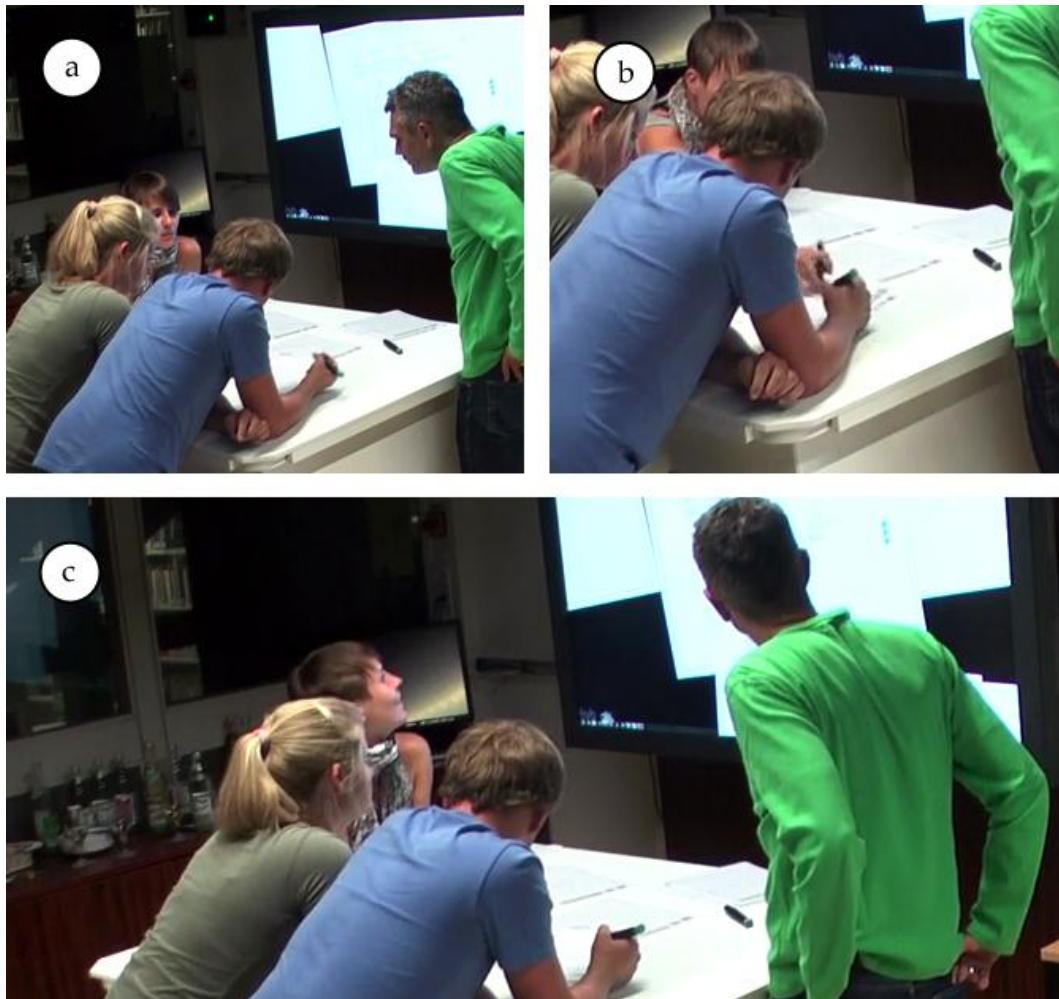
Figure 52. (a) idea discussion (person with the blue shirt is speaking at that moment), (b) participant to the diagonal opposite performs a highlighting of the current idea to see a detailed view of the idea on the display, (c) every participant, including the facilitator then shifted the focus of their attention towards the display. The speaker (blue shirt) still considered the physical artifact.

The participants mentioned that the display actually helped them to demonstrate their ideas. However, at the same time they concerned that this digital surface partly distracted them from idea generation at some point, meaning that there were also potential issues identified with the display. Based on the video analysis, the design students often looked at the digital sketch (which was highlighted on the display at that moment) whenever they drew on the corresponding physical sketch. According to the statement of a participant, she reasoned that she used the display to confirm whether the recent drawn strokes had transferred to the digital version. She hence looked up to the display until the drawn strokes appeared on it. In this case, she used the peripheral display to identify whether the computer has successfully handled the design input. Subsequently, the digital artifact attracted more attention, even though she had the analogous sketch variant in front her. The video analysis reveals also, that

some participants often highlighted sketches without any given reason after they supplemented the analogous sketch (see Figure 53a & b) (e.g. without the intention to discuss their modification).

Figure 53. Image on the left-hand side (a): The creative worker with the blue shirt supplements the idea. On the right-hand side (b), he immediately highlights the sketch on the display without the intention to discuss it.

Generally, it is assumed that this behavior is due to the fact that the phases of discussion, presentation and idea creation were almost blurred across both groups, meaning that the creative workers rapidly shift from ideation to discussion and vice versa. This probably explains why the highlighting-function was often utilized in the wrong context and distracted the participants, even if only slightly, from other tasks.

4.3.5   Results: Rating-function

The rating-function has the purpose to replace the traditional way of rating with green glue spots by means of circles the participants have to draw into the interactive field of the physical sketch. Additionally, the digital variant becomes enriched with digital green glue spots in order to provide rapid system feedback related to the users input. In addition, it should ease the distinction between relevant and non-relevant ideas when the participants look at the collection of digital artifacts on the display (the ideas with more green glue spots are more important). Referring to the results of the questionnaire, there were potential usability issues identified, since the creative workers mentioned that this function wasn't as easy to use as the other features (printing, highlighting) ($M = 3.29, SD = 2.14$, see Figure 54). They also disagreed with making circles for rating a sketch ($M = 5.29$, $SD = 2.06$, see Figure 55). However, the high standard derivation of both question-items should be considered as well, as this clearly

indicates that there was no overall consensus about their ranking, meaning some of the participants agreed that it was easy to rate an idea and they liked drawing circles.
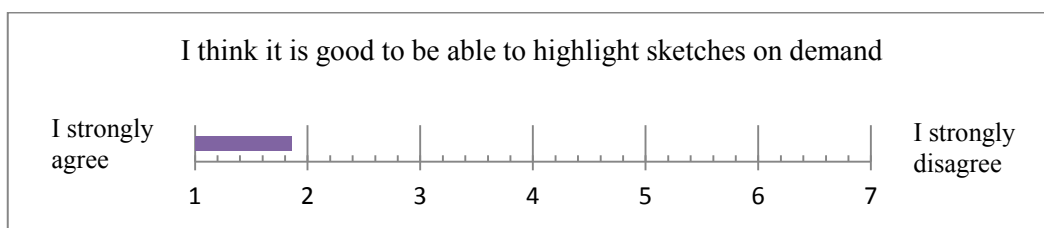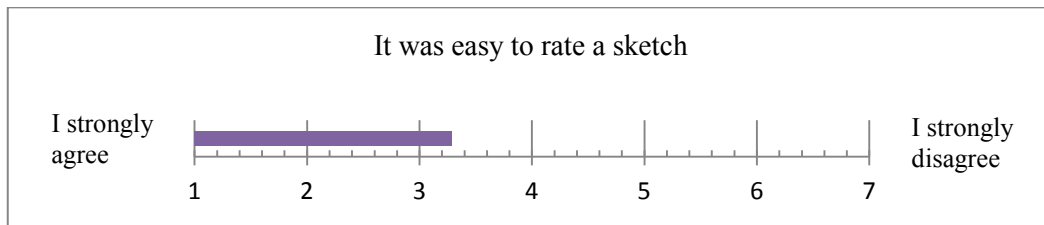

Figure 54. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants liked it that they were able to freely decide to use this function.
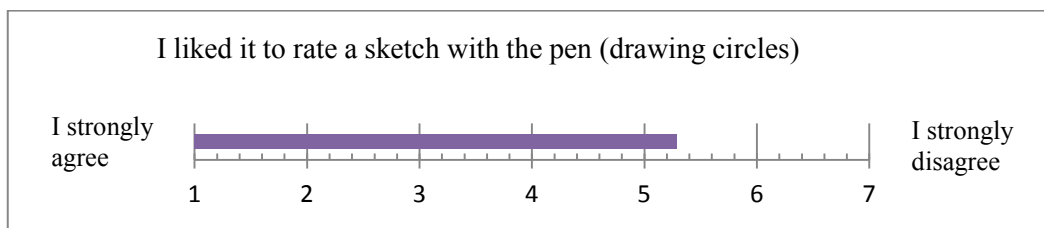
Figure 55. Strongly agree = 1 to strongly disagree = 7. This figure shows that the participants disagreed with making circles in order to rate a sketch.

Based on the focus group, some participants reported that they were confused about the rating field (see Figure 41, the green field). For example, one design student crossed out the pre-printed circles, even though the participants were introduced into the paper-based functionalities and the ways in which they are to be used correctly. Another participant confused the rating field with a scale and thought that the circle at the top implicates more value than the circle at the bottom. One participant also stated that this rating field limits evaluation, since he wanted to add more annotations to make his decision comprehensible, or to notice the status of the idea-development e.g. "*idea still in progress*".

The rating-phase was initiated and accompanied with sorting and clustering activities. Therefore they extensively used the paper-artifacts, e.g. they dragged around and flicked through the sketches, they pointed with their fingers on them and they passed the sheets to other team members. In three of four sessions, the students and the facilitator discussed and rated the ideas on the table (see Figure 56a & b).

In one session, the facilitator ordered to attach the artifacts to the bulletin board (this brainsketching session was applied without digital support). Accordingly, annotations, discussion and the idea evaluation took place on the vertical surface (see Figure 56c))[29].

At the end of the rating-phase, one group automatically shifted the focus of their attention from the table away towards the display with the intention to rearrange and to cluster the most important ideas (the ideas with the most ratings) into meaningful categories (see Figure 56e) - for example from top to down or by size. One participant stated during this activity:

–   *"I guess it is hard now to find and pick out the sheets again and put them on there [she pointed on the display] so that they are large. Actually everyone has focused the attention now on the display and therefore, we should move to, and work with it"*

The facilitator confirmed within the focus group: *"Now, I want to work digitally"*, meaning that he would also prefer to use digital means for clustering after idea generation took place. Unfortunately, this display was non-interactive, since this surface was intentionally employd for supporting idea reflection not idea manipulation.

This situation points out that the participants disregarded the physical artifacts on the table and they freely turned their attention toward the digital workspace. To conclude, since both surfaces (bulletin-board & digital display) are used for creating an overview of the design space and are used for reflection activities, the non-interactive display does not differ crucially from the physical bulletin-board. However, the interactive digital display allows, in contrast to the physical variant, the integration of additional functionalities into the workflow of the design session and exemplifies the main benefit of computational power. All in all, this argues for an integration of a large display in order to maximize power. In doing so,the participant named features like image retrival by key-words, by feature-extraction or by keyboard-input (virtual or physical keyboard) to search for inspiration, to create new ideas, or to enrich the virtual sketches with further design information. In addition, this enables also the digital archiving of the group-based output.

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[29]It is likely that this group wouldn't have used the bulletin board, if the facilitator hadn't ordered it, due to the fact that this group also preferred the digital display in the second brainsketching session with digital support (see Figure 56d).
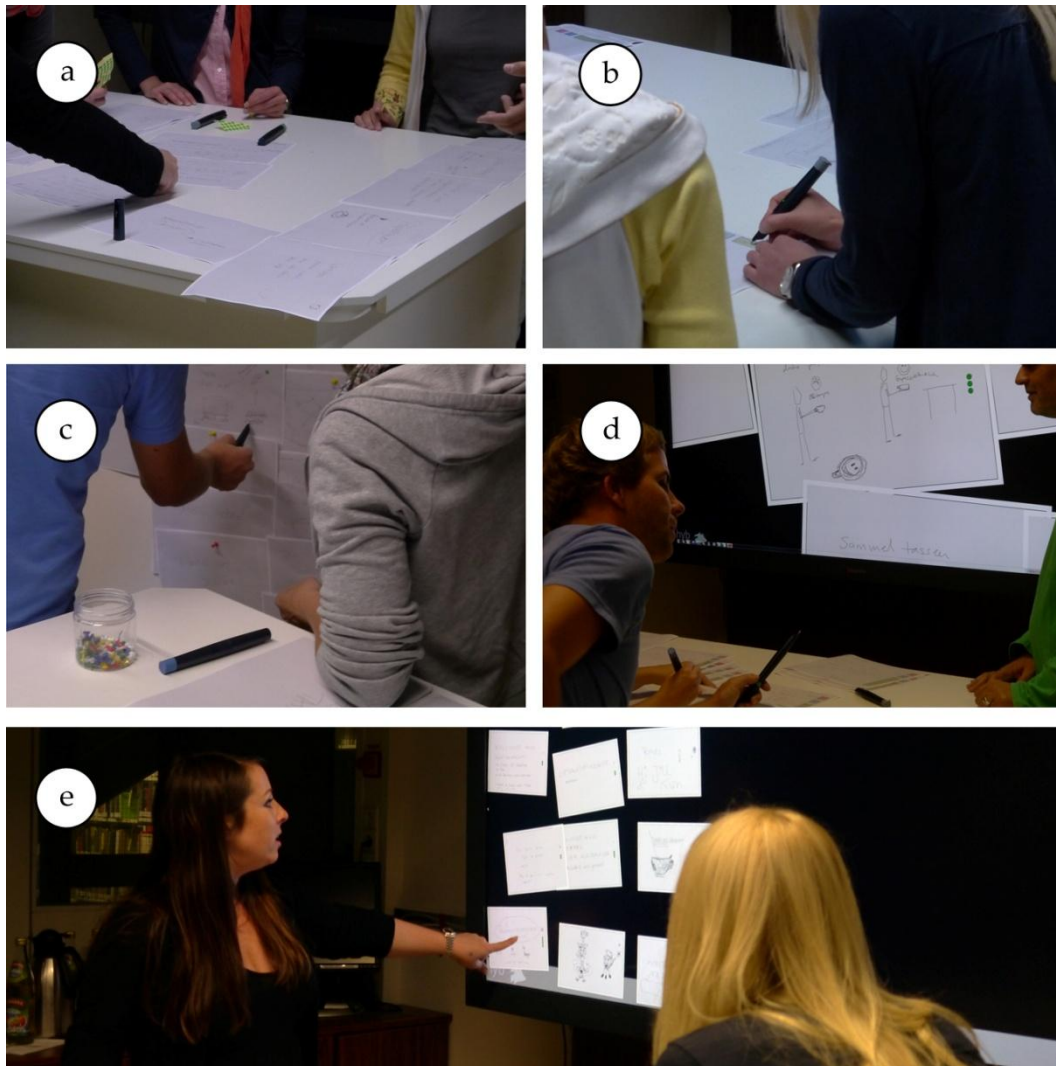
Figure 56. The creative workers used mainly the table as workspace for rating activities (only one group performed the rating-activity at the bulletin-board (c)), disregarding whether technology was integrated or not (a) & (b) & (d). Image (e) also clearly shows that the participant intuitively would interact with the digital artifacts for design analysis (however, this display was intended to be non-interactive).

4.4   Evaluating the Computational Support for the Facilitator

This behavioral study investigates the way in which the facilitator guides the group through the session and the ways in which the provided set of functionality (see Figure 57) influences the moderation of the creative session accordingly.

4.4.1   Results Facilitator: Workspace-Design

Figure 57. Set of functionality for the facilitator.

Based on the analysis of the four sessions (two with-, two without technology), the facilitator permanently encouraged the creative workers in thinking aloud. In doing so, he asked the design students about their opinions and he fostered individual and group-based reflection on single ideas. He often combined the essence of multiple ideas e.g. the current idea of interest with recent generated design information (combination of matrices of thought according to Warr & O'Neill 2005) and he assigned tasks to participants e.g.: "*write that down please that's a good idea*". At last, the facilitator also drew and wrote down thoughts for undertaking idea externalization as well, which means that he often shifted his perspective and role from a moderator to a creative worker and vice versa. Generally, the sessions with technology support hardly affected his behavior regarding the way in which he guided the creative workers through the phases of ideation, idea reflection and idea rating. He never used the moderator's tool, meaning that he never went away from the table and he never left the creative workers on their own (Figure 58, top). Referring to his statement, he explained that he didn't want to leave the group in order to be permanently aware of every written, verbal-, and non-verbal output at any time. Subsequently, he would use the moderator's tool later on after the session. However, he also mentioned that he was only able to manage the group work because the group's size was very small (3 persons).

At the next computer-supported brainsketching session, a second moderator was engaged, who was able to concentrate on utilizing the features of the digital tool (Figure 58, bottom). This person has been termed as co-facilitator or co-moderator. Based on the observation, he primarily spent time in navigating and panning through the hyperbolic-space by looking at the virtual ideas and watching their evolution towards a tree. This co-facilitator used the interactive tree-visualization for visual and spatial orientation, since he flipped through the virtual ideas in a playful manner. By means of the questionnaire, he agreed that the hyperbolic tree visualization facilitates an overview of the group-based productivity and fostered awareness of the creative activities of the participants

(by the glowing-effect that fades off step-by-step). He also stated that this kind of tree-view enables the detection of fixations. But there was also a shortcoming mentioned, since it was difficult to navigate directly to an idea of interest e.g. to the idea, which was currently being discussed by the group. Therefore, he proposed a special glowing-effect, so that those ideas on the group's display are highlighted within the tree.

Figure 58. At the top: moderation without an additional facilitator; at the bottom: moderation with additional facilitator support.

4.4.2   Results Facilitator: Sketch-Based Functionalities

The co-facilitator often zoomed onto virtual sketches, using ZOIL semantic-zooming service, during the browsing-activities. Accordingly, the detail-view was basically used closely followed by spatial navigation. He also zoomed onto virtual sketches, when these were "glowing" (when a creative worker drew on physical sketch). Referring to the questionnaire, he reasoned that he used the

zooming-functionality for regarding every detail of the design information, to have access to the sketch-related functionality and to watch the development of an idea bit by bit (Figure 59, left).

Regarding the "identification"-function, he stated that he used this feature for displaying the contributions of every creative worker and for making the differences between the ideas visible (especially between earlier ideas) (Figure 59, right). Moreover, this function could also help to identify every participant afterwards when applying patents.
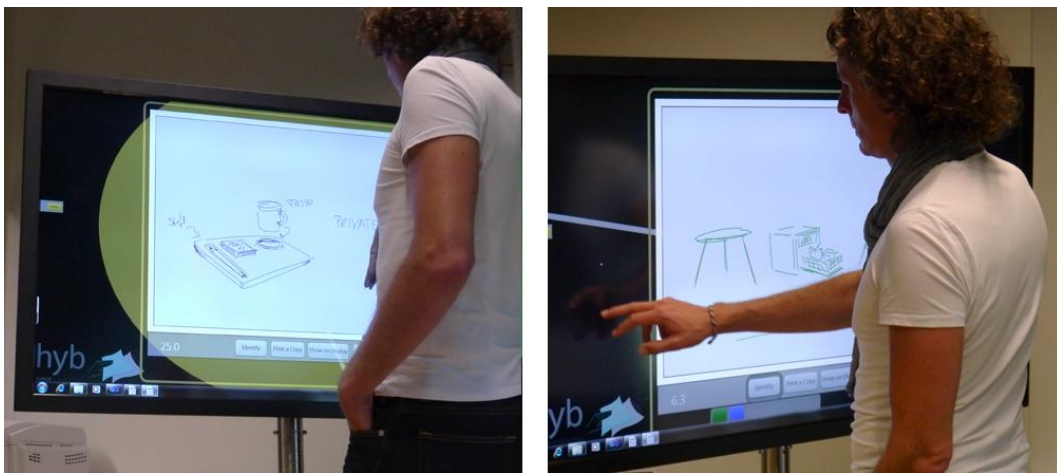
Figure 59. The facilitator often zoomed onto ideas that are being modified (image on the left-hand side) or to he made the participant's contributions visible (image to the right).

During panning and navigation, the co-facilitator also shifted the focus of his attention from the display to the group in order to observe their sketching activities. He also analyzed the group's reaction when sending arbitrary virtual sketches quietly to their display without informing them about his move (see Figure 60, the image to the top and the image to the bottom). According to his statement, he used the highlighting-function to emphasize ideas that should be taken into account for inspiration or for re-interpretation. Referring to the results of the questionnaire, he therefore highly appreciated this functionality.

Both moderators agreed within the focus group that the co-facilitator should also have the ability to cluster and classify the design output digitally at the moderator's display. The co-facilitator should also be able to make the current arrangement of the virtual sketches apparent to creative worker e.g. by transferring the clusters to the creative worker's display. Subsequently, they can use the pre-clustered ideas together with the moderator as initial input and inspiration for interconnecting ideas meaningfully. The facilitators stated that they would highly appreciate computational cluster support while the creative session takes place, since they spent much time afterwards evaluating and

linking the design output with respect to the objectives. One statement of a facilitator confirms:

– *"Much of what we are doing is sorting and trying to understand, why ideas were being generated, how many ideas were already being created and whereupon not enough ideas were being generated; that's why clustering is essential [in order to create an overview of the design space]"*

Figure 60. The co-facilitator could easily shift his focus from the tool to the group for observation and vice versa.

Within the phases of idea creation and idea reflection, the facilitator who guided the group of creative workers not only got support by the co-facilitator in terms of sketches that were being sent to the group's peripheral display, but also got support by physical sketches that were being printed by the co-facilitator. The co-moderator reasoned that he wanted to support the group with additional input by means of the printed artifact. In one situation, the group moderator went to the co-moderator with two sketch-artifacts in his hand and he asked the co-moderator to combine those two sketches as these ideas are "immediately" to be

used for further refinement (see Figure 61).

This situation clearly indicates that there is a basic need for merging thoughts into a physical design artifact as this situation also fostered the interplay of the moderator and co-moderator. Referring to the questionnaire, the co-moderator stated that the sketch-combine-, and the printing-functionality both are highly necessary for bridging the digital and the physical world, so that the digital content is becoming real. Hence he highly appreciated the utilization of these two features.
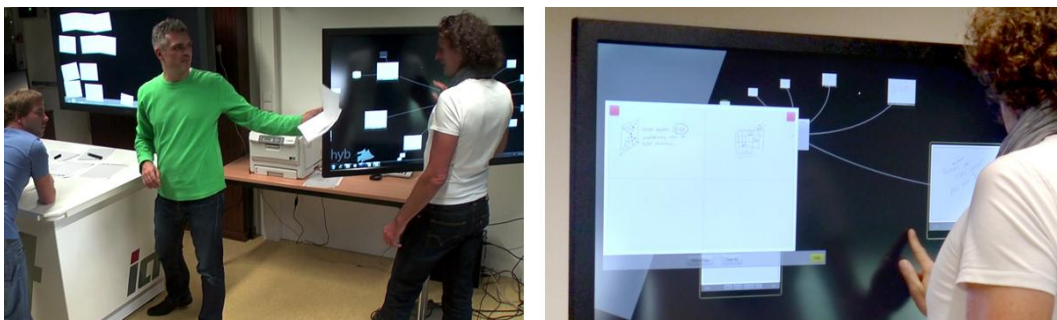
Figure 61. Interplay among facilitator and super-advisor in terms of multiple ideas that are to be combined.

4.5   Discussion

The social factors and the design fixations were being initially used as a basis for making decisions about the way in which brainsketching activities can be enriched meaningfully with digital means. Therefore, a case study was conducted to investigate the general benefits and pitfalls of the *hyb*-system together with its interaction techniques.

Digital Workspace: Creative Workers. Regarding the first design decision, it was aimed to preserve the basic workflow of brainsketching in order to address *Production Blocking* by using an ordinary table and pen & paper. With respect to the second design decision, it was aimed to enrich the creative process with computational power through interactive paper-artifacts and a peripheral non-interactive display for addressing *Evaluation Apprehension* and supporting phases of discussion. Generally, no differences were examined between the technology and the non-technology conditions regarding the single phases of the design technique (ideation, distribution, discussion, and rating). It is argued that the moderator guided the participants in a very powerful manner. One participant for example reported during the focus group:*"So, the things we've done up to now, didn't distinguish much from what we have done before"*, meaning that she didn't

precept any differences relating to the workflow when using the digital tool. Aside from the contributions of the facilitator, the results of the questionnaire also led to the assumption that the pen and paper-based work, augmented with interactive areas, helped to make the interaction with the *hyb*-system easily comprehensible for the design students. Hence it didn't hinder them form accomplishing their creative tasks in general.

Reviewing the functions for the creative workers, the printing-function for example has the potential to foster the reuse of sketches, especially when crucial supplementations or modifications are to be made. This function eases the violation of the design artifacts as seen in Figure 48b & b1 (they used the duplicates also to scratch out particular aspects of an idea and it is hence likely that this function supported them to express their rejection). Referring to the rankings of the design students, the printing-operation is generally useful within sketching activities. Therefore, linking the finding of this functionality to its initial purpose, it is assumed that this function especially would offer help to those people that have any modification apprehensions, especially when these apprehensions occur unconsciously. The main benefit of this function however, a finding of the user study, is that it supports exploration and divergent thinking by allowing for making multiple variants of a single idea by different persons, simultaneously (according to the statement and behavior of the facilitator).

In review of the nature of the display and the highlighting-functionality, it is clear, that they were both frequently used throughout the design session and there was consensus among the participants that this functionality helped them to demonstrate their ideas to the group. The verbal articulation mainly took place at the table and they mainly used the analogous artifacts for idea communication, which also meant that the digital display didn't cause a shift of focus albeit some participants stated that they were slightly distracted by the display. Concerning this possible drawback, an approach was named by the facilitators by offering a *function-deactivation service*, so that the facilitator can control the use of this function. This however increases the tradeoff between reality vs. power, due to fact that the facilitator must handle a new task (the activation and deactivation of the highlighting-function) additionally to his ordinary tasks e.g. managing the group work. Nevertheless, according to the statements of the participants the main benefit of this display and the highlighting-function is seen in design sessions with more than three participants. This is so because there is massive design input and the participants have to require more effort to direct the attention of the others e.g. for demonstrating modifications or novel thoughts.

Considering the rating-functionality, it differs from the printing-, or the highlighting-function crucially as this feature rather replaces a traditional design practice than augments it with additional power. In this sense, the creative

workers were forced to use this function in order to finalize the brainsketching session. The participants generally disagreed with the way in which the rating-activity is to be performed, since they disliked it to draw circles and they were partly confused with the rating field. On the other side however, they appreciated the use of digital power within the phases of rating in order to discuss, to modify / enrich and to rearrange the rated sketches digitally on the display into meaningful clusters. Hence, the conclusion is that when the digital design-artifacts become directly accessible on the group's display, this allows for an easy transition from reality to power, since the participants and the facilitator freely shifted their focus from the real world to the digital word. Subsequently, this provides the opportunity to offer additional functionality and may enhance the group-based negotiation as well as the digital archiving of their design solutions. There is however a tradeoff to handle when integrating a display into the session. On the one side, it is attracting some creative worker's attention too much; on the other side, it offers new ways in designing computational support for convergent phases and hence adds more power to the interface.

Addressing RQ1. As a result of the observation, no violations of the original workflow as well as of embodied practice have been identified due to the integration of the digital tool. This also means that the functionality for addressing RQ1 was being successfully implemented. The resulting categories from the qualitative analysis are listed in Table 7 (creative workers) in order to provide an overview of the functionalities and their essence.

Digital Workspace: Facilitator. Regarding the results of the facilitator, he was intensively involved in the session with guiding the group work. Thereby, he practiced the exploration of new solutions, he encouraged others to generate and to re-interpret ideas (phases of ideation and distribution) and he was willing to reach a common understanding of each idea by fostering communication and "thinking aloud". He didn't use the digital tool, since he was afraid to lose the control of the group and design moves of the participants accordingly (drawings, thoughts, gestures etc.). Hence, this finding led to the recommendation to integrate a second facilitator into problem-solving process, as the second facilitator could concentrate on utilizing every feature of the provided set of functionality. In doing so, this co-facilitator mainly used the interactive hyperbolic tree and ZOIL's semantic zoom functionality in order to browse and flip through the design space. According to his statement, the hyperbolic-tree's native visualization and navigation has the potential to improve the perception of design fixations and the yellow glowing-effect additionally allowed for awareness of every participant's design-activity within the design session. As a result, the interactive hyperbolic tree visualization successfully served the purpose for revealing cues of *Early Fixation*. Referring to the findings of the "identification"-functionality to its initial purposes, this feature wasn't used for

identifying less contribution during the session (*Free Riding*) as this inhibitor of creativity was apparently approached by the facilitator who permanently encouraged the people in participation. Hence, this function is rather beneficial for a) making modifications of different people visible (allows the co-facilitator to track the development of a sketch) and b) after the design session, this function could be helpful for the personalization of each idea for bringing output and person into relation, especially in case of a patenting.

The main benefit of the moderator's highlighting-, sketch-combination and printing-functionality is seen in performing information-input to the group for leading the development of the ideas towards new directions. Thereby, the printing-operation helped to bridge the digital-physical barrier in terms of printing combinations of multiple ideas to paper (hence therefore essentially); and the digital variant (highlighting-function) enabled him to control the viewport of the group's display for emphasizing interesting ideas.

Addressing RQ2. According to the finding of this case study, the largest benefit of the *hyb*-system however is seen primarily in supporting the value of clustering, classification and organization through the co-facilitator. With it, he can simultaneously interconnect the group's output on his display with respect to the initial objective. This however, also requires a new visualization-style of the design space in addition to the hyperbolic-tree representation. As a result, relating the findings of the case study to RQ2, the *hyb*-system didn't have any impact on the moderation with only one facilitator, since one facilitator alone had difficulties in handling both the group and the *hyb*-system simultaneously. Hence, a second facilitator who was able to utilize the whole set of functionalities during the session has been involved into the brainsketching process, meaning that the *hyb*-system created a new user-role e.g. a person who operates mainly in the background and analyzes the output of the participants. One moderator concluded:

- *"Tom [the name of the co-facilitator] contributes to the problem-solving process and he can ask specific questions to the facilitator in-the-field or to the group. This wouldn't make the session more creative but more productive, as the supervisor can ask the 'better' questions"*
- *"I also claim that the overall-result will be notably better [according to the 'better' questions by means of the analysis-support of the facilitator's too]*

These statements lead to the assumption that a second facilitator is necessary in order to offer additional support for problem solving meeting. Thus, the *hyb*-system influences the *moderation, since a new co-moderator* is required, who gives *instructions* and *asks questions* about the design content. This person is also able to

perform design input by means of a combining, printing and highlighting functionality for contributing to the effectiveness and quality of the group work. Table 7 (facilitator) provides an overview of the resulting categories from the qualitative analysis.

Table 7. Resulting categories of the tool support for the creative workers.

Creative Workers	
Variable	Resulting Categories
Workspace: Design Environment & Anoto Technology	• Table and pens have been used for individual and collaborative ideation • Ideas were sorted, clustered and pooled • Table was storage place for personal objects • bulletin-board wasn't used • Table should be larger in order to have more design space and space for accomplishing individual tasks (ideation, sorting, browsing). • Pens with different colors should be available for supporting highlighting aspects on the sketched artifact
Printing-Function	• Helpful to persist ideas (take ideas home) • Enables divergent thinking in parallel by allowing splitting the design direction • Intensifies the chance of crucial modifications by minimizing inhibitions violating the design content. • Print-process lasted to long • Waste of resources
Highlighting-Function	• Supports the introduction of novel ideas (foster equal visual access) • Helps to make modifications and novel ideas apparent to the group • Used display for system feedback • Useful in large group situations (more than 3 members) • Distracted participants, since the display and the digitalized ideas unconsciously required more attention

	• Overview within the design session hardly used
Rating-Function	• Enables a better overview and a fast identification of important ideas amongst others • Overview of rated sketches facilitated a smooth transition from the physical world to the digital world (creates a social digital surface). • Rating must be better visible on the display (by size, by order e.g. from top to down) • Space on the interactive paper for annotations wanted • Scoring by crossing-out instead of making circles

Facilitator	
variable	Resulting Categories
Workspace & Design Environment	• Group-moderator acts as also as creative worker • Confirmed using pen and paper for ideation • Moderator handles the group's output: he encouraged the participants in idea generation, he encouraged the creative workers in idea-refinement, and he linked and combined ideas mentally. • With one facilitator: One facilitator can utilize the tool's functionalities when groups are larger • Co-facilitator: Second facilitator needed (co-facilitator) for exploiting the tool's functionalities.
Interactive Hyperbolic-Tree Visualization	• Interactive tree enables overview of the design session and fosters idea browsing • Branches and nodes helps to keep track of the idea development (branches communicate a design history) • Glowing helps to keep track of the design action • Branches and nodes disclose fixations • Waste of space: Tree inappropriate for visualizing only few ideas (at the beginning of the session) • Lack of Accuracy: Tree inappropriate when searching for a precise idea • Lack of access: Access to the window of the creative workers wanted for clustering and classifying ideas in parallel. Pre-clustering helps the co-facilitator to mediate interconnections

	between thoughts to the group
Identification-Function	• Coloring the design contributions helps to reveal the differences between the source idea and its branches and eases the tracking of the development. • Helps to reveal the creator of an idea in case of a patenting • Fail of Initial Purpose: Not used for minimizing free riding, as this was done by the moderator
Printing-Function & Sketch-Combining-Function	• Meets the need for merging digital artifacts for creating novel design input for the group (inspiration) • Bridges the digital-physical world so that virtual artifacts are becoming real. • Physical Input for the group (combined as well as single ideas)
Highlighting-Function	• Inspiration for the group by sending idea to the group's display • Drawing the groups attention to the idea of interest

5 Conclusion

This master thesis research relates to social creativity and encompasses the analysis of collaborative activities (section 2), the examination of drawbacks and the design of customized solutions (section 3) and a group-based user study in order to verify those concepts (section 4). The overall aim of this master thesis is to support and to improve the brainsketching activity by enhancing this social creative process with computer technology in a meaningful way.

5.1 Resuming the Characteristics of Social Creativity

The starting point of this research was an analysis of social creativity and of closely related subject matters e.g. the nature of creativity, sketching and the related research.

In doing so, the research of Vyas et al. (2009) have been considered to give an understanding of the design practice and its underlying collaborative nature. They concluded that the physical environment and the body are both to be considered as tools within design and idea externalization. For instance, the designers created personal, individual, but also public and shared surfaces on tables and walls for applying different variants of design techniques e.g. sketching. Thereby, sketching is a concrete method of idea externalization (Vyas et al., 2009), and many authors like Buxton (2007), Johnson et al. (2008) and Craft & Cairns (2009) associate with sketching a design method, which enhances creativity through ambiguity and supports lateral ideation and idea reinterpretation within divergent design phases. Cook & Bailey (2005) further confirm the use of traditional media for conducting sketching, as they revealed that professional designers highly appreciate the use of ordinary pen and paper in early design phases for performing "lateral transformations"[30].

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[30] This term means massive idea *exploration* like creating a variety of new ideas. In contrast, the idea *refinement* is termed as "vertical transformations" (Goel, paraphrased by Johnson et al. 2008).

With focus on negative effects of social communication, researchers like Diehl & Stroebe (1990) and Warr & O'Neill (2005) introduced within this context three factors that prevent social interaction.

- *Production Blocking*: The persons can't verbally express their ideas in the moment when they are occurring. Therefore, synchronous (simultaneous) idea communication such as writing helps to overcome production blocking.
- *Evaluation Apprehension*: The participants fear the criticism of others. It is suggested to decrement the identification between the ideas and its creator (more anonymity).
- *Free Riding*: The participating persons don't contribute to the problem solving process. Therefore, it is suggested to increment the identification between the ideas and its creator (less anonymity).

Due to the trade-off between evaluation apprehension and free riding, Linsey et al. (2005) for example used different colored pens for fostering anonymity amongst the outputs of the participants. At the same time, a creativity moderator however can still match the color to its owner, which prevents participants from social loafing.

In the next step it was then considered how collaborative sketching activities have been approached by the related HCI research. As a result, the related work mainly replicated walls and tables with digital interactive displays in order to mimic real-world scenarios. Limitations to reality have been found, as they implemented the tools for divergent and convergent activities with artificial devices e.g. stylus-based handheld computers or digital whiteboards. Moreover, the negative social factors "were either completely disregarded or were mentioned only marginally, which contradicts the intention of the authors in terms of supporting social creativity" (Budzinski, 2011b, p. 3). Therefore, this master thesis research strives for adapting digital solutions closely to issues of collaboration by taking the social influences and a rule-based design technique into consideration. An appropriated and demonstrative design method is brainsketching promoted by van der Lugt (2002a) (Budzinski, 2011b).

5.2 Resuming the Interaction Concepts of hyb's Computational Brainsketching-Support

The findings the analysis are used as a basis for designing the system. This part mainly concerns the development of the design criteria in relation to two user-types, namely the creative worker - who creates design content - and the

facilitator - who moderates the idea generation session. Therefore, the theoretical framework – Reality-Based Interaction (RBI) – introduced by Jacob et al. (2007), as well as observations of university's design students, have been taken into account in order to examine potential tradeoffs between power and reality. Thereby, some characteristics of reality are to be considered as crucial for the success and effectiveness of the design technique and should be hence preserved (phases of ideation & discussion and the cycles of distribution). But at the same time, limitations or divergences of reality were identified that are worth being enhanced with computer power (impaired visibility to design artifacts, no use of the bulletin board). Moreover, due to the fact that emotions and creativity are affected by other people within group-related activities, a review of creativity related issues like the social factors as well as the fixation-phenomenon have been considered in addition to the RBI-framework for defining a set of final design-criteria (see Table 4).

5.2.1   Supporting the Creative Workers

As a result, drawing upon the findings of Warr & O'Neill (2005) and van der Lugt (2002a), the original workflow of the design technique is to be preserved, since brainsketching itself partly faces *production blocking*. The next issue e*valuation / modification apprehension* was aimed to allow the participants to create physical copies of the sketched ideas in order to overcome one's inhibitions to draw on other's paper-artifacts and to foster the reuse of ideas accordingly (a sketching-related interpretation of *evaluation apprehension* was termed hence as *modification apprehension*). In order to preserve the workflow of the design technique but enable also additional functionality – RQ1 - the following three key decisions were made:

- An ordinary table was employed as familiar physical workspace for maintaining individual idea reflection and group-based communication.
- For adding power, Anoto's digital pen and paper technology is used for creating paper-computer interfaces with interactive areas (functions that support the creative workers). At the same time, the participant can still work with ordinary pen and paper that preserves individual ideation. The functionality that was integrated support *printing*, *highlighting* and *rating* and the digital pen is to be used as an input device.
- The session was composed with a non-interactive peripheral display for supporting the phases of discussion (improving the visibility of the design content) and for enhancing the paper-computer interface with visual feedback (e.g. whether the paper-functions were successfully handled by the computer or not). Additionally, this peripheral display also replaces the bulletin-board, as every highlighted artifact stays

attached on the display automatically. Hence this display serves as a "wall of inspiration".

5.2.2   Supporting the Facilitator

In order to support the facilitator, the two related issues of creativeness, *free riding* and *early fixation* (literarily investigation, Warr & O'Neill, 2005; van der Lugt, 2002a; and Valancich et al., 1994) have been used as guideline, together with the experiences gained during a participatory observation of a creativity workshop. Concerning *free riding*, it was suggested to offer a tracking mechanism of each participant's contributions within the design session so that the facilitator is aware of every individual's productivity. According to Linsey et al. (2005), using colored pens enables the facilitator to match the design content to its creator and fosters anonymity among the participants to some degree. Concerning *early fixation*, it was assumed to provide an overview of the design space and a mechanism that allows for basic manipulation of the digital artifacts, so that the facilitator is able to reflect upon the group-related productivity and can work with the digital artifacts at the same time. Finally, the following features have been enveloped:

- A function has been implemented that colors the digitalized strokes (on demand) with respect to the pen ID and the pen owner accordingly.
- The development of an idea is represented by means of a tree (each modification generates branches and leaves). Additionally, an interactive hyperbolic tree-visualization according to Lamping et al. (1995) has been used for providing a combination of a focus, -and a content view of all trees. Therefore, the hyperbolic tree scales dynamically according to number of ideas and adjusts these automatically during the design session.
- The digital sketches (nodes of the tree) also offer functionalities so that the facilitator can print-, highlight- and combine sketches.

5.3   Resuming the Case Study for Evaluating hyb's Interaction Concepts

The notion of the above-mentioned interaction concepts has been implemented and is demonstrated within a system (*hyb*), which promotes the dynamical work of both the creative workers and the session-moderators. In order to investigate the systems impact on informal activities e.g. ideation, idea-discussion, idea-distribution and idea-rating; and to study how the tool affects the moderation of

these sessions, two case studies have been conducted to capture the initial reactions from seven design students (divided into two groups) and from two professional moderators with expertise in creative problem solving. Their statements helped to evaluate and to improve the system's interface (paper-based functions, interactive tree-visualization) as these results allow for facing the initial research questions.

Therefore, the user study was designed according to a *within-subject* procedure with two different treatments – without & with computer support – lasted for two days with one group per day. Using a within-subject study design enables the participants to compare the different treatments (with or without digital support) and they could hence better reveal the pitfalls and the strengths of the system, as well as its impact on embodied practice. Thereby, the first group was moderated by one moderator and the second group was moderated by two moderators – the moderator from the first group and a second co-moderator – as the first moderator stated that he was overwhelmed handling the system and the group synchronously. This also means that the moderator didn't used *hyb's* moderation support during the first meeting.

The collected data was then analyzed with respect to the *general applicability*, *the functions* and the *user behavior*. Therefore a qualitative analysis, derived from Mayring (2000; 2010) and Mayring & Brunner (2007), has been chosen for applying a systematic approach when interpreting the data. As a result, RQ1 is considered as successfully achieved, since the interaction concepts as well as the integrated technology (paper-based interface, peripheral display) didn't crucially conflict with the original workflow of brainsketching. At the same time, this system enables additional functionality as to idea communication and diverged thinking. The main benefit has been examined during the phases of rating due to the fact that the rating-functionality promoted working on the digital surface, meaning that the participants and the moderator would prefer to utilize the display and the digital artifacts rather than the physical artifacts on the table. Drawing upon this finding, composing the workspace with an interactive surface provides the opportunity to add more power to the computer interface by offering more functionality to the creative workers and to the moderator within brainsketching (in this case, the display serves as a window to digital world). Considering RQ2, the findings of the user study clearly point out the system's impact on moderation, since this tool created a) a new administrative role within the creative process (co-moderator) and b) the moderator's set of functionality supports the value of analysis and it fostered synergy effects amongst the co-moderator, the moderator and the design students.

As a result, it is considered that the *hyb*-system, and its underlying bundle of interaction concepts, successfully supports the social creativity as well as the

moderation of brainsketching sessions. This thesis however also points out new challenges and opportunities that emerge for future work regarding sketching activities that are augmented with computational support.

5.4   Future Work

The outcomes of the empirical study reveal that additional features for reflection and clustering are required and essential for enhancing the effectiveness of the group-related performance and for making the organization of every idea more efficient. Therefore, the future work will introduce new concepts, but will also focus on current issues related to the interface for leveraging *hyb's* potentials.

5.4.1   Interface Design: Elaborating and Augmenting the Paper-Based Interaction Concept

Due to the questionnaires and the focus group, various issues with the paper-based interface have been identified and denoted in section 4.3 (p. 65). Thereby, the criticism mainly related to the salient appearance of the buttons and to the missing space for individual or context-related annotations. Summed up, this lead to the design of the following new paper-based interface (see Figure 62).
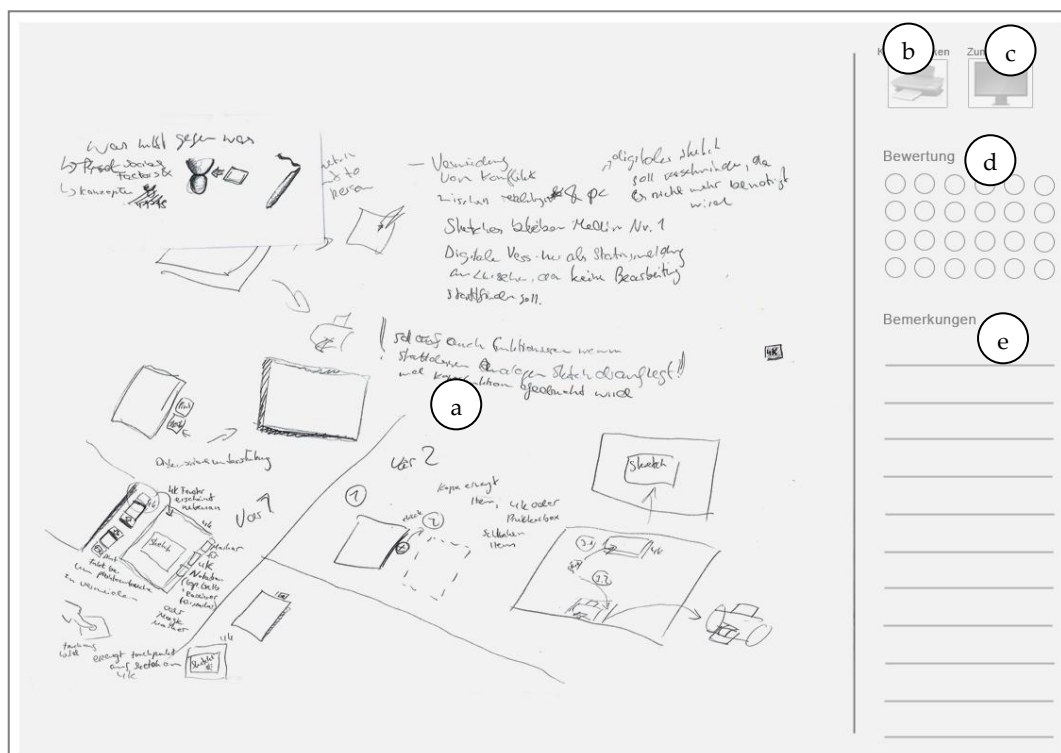

Figure 62. Paper-interface with re-designed interactive areas (image composed with token).

1) *Drawing Area*: This field still represents the drawing area and is visually separated from the interactive functions by means of the thin line (Figure 62a).

2) *Printing-Function*: The printing-function is illustrated with means of a little icon (as suggested by the design students), and the button has less opacity in order to attract less attention[31] (Figure 62b).

3) The *Highlighting-Function*: The highlighting-function is divided into its essentials: *sending* and *focusing*

    a. *Sending*: The use of the sending-function will put this sketch virtually on the display space as the highlighting-function did before, however *without* causing a zooming-animation. Using the sending-function again will remove the virtual sketch from the display space. In doing so, using no zooming-feature ensures an overview of every attached idea. The sending-function is also illustrated by a small icon with less opacity[32] (Figure 62c).

    b. *Focusing*: In order to highlight an idea by zooming, a special tangible object called "focus-token" is to be used. By placing this token onto a sketch, the system automatically zooms onto the corresponding virtual version (as the highlighting-function did before) (Figure 63a). By lifting the focus-token from the sketch, the system accordingly zooms out and the overview is restored (Figure 63b).

Thereby, the focus token is to be kept safe from the creative workers with the help of a preserver e.g. by means of a moderator. In doing so, mapping the focus-functionality onto a single physical object aims at controlling this feature, e.g. the moderator can hand this object to a person who wants to emphasize an idea within the discussion. It is assumed that this mechanism minimizes those distractions that were being caused by improper use of this service during phases of ideation and idea distribution (especially by dominant group members who constantly used the highlighting-function without any reasons). Accordingly, the new focus-token is a powerful instrument for the moderator in order to coordinate the discussion easily (the focus-token is actually only a prototype, made of an ordinary carton package with an Anoto pen inside. Due to a hole at the bottom of this package, this pen has contact to the paper beneath (see Figure 63, left). Thereby, the system is programmed to zoom always onto the sketches touched by this pen according to its specific pen ID).

4) The *Rating-Function*: This field of circles is to be used for scoring the idea. The arrangement of the single circles shouldn't suggest a scale and shouldn't

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[31] image source of the printer-icon: http://www.pctechnik-koblenz.de/drucker.jpg (last access 23.01.2012)

[32] Image source of display-icon: http://www.psdgraphics.com/file/black-lcd-display.jpg (last access 23.01.2012)

confuse the creative workers. In doing so, the user solely has to cross out the circles (Figure 62d).

5) The *Annotation Field:* This field complements the rating-function in terms of textual information, since the participants stated that they miss space for writing comments or suggestions (Figure 62e).
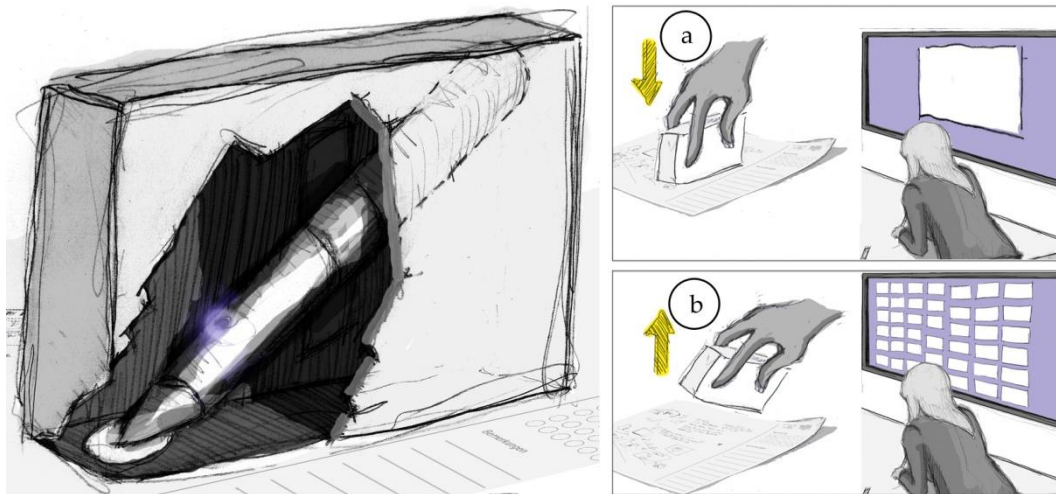
Figure 63. Using „Anoto-Token" for highlighting.

5.4.2 Supporting the Value of Design-Information Management: Interaction Models for Clustering

The display within convergent design activities during idea reflection and idea rating allows for extending the scope of functionality without conflicting embodied practice of the creative workers and the moderator. By transforming this display – mainly used for reflection - to an interactive digital-social surface, the virtual sketches will become interactive; this could foster the value of organizing creative output collaboratively (Figure 64). Additionally, features can be integrated into this process with appropriate interaction techniques for supporting archiving of important design-solutions and for providing access to the World Wide Web. Especially the latter one allows for image- or text retrieval, based on the content of the sketches, for searching for inspiration or for enriching the virtual design artifacts with additional information. Hence, the digital display almost replicates existing practice with the physical bulletin-board, but the digital variant provides the opportunity to integrate more computational power into the design process for increasing the quality of creative outcomes.

Figure 64. Supporting value of clustering for the problem solving group.

On the other side, supporting the cognitive activities of organizational thinking appeared as an essential requirement for the co-moderator as well. Therefore, the sketches on the creative worker's digital workspace should be shared with the co-moderator e.g. by offering – in addition to the hyperbolic space – a view onto their workspace. Therefore, this view can be dynamically spanned across the display space (Figure 65a), so that the virtual artifacts on the group's display become accessible for the facilitator (Figure 65b). In the sense of sharing and exchanging, the facilitator should also be able transfer the rearranged sketches, after organizing them into meaningful clusters, back to the group (Figure 65c). Consequently, this mechanism of information management aims at supporting alternating clustering-activities that improves the interplay of co-moderator, moderator and the group members. This thereby contributes to an effective and intensive collaboration that probably increases also the quality and quantity of the group's performance. According to the statements of the facilitators, the ability to group the design outcome in parallel would also shift this inevitable task from the "back-office" into the active session and thus speeds up the overall information organization.
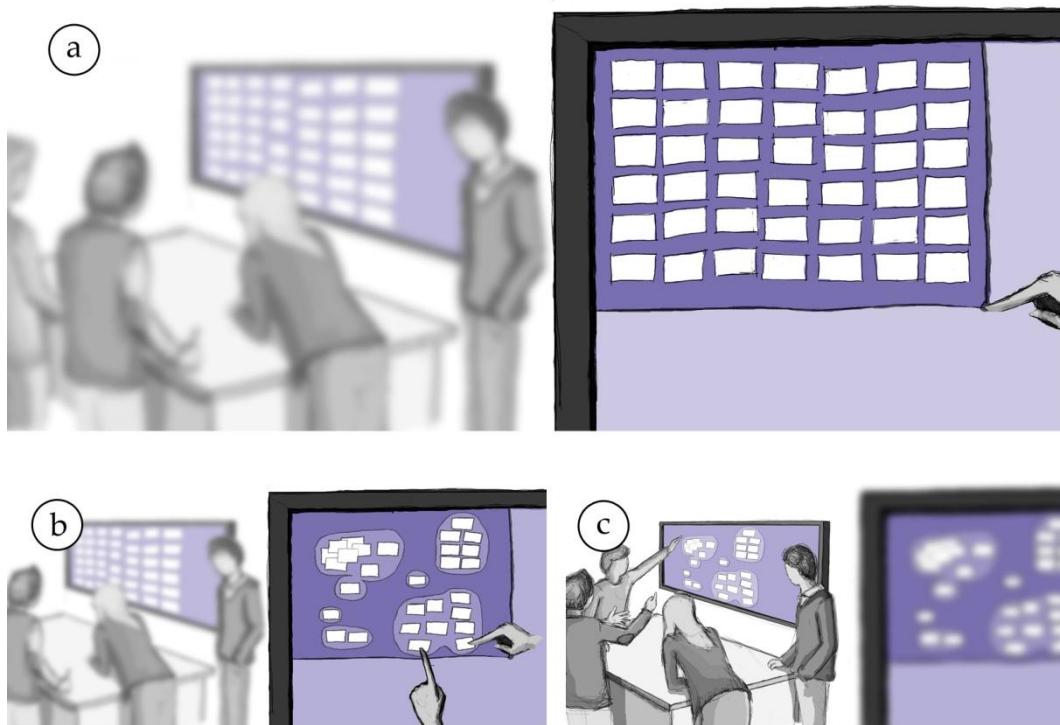
Figure 65. Supporting value of clustering for the co-facilitator.

5.4.3   Further Investigations: Utilizing the Linkography Approach

The next step would be then to investigate an idea generation process, based on the system with the new interaction models, in order to make inferences about the functioning of the technology and its impact on the effectiveness of the group work. According to van der Lugt (2001), there are two experimental approaches common "in the field of creativity research" (p. 51):

1. *Comparing outputs*: This approach studies the characteristics of the output by comparing the differences like the *quality* or the *quantity* of the outcomes with respect to several treatments and a control group. Regarding the quantity of the results, he states: "As most of these studies refer to the quantity of results, or quantity of 'good' ideas generated per person per time unit, they really investigate the supposed efficiency" (p. 51). Considering the quality of the results, he states that: "The quality, or creativeness, of products is mostly studied using psychometric approaches. A well-known example […] is the Creative Product Semantic Scale (Besemer & O'Quin, 1986), which is used by non-expert raters" (p.51, 52) and breaks down the creativeness into meaningful dimensions. Examples are "Novelty (Original, Surprising, Germinal)", or "Resolution (Valuable, Logical, Useful)" (p.52). The raters can then measure the

effectiveness of the idea generation meeting by scoring the design output with respect to those dimensions.

2. *Comparing processes*: In contrast to the comparison of the resulting ideas, this approach is rather suited for investigating the process and its structure itself in order to reach an understanding of "what happens during the process of generating ideas" (p. 56). Therefore, interrelations between ideas and the interpersonal interactions are studied by means of "links". Thereby, ideas and thoughts that, for instance, build upon each other are to be linked (also with respect to its creators) that overall forms a "network of links". Subsequently, the stronger the network of links, the more effective the idea generating meeting was, which is also "an indicator for quality of the process" (p. 57). This approach is generally known as "Linkography" and has been once introduced by Goldschmidt in 1996 (Goldschmidt paraphrased by van der Lugt, 2001).

Applying Linkography. The author suggests that comparing the outcomes alone hardly measures the characteristics of the teamwork and the way in which different design techniques "contribute to the development of design solutions" (p.56) appropriate. By following his line of thought, the analysis-approach for the next *hyb*-system hence is to concentrate mainly on the "differences on the structure of the process" (p. 56) and the network of linked ideas in order to identify what role the additional clustering-mechanism and the novel interaction techniques play within the process of brainsketching.

Therefore, the linkography is to be applied and adapted to the context of computational sketching, meaning that one group conducts two design meetings with two different treatments *with* or *without* computer support (within-subject design, see section 4.1). In order to answer the question how to establish "links", it depends on a definition of a "link system". Van der Lugt (2001) for instance used the following criteria:

- By considering "similarities in subject matter" (p. 66) e.g. link those ideas that apparently build on each other (source and resultant idea, by resembling aspects etc.).
- By analyzing the interactions of the participants with respect to articulation, direction of view and gestures e.g. links are to be made when a person relates verbally to, looks at, or points on earlier ideas when he or she introduces a new one.

Once the links between the sketched ideas have been established, one can infer the particular characteristics of the link – called indices - e.g. the person who established a connection or the way in which the connection was established.

Van der Lugt (2001) for example used the following indices:

- The *link density (LD)* is a number, which reveals the relative "integratedness" (p. 70) of the process. A high link density implies that there are many connections between ideas and earlier ideas.
- The *Self-link index (SLI)* is a measure for the links "that designer make with their own ideas" (p. 70). There are also interpersonal links, when designers built on other's ideas. A high self-link index indicates that the participants rather build on their own previously generated ideas and the idea generation accordingly took place individually, whereas a low self-link index indicates that ideas of others were being extensively used (indicates a "well-integrated" group process).
- The *Link-type indices (LTI)* reveal the nature of the connection e.g. did the person draw only minor supplementations (the number of small alterations), major modifications (the number of different variants) or even tangential modifications (the number of novel ideas on base of earlier ones).

All in all, these indices help to quantify "general characteristics of the meeting process" (van der Lugt, 2002a, p. 46) and allow for a statistical analysis, which hence enable the comparison of different design sessions. By transferring this approach of the linkography towards future investigations, brainsketching sessions conducted with or without computer support can be quantitatively compared. This leads to the following two hypotheses, since it is assumed that the computational brainsketching support crucially affects these link-indices:

- Hypothesis 1 (H1): The computer support (*hyb*-system) increases the number of *interpersonal-links* and thus fosters a more group-integrated process
- Hypothesis 2 (H1): The computer support (*hyb*-system) increases the number of *supplementations* and *modifications* and thus fosters the development of ideas

Regarding Hypothesis 1, the depended variable is represented by means of a *lower self-link index* and regarding Hypothesis 2, the depended variable is represented by means of a *higher link-type index* for supplementations and for modifications.

According to expectations, the bundle of functions for emphasizing ideas, for combining and for clustering sketches should all in all, together with the contribution of a co-moderator who can detect fixations, increase the number of

interpersonal-links and should hence minimize the *self-link index*. It is also suggested that the utilization of the printing-function increases the *link-type index* for supplementations and modifications, since participants with modifications apprehensions should be encouraged in drawing on other's ideas.

To conclude, the application of computer technology in brainsketching activities posed challenges that overall seem to be met for now. Nevertheless, in order to have evidence in the final analysis, only the linkography helps to clarify whether the computational brainsketching support emerges beneficial or not. If so, this could provide valuable insights in the fields of creativity and human-computer interaction, when dealing with the essential questions *why* and *how* these communities can profit from technology.

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Appendix A Evaluation Documents

This appendix contains the documents (questionnaires etc.) that were handed to the participants (creative workers, facilitators) during the user study. Thereby, these documents are written in German.

- Post-Test Questionnaire for the creative workers
- Post-Test Questionnaire for the facilitators
- Interview manual for the experimenter during the focus group

Fragebogen

A) Gesamteindruck des Prototyps

Bitte geben Sie mithilfe der folgenden Fragen Ihren Gesamteindruck zu dem Brainsketching Prototypen wieder

Ich war mit der Leistung und den Funktionen des Systems zufrieden

Stimme überhaupt nicht zu	Stimme völlig zu

Es war einfach für mich, neue Ideen und Richtungen zu erschließen

Stimme überhaupt nicht zu	Stimme völlig zu

Es war sehr einfach über das System Ideen und Konzepte mit andern Leuten zu teilen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich würde mich freuen dieses System regelmäßig zu nutzen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich war im Stande kreativ zu sein während der Aktivität

Stimme überhaupt nicht zu	Stimme völlig zu

Meine Aufmerksamkeit richtete sich ausschließlich auf die Kreativaktivität, sodass Ich das System völlig vergaß

Stimme überhaupt nicht zu	Stimme völlig zu

Das System half mir Ideen und Veränderungen zu verfolgen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich hatte Spaß bei der Verwendung des Systems

Stimme überhaupt nicht zu	Stimme völlig zu

Die Ideen die ich produzieren konnte, waren den Aufwand wert

Stimme überhaupt nicht zu	Stimme völlig zu

Das System unterstütze mich expressiv zu sein (sich bildreich, rhetorisch, emotional auszudrücken)

Stimme überhaupt nicht zu	Stimme völlig zu

Ich war so stark mit der Designaktivität beschäftig, dass ich dabei das System gar nicht mehr bemerkte

Stimme überhaupt nicht zu	Stimme völlig zu

Das System unterstützt die Arbeit mehrerer Nutzer

Stimme überhaupt nicht zu		Stimme völlig zu

Bezüglich der Aktivität, die ich eben gemacht habe, war für mich das wichtigste (Nur ein Feld pro Box ankreuzen):

Die Erschließung neuer Ideen und Möglichkeiten		Die Zusammenarbeit mit anderen Menschen

Die Erschließung neuer Ideen und Möglichkeiten		Spaß bei der Verwendung des Systems

Die Erschließung neuer Ideen und Möglichkeiten		Ergebnisse erzeugen, die den Aufwand wert waren

Die Erschließung neuer Ideen und Möglichkeiten		Sich in die Designaktivität voll und ganz vertiefen

Die Erschließung neuer Ideen und Möglichkeiten		Kreativ und ausdruckstark zu sein

Die Zusammenarbeit mit anderen Menschen		Spaß bei der Verwendung des Systems

Die Zusammenarbeit mit anderen Menschen		Ergebnisse erzeugen, die den Aufwand wert waren

Die Zusammenarbeit mit anderen Menschen		Sich in die Designaktivität voll und ganz vertiefen

Die Zusammenarbeit mit anderen Menschen	Kreativ und ausdruckstark zu sein

Kreativ und ausdruckstark zu sein	Ergebnisse erzeugen, die den Aufwand wert waren

Kreativ und ausdruckstark zu sein	Sich in die Designaktivität voll und ganz vertiefen

Kreativ und ausdruckstark zu sein	Spaß bei der Verwendung des Systems

Spaß bei der Verwendung des Systems	Sich in die Designaktivität voll und ganz vertiefen

Spaß bei der Verwendung des Systems	Ergebnisse erzeugen, die den Aufwand wert waren

Sich in die Designaktivität voll und ganz vertiefen	Ergebnisse erzeugen, die den Aufwand wert waren

B) Umgang mit den Design-Artefakten

Das Erstellen der Skizzen auf dem Papier (Ideen auf das Papier zeichnen) fiel mir leicht

Stimme völlig zu	Stimme überhaupt nicht zu

Ich hatte Hemmungen, auf die Skizzen anderer zu zeichnen

Stimme völlig zu	Stimme überhaupt nicht zu

Das Zeichnen **kleinerer** Änderungen (bsp. Ergänzungen) auf die Skizzen anderer fiel mir schwer
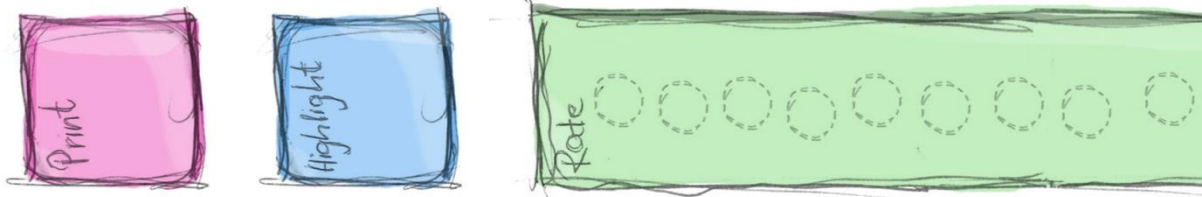
Stimme völlig zu	Stimme überhaupt nicht zu

Das Zeichnen **größerer** Änderungen auf die Skizzen anderer fiel mir schwer

Stimme völlig zu	Stimme überhaupt nicht zu

C)Interaktion mit dem Prototyp – Die Computerfunktionen

Die Bedienung der Computerfunktionen auf dem Papier war einfach

Stimme völlig zu	Stimme überhaupt nicht zu

Die Computerfunktionen auf das Papier zu bringen finde ich gut

Stimme völlig zu	Stimme überhaupt nicht zu

Weiterhin mit Papier und Stift zu arbeiten / zeichnen finde ich gut

Stimme völlig zu	Stimme überhaupt nicht zu

Mir war klar, dass die Computerfunktionen auf dem Papier nur eine Auswirkung auf die dazugehörige Papierzeichnung haben

Stimme völlig zu	Stimme überhaupt nicht zu

D) Interaktion mit dem Prototyp – Die Druckfunktion

Haben Sie während der Aktivität eine Skizze ausgedruckt

Ja	Nein

Falls ja, bitte bewerten Sie folgende Aussagen:

Die Möglichkeit zu haben Skizzen auszudrucken / zu kopieren finde ich gut

Stimme völlig zu	Stimme überhaupt nicht zu

Diese Funktion nutzte ich, um das Original zu erhalten

Stimme völlig zu	Stimme überhaupt nicht zu

Diese Funktion nutzte ich, um kleine Änderungen zu machen

Stimme völlig zu	Stimme überhaupt nicht zu

Diese Funktion nutzte ich, um große Änderungen zu machen

Stimme völlig zu	Stimme überhaupt nicht zu

Die Skizzen auszudrucken / zu kopieren war einfach

Stimme völlig zu	Stimme überhaupt nicht zu

Das Display war für das Feedback der Druckfunktion hilfreich

Stimme völlig zu	Stimme überhaupt nicht zu

E) Interaktion mit dem Prototyp – Die Anzeigefunktion

Haben Sie das Display für die Vorstellung und Erklärung Ihrer Ideen genutzt?

Ja	Nein

Falls ja, wo lag während dieser Aktivität Ihr Aufmerksamkeitsfokus

   Der digitalisierten Skizze

   Der analogen Skizze

Falls ja, beurteilen Sie diese Funktion grundsätzlich als hilfreich für die Kommunikation Ihrer Ideen?

Sehr hilfreich	Wenig hilfreich

Falls ja, zu welchem Ausmaß hatten Sie das Gefühl, dass die Bedienung des Prototyps Sie von der Erklärung Ihrer Ideen ablenkt?

Sehr abgelenkt	Überhaupt nicht abgelenkt

Die Skizzen auf dem Display anzeigen zu lassen war einfach

Stimme völlig zu	Stimme überhaupt nicht zu

Die Möglichkeit zu haben, Skizzen erst bei Bedarf auf dem Display anzeigen zu lassen, gefiel mir gut

Stimme völlig zu	Stimme überhaupt nicht zu

Wie gut konnten Sie der Vorstellung der Ideen Ihrer Gruppenmitglieder insgesamt folgen?

Sehr gut	Überhaupt nicht

Die kollektive Darstellung der Skizzen auf dem Display hat mich zu neuen Ideen inspiriert

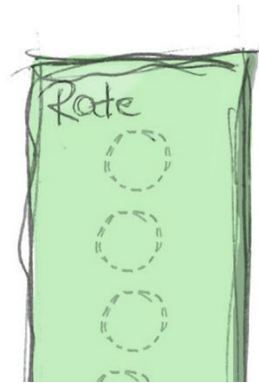|	
Stimme völlig zu	Stimme überhaupt nicht zu

Mich hat die mehrfache Darstellung der Skizze (einmal digital und einmal analog) verwirrt

Stimme völlig zu	Stimme überhaupt nicht zu

F) Interaktion mit dem Prototyp – Die Bewertungsfunktion

Haben Sie während der Aktivität eine Skizze bewertet

Ja	Nein
Falls ja, bitte bewerten Sie die folgenden Aussagen:	
Eine Skizze zu bewerten war einfach	
Stimme völlig zu	Stimme überhaupt nicht zu
Die Bewertungen mit dem Stift umzusetzen (kreisförmige Zeichnung) gefiel mit gut	
Stimme völlig zu	Stimme überhaupt nicht zu
Die Bewertung empfand ich als Einschränkung, da ich nur eine bestimmte Sache auf der Skizze bewerten wollte und nicht die gesamte Seite	
Stimme völlig zu	Stimme überhaupt nicht zu

G) Interaktion mit dem Prototyp – Verbesserungen

Gibt es Änderungen, die Sie gerne an den Skizzen vorgenommen hätten, die aber nicht möglich waren?

Ja	Nein
Falls ja, welche?_____	
_____	
_____	

Gibt es zusätzliche Funktionen, die Sie sich auf dem Blatt gewünscht hätten?

Ja   Nein

Falls ja, welche?_____

_____

_____

Gibt es Funktionen, die Sie sich auf dem Kontextdisplay gewünscht hätten?

Ja   Nein

Falls ja, welche?_____

_____

_____

Vielen Dank für Ihre Teilnahme!

Fragebogen Moderator

A) Gesamteindruck des Prototyps

Bitte geben Sie mithilfe der folgenden Fragen Ihren Gesamteindruck zu dem Brainsketching Prototypen wieder

Ich war mit der Leistung und den Funktionen des Systems zufrieden

Stimme überhaupt nicht zu	Stimme völlig zu

Es war einfach für mich, neue Ideen und Richtungen zu erschließen

Stimme überhaupt nicht zu	Stimme völlig zu

Es war sehr einfach über das System Ideen und Konzepte mit andern Leuten zu teilen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich würde mich freuen dieses System regelmäßig zu nutzen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich war im Stande kreativ zu sein während der Aktivität

Stimme überhaupt nicht zu	Stimme völlig zu

Meine Aufmerksamkeit richtete sich ausschließlich auf die Kreativaktivität, sodass Ich das System völlig vergaß

Stimme überhaupt nicht zu	Stimme völlig zu

Das System half mir Ideen und Veränderungen zu verfolgen

Stimme überhaupt nicht zu	Stimme völlig zu

Ich hatte Spaß bei der Verwendung des Systems

Stimme überhaupt nicht zu	Stimme völlig zu

Die Ideen die ich produzieren konnte, waren den Aufwand wert

Stimme überhaupt nicht zu	Stimme völlig zu

Das System unterstütze mich expressiv zu sein (sich bildreich, rhetorisch, emotional auszudrücken)

Stimme überhaupt nicht zu	Stimme völlig zu

Ich war so stark mit der Designaktivität beschäftig, dass ich dabei das System gar nicht mehr bemerkte

Stimme überhaupt nicht zu	Stimme völlig zu

Das System unterstützt die Arbeit mehrerer Nutzer

Stimme überhaupt nicht zu		Stimme völlig zu

Bezüglich der Aktivität, die ich eben gemacht habe, war für mich das wichtigste (Nur ein Feld pro Box ankreuzen):

Die Erschließung neuer Ideen und Möglichkeiten		Die Zusammenarbeit mit anderen Menschen

Die Erschließung neuer Ideen und Möglichkeiten		Spaß bei der Verwendung des Systems

Die Erschließung neuer Ideen und Möglichkeiten		Ergebnisse erzeugen, die den Aufwand wert waren

Die Erschließung neuer Ideen und Möglichkeiten		Sich in die Designaktivität voll und ganz vertiefen

Die Erschließung neuer Ideen und Möglichkeiten		Kreativ und ausdruckstark zu sein

Die Zusammenarbeit mit anderen Menschen		Spaß bei der Verwendung des Systems

Die Zusammenarbeit mit anderen Menschen		Ergebnisse erzeugen, die den Aufwand wert waren

Die Zusammenarbeit mit anderen Menschen		Sich in die Designaktivität voll und ganz vertiefen

Die Zusammenarbeit mit anderen Menschen	Kreativ und ausdruckstark zu sein

Kreativ und ausdruckstark zu sein	Ergebnisse erzeugen, die den Aufwand wert waren

Kreativ und ausdruckstark zu sein	Sich in die Designaktivität voll und ganz vertiefen

Kreativ und ausdruckstark zu sein	Spaß bei der Verwendung des Systems

Spaß bei der Verwendung des Systems	Sich in die Designaktivität voll und ganz vertiefen

Spaß bei der Verwendung des Systems	Ergebnisse erzeugen, die den Aufwand wert waren

Sich in die Designaktivität voll und ganz vertiefen	Ergebnisse erzeugen, die den Aufwand wert waren

B) Interaktion mit dem Prototyp – Der hyperbolische Baum
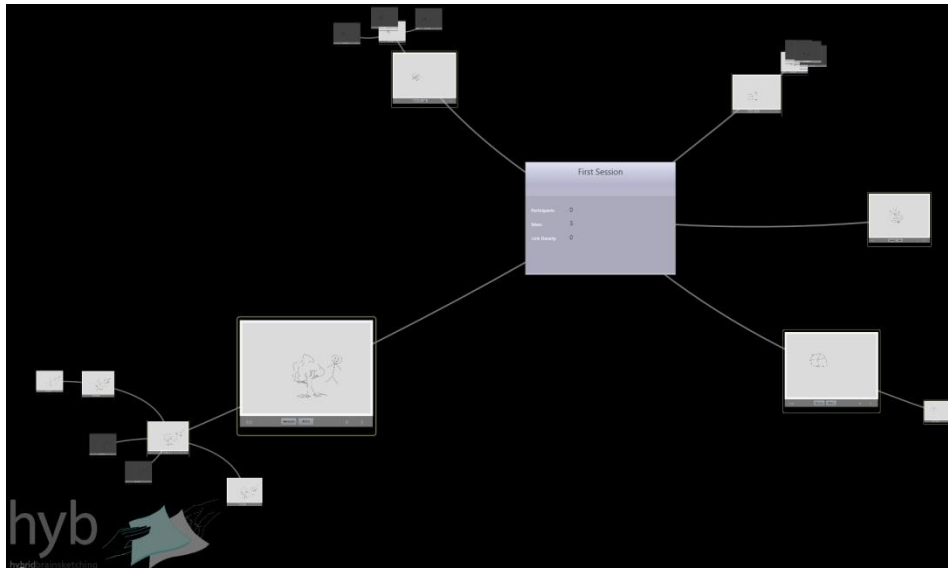
Zu welchem Ausmaß erleichtert Ihnen die Baumdarstellung, einen Überblick über das Geschehen im Meeting zu bewahren

Große Erleichterung	Überhaupt keine Erleichterung

Die Baumvisualisierung ermöglichte eine Übersicht der Produktivität des Meetings

Stimme völlig zu	Stimme überhaupt nicht zu

Die hyperbolische Anordnung der Skizzen (kreisrunde Anordnung der Äste) gefiel mir gut

Stimme völlig zu	Stimme überhaupt nicht zu

Die Baumvisualisierung machte es einfach, die Fortentwicklung der Ideen zu verfolgen

Stimme völlig zu	Stimme überhaupt nicht zu

Die Baumvisualisierung ist hilfreich, um Ideenfixierungen zu entdecken

Stimme völlig zu	Stimme überhaupt nicht zu

Die farbige Umrahmung der Skizzen-Artefakte…
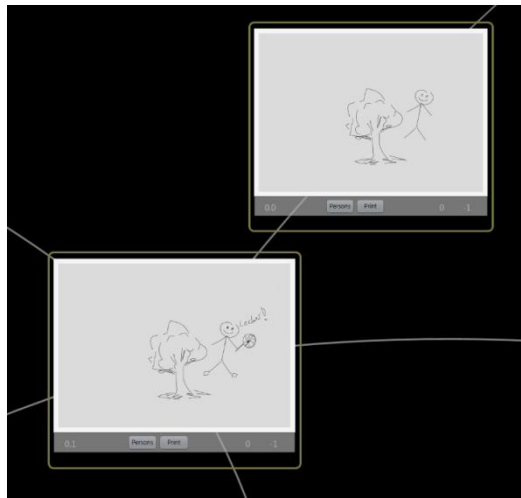
…half mir bei der Orientierung im Baum

Stimme völlig zu   Stimme überhaupt nicht zu

… half mir von Kopie und normaler Ideenweiterführung zu unterscheiden

Stimme völlig zu   Stimme überhaupt nicht zu

…hat mich verwirrt

Stimme völlig zu   Stimme überhaupt nicht zu
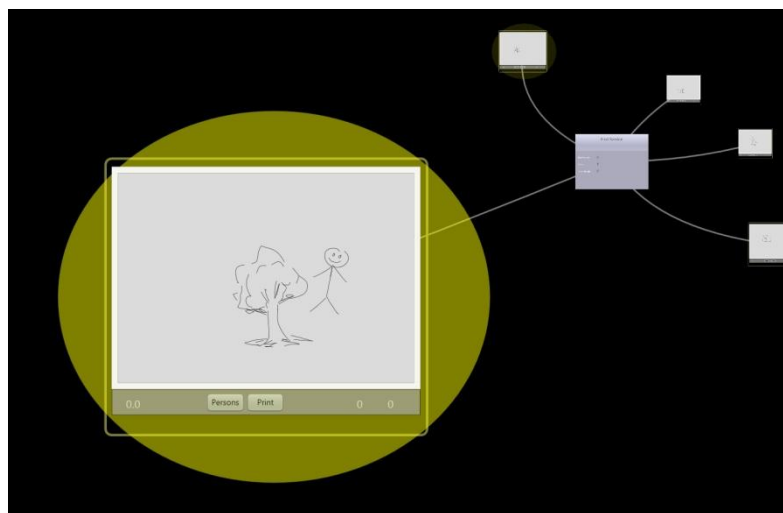
Das gelbe „Glühen" der Skizzen auf denen zuletzt gezeichnet wurden, erleichterten es mir, einen Überblick über das Geschehen im Meeting zu bewahren

Stimme völlig zu   Stimme überhaupt nicht zu

Ich empfand das „Glühen" der Skizzen als lästig

Stimme völlig zu	Stimme überhaupt nicht zu

Das „Glühen" der Skizzen half mir, einzelne Ideen zu finden

Stimme völlig zu	Stimme überhaupt nicht zu

C) Interaktion mit dem Prototyp – Navigation, Manipulation

Beim Navigieren durch den Baum verlor ich öfters die Orientierung

Stimme völlig zu	Stimme überhaupt nicht zu

Haben Sie im Laufe des Meetings die Zoom-Funktion verwendet (mehrfach Ankreuzung möglich)

Ja	Nein

Falls ja, zu welchem Zweck haben Sie diese Funktion genutzt?

    für eine Detailansicht interessanter Inhalte

    weil die Standardansicht generell zu klein war

    um die Funktionen einfacher ausführen zu können

    Sonstiges: _____

_____

_____

Haben Sie im Laufe des Meetings diese Druckfunktion verwendet (mehrfach Ankreuzung möglich)

Print a Copy

Ja	Nein
Falls ja, zu welchem Zweck haben Sie diese Funktion genutzt?	
um eine Weiterentwicklung dieser Idee zu forcieren	
Falls ja, zu welchem Ausmaß sind Sie überzeugt davon, dass Sie dadurch die Weiterentwicklung der Idee beeinflusst haben	
Überhaupt nicht	In hohem Maße
um den Fokus der Gruppenarbeit zu lenken	
Falls ja, zu welchem Ausmaß sind Sie überzeugt davon, dass Sie dadurch den Fokus der Gruppe beeinflusst haben	
Überhaupt nicht	In hohem Maße
Sonstiges:_____ _____ _____ _____	

Die Funktion, Skizzen über die Baumvisualisierung auszudrucken…

… finden Sie generell sinnvoll	
Stimme völlig zu	Stimme überhaupt nicht zu
…finden Sie notwendig	
Stimme völlig zu	Stimme überhaupt nicht zu

Haben Sie im Laufe des Meetings die Funktion für die Personen-Farbzuordnung verwendet (mehrfach Ankreuzung möglich)

Ja   Nein

Falls ja, zu welchem Zweck haben Sie diese Funktion genutzt?

   um den Beitrag einer Personen zu dieser Skizze ersichtlich zu machen

   Sonstiges _____

_____

_____

Die Funktion, Personen-Farbzuordnung…

… finden Sie generell sinnvoll

   Stimme völlig zu   Stimme überhaupt nicht zu

…finden Sie notwendig

   Stimme völlig zu   Stimme überhaupt nicht zu

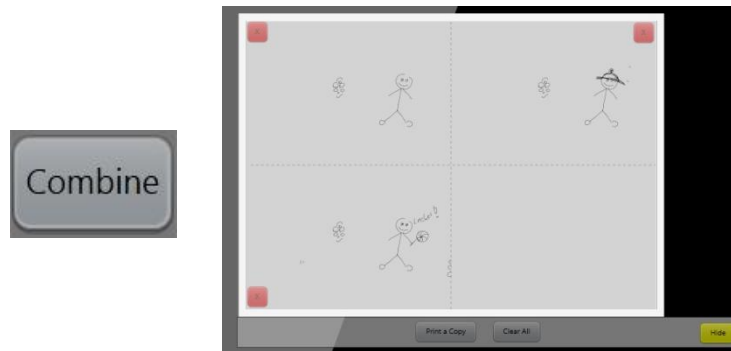Haben Sie im Laufe des Meetings eine Idee auf das Gruppen-Display gesendet (mehrfach Ankreuzung möglich)

Show on Display

Ja	Nein

Falls ja, zu welchem Zweck haben Sie diese Funktion genutzt?

_____

_____

_____

Die Funktion, Ideen auf das Gruppen-Display zu schicken…

… finden Sie generell sinnvoll	
Stimme völlig zu	Stimme überhaupt nicht zu
…finden Sie notwendig	
Stimme völlig zu	Stimme überhaupt nicht zu

Haben Sie im Laufe des Meetings Ideen kombiniert und ausgedruckt (mehrfach Ankreuzung möglich)
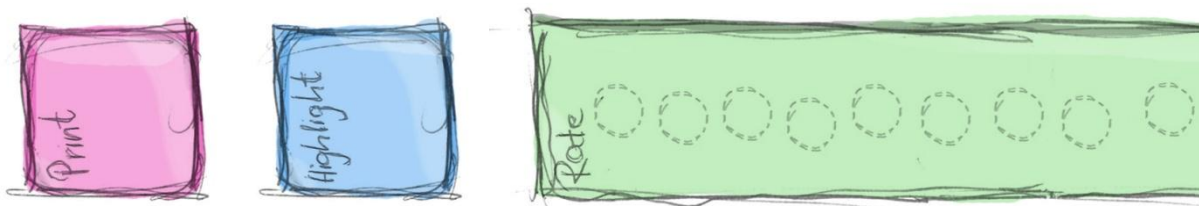

Ja	Nein

Falls ja, zu welchem Zweck haben Sie diese Funktion genutzt?

_____

_____

_____

Die Funktion, Ideen kombinieren zu können…

… finden Sie generell sinnvoll

Stimme völlig zu   Stimme überhaupt nicht zu

…finden Sie notwendig

Stimme völlig zu   Stimme überhaupt nicht zu

D) Interaktion mit dem Prototyp – Die Papierfunktionen für die Kreativarbeiter

Die Computerfunktionen auf das Papier zu bringen finden Sie gut

Stimme völlig zu   Stimme überhaupt nicht zu

Weiterhin mit Papier und Stift zu arbeiten / zeichnen finden Sie gut

Stimme völlig zu   Stimme überhaupt nicht zu

G) Interaktion mit dem Prototyp – Verbesserungen

Gibt es Änderungen, die Sie gerne an den Skizzen vorgenommen hätten, die aber nicht möglich waren?

Ja   Nein

Falls ja, welche?_____

_____

_____

_____

Gibt es zusätzliche Funktionen, die Sie sich vom System gewünscht hätten?

Ja   Nein

Falls ja, welche?_____

_____

_____

_____

Gibt es Funktionen, die Sie sich auf dem Kontextdisplay gewünscht hätten?

Ja   Nein

Falls ja, welche?_____

_____

_____

_____

Vielen Dank für Ihre Teilnahme!

Interview Kreativarbeiter – Leitfaden

A) Ablauf

_____

Wie beurteilen die Studenten den Ablauf der Gruppenarbeit im Vergleich zu beiden Varianten (mit / ohne Technik)

_____

_____

_____

_____

_____

_____

_____

B) Rollenveränderung

_____

Hat sich eure Rolle oder Verhalten geändert, durch die Tatsache, dass Ihr bestimmte Funktionen nutzen konntet?

_____

_____

_____

_____

_____

_____

_____

C) Verhalten Moderator

_____

Gab es Unterschiede beim Verhalten des Moderators und hat sich seine Rolle verändert, durch den Einsatz der Technik?

_____

_____

_____

_____

_____

_____

_____

_____

D) Funktionen

_____

Könnt Ihr nochmal die Funktionen generell und frei bewerten?

_____

_____

_____

_____

_____

_____

_____

Könnt Ihr Beispiele nennen warum Ihr die Funktionen verwendet habt *(wichtig warum haben die Studenten gedruckt)*?
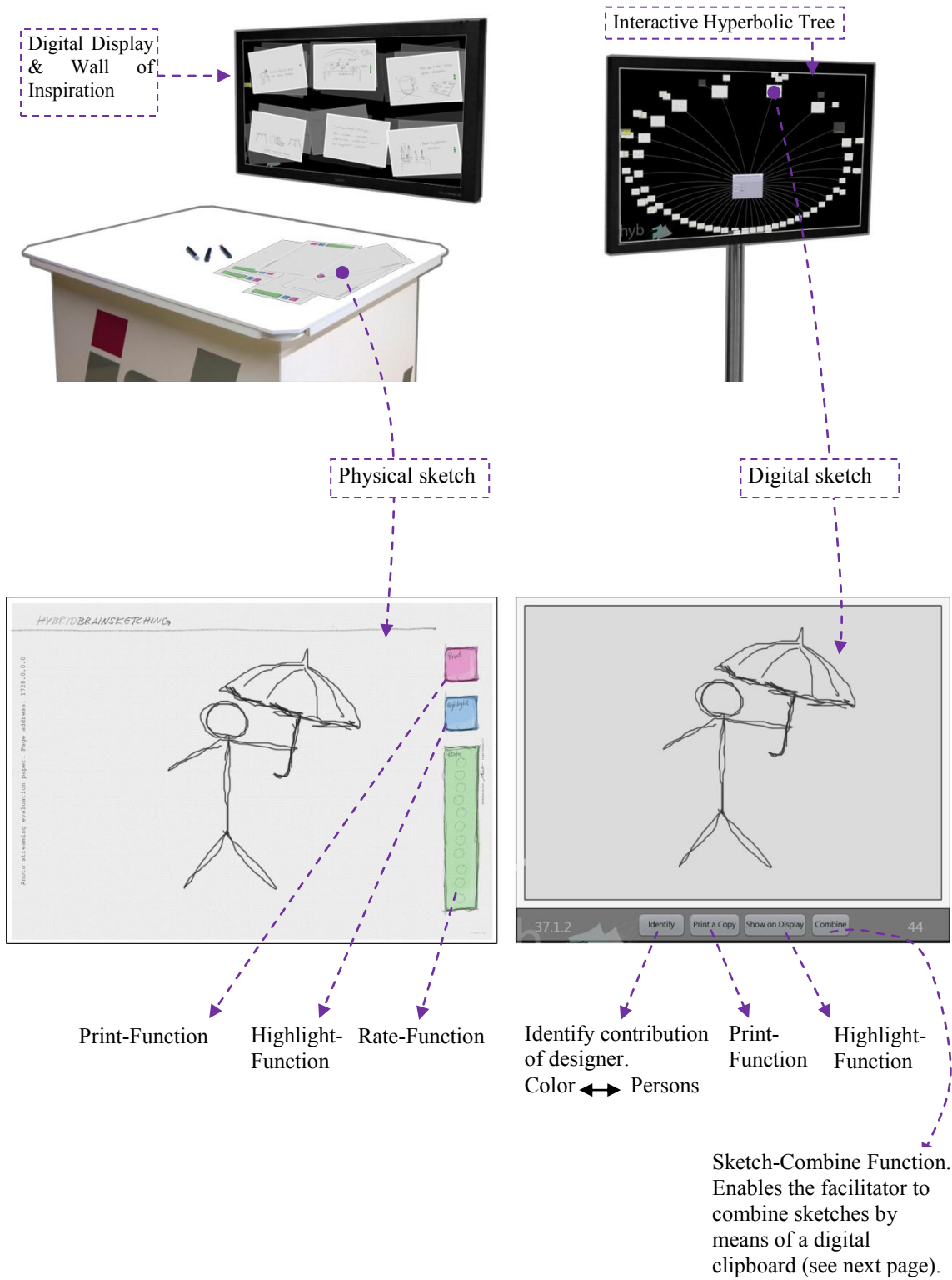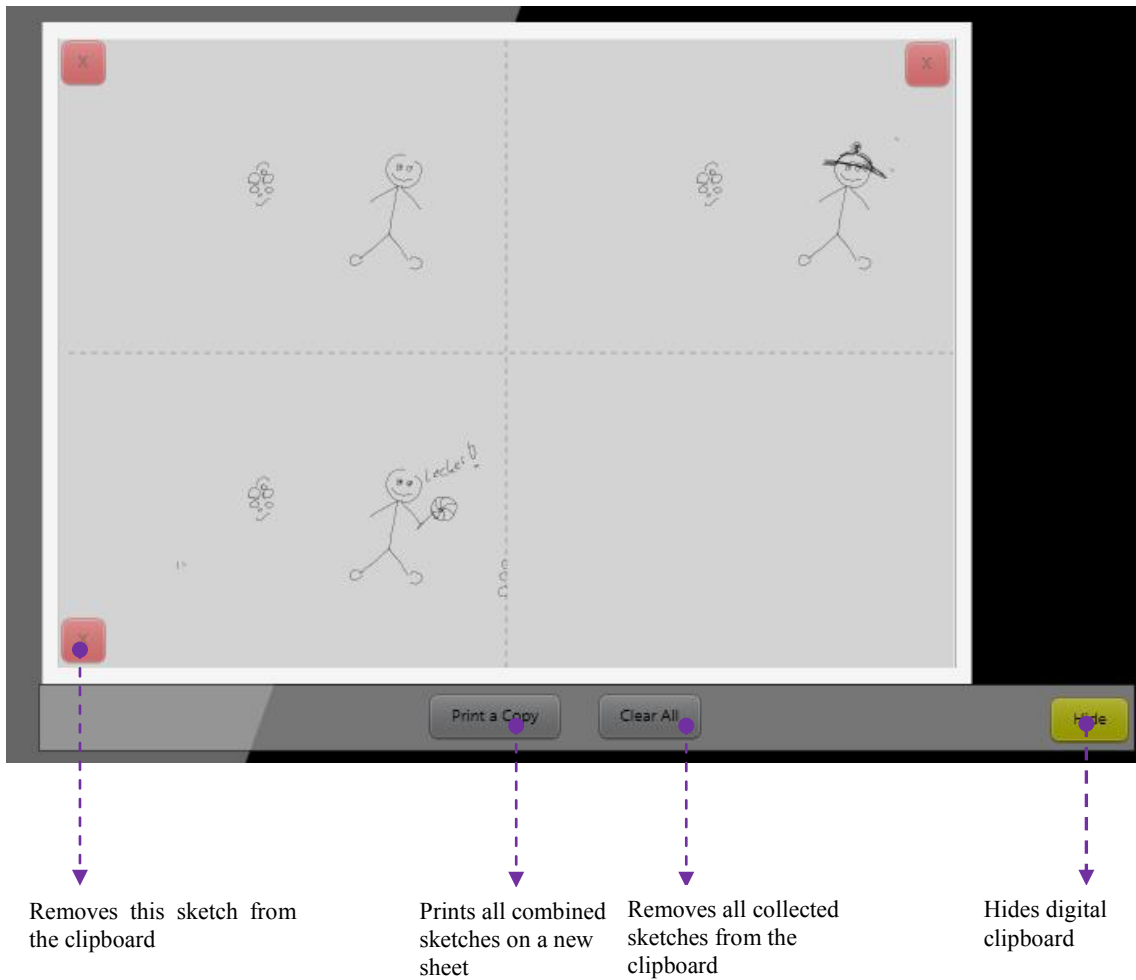
_____

_____

_____

_____

_____

_____

_____

Appendix B Overview of the hyb-System

Overview of the final *hyb*-System e.g. functions and the workspaces.

Overview of the final *hyb*-System for the creative workers (left) and the facilitator (right)
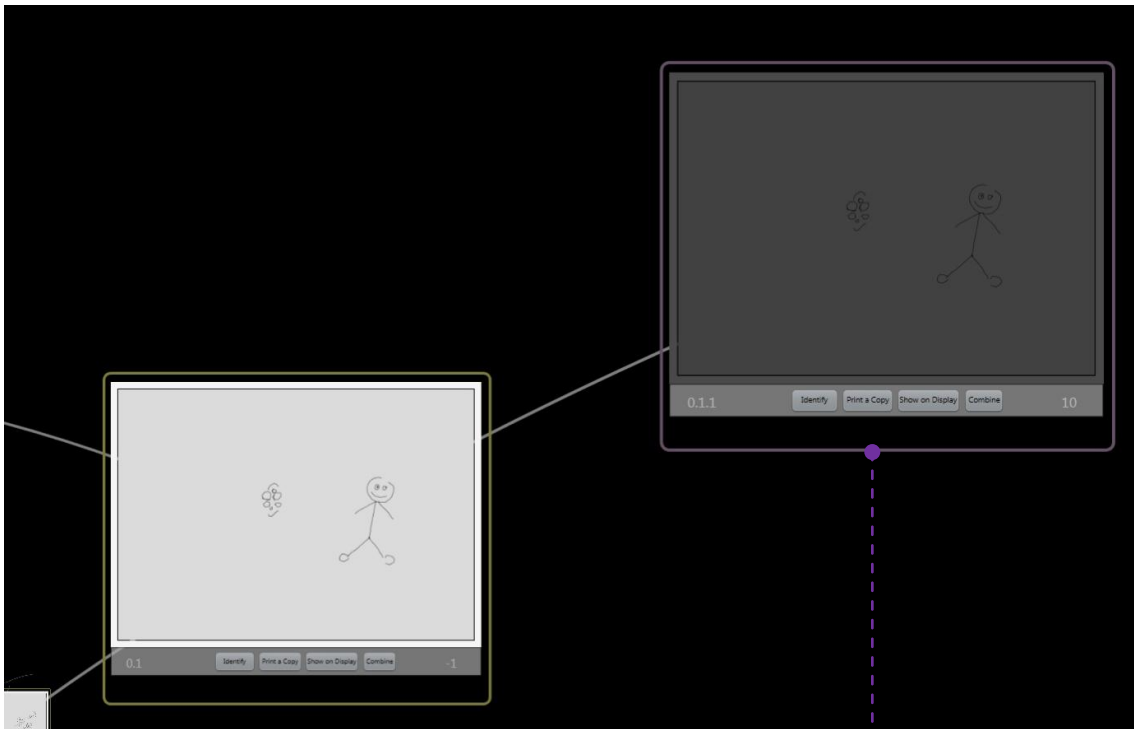

Digital Display & Wall of Inspiration

Interactive Hyperbolic Tree

Physical sketch

Digital sketch

Print-Function   Highlight-Function   Rate-Function

Identify contribution of designer. Color ⟷ Persons

Print-Function   Highlight-Function

Sketch-Combine Function. Enables the facilitator to combine sketches by means of a digital clipboard (see next page).

The digital clipboard for the facilitator. It appears when the facilitator combines digital sketches. Every sketch is arranged within a grid.
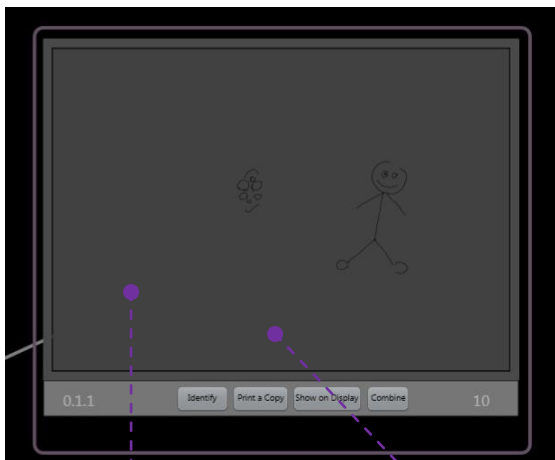

Removes this sketch from the clipboard

Prints all combined sketches on a new sheet

Removes all collected sketches from the clipboard

Hides digital clipboard

Orientation for the facilitator

Yellow frame reveals that this digital sketch belongs to the source idea (left) that also has a yellow frame. Thus, this sketch was modified by another person.
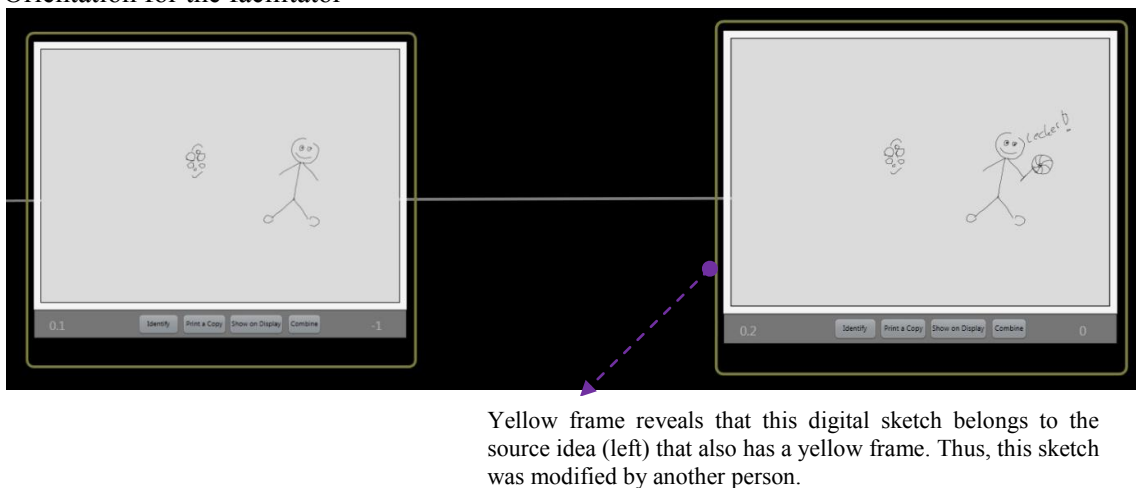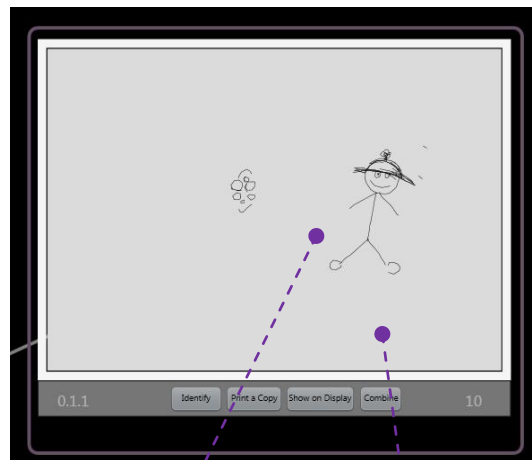
The purple frame shows that this digital sketch is a duplication of the sketch to the left
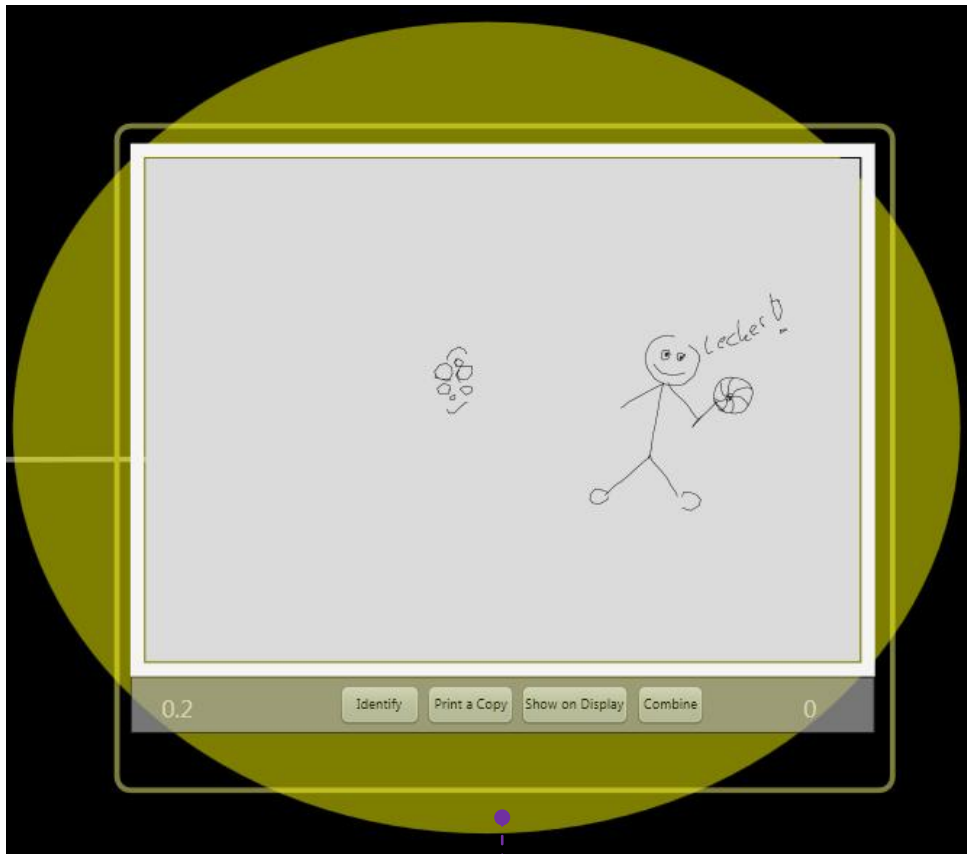

The background color is grey when the printed sketch (the corresponding physical artifact) wasn't yet used.

Sketch-related functionality is disabled as long as the corresponding physical is unused.

The background color turns from grey to white when somebody draws on the corresponding physical sketch.

The buttons become accessible

The yellow „glowing" frame demonstrates that this sketch is being used at the moment, meaning that somebody draws on it. This "glowing" effect fades out after 30 seconds in order to offer a better overview of the recently used ideas.

Appendix C DVD Content

This DVD contains the evaluation documents, the images that were being used for this thesis artifact, the data recordings from the user study e.g. videos, questionnaires and the data analysis of the qualitative content.

Images	Images that were being used within the thesis
Questionnaires	The questionnaires and the interview document
Analyzed Data	The logged images that were being produced during the session. The results of the questionnaires and the results of the qualitative data analysis
Study Documents	Documents that describe the process of the pre-test and the final user study
Thesis Documents	The documents that belong to this master thesis research, e.g. the masters seminar, the documentation of the masters project and the master thesis document
Videos	The videos of the user study