GLOBALLY DISTRIBUTED ENGINEERING TEAMS IN COMPUTATIONAL FLUID DYNAMICS AND IN PRODUCT DEVELOPMENT

A Thesis

by

SUSANNE REGINA SCHMIDT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Mechanical Engineering

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Approved by:

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ABSTRACT

Globally Distributed Engineering Teams in Computational Fluid Dynamics
and in Product Development. (August 2010)

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Globally distributed engineering teams are a reality in globally operating companies. However, research on teams is often done by psychologists, with a focus on general team building and working processes, and seldom on engineering teams and the challenges and benefits that are specific to them. In this thesis, experimental research on two globally distributed engineering teams is presented. First, one instance of globally distributed teams in computational fluid dynamics is scrutinized. Second, experimental research on idea generation methods used in globally distributed teams during the conceptual design phase of the product development process is presented.

An experimental study simulating the global distribution of a three person Computational Fluid Dynamics team shows that successful sequential processing of a problem is possible given technological support by different internet based technologies.

Three succeeding studies researched the influence of space and time during idea generation for an engineering problem, leading to the conclusion in the final study that idea generation in distributed engineering teams is a valid option. It is shown that the idea generation method has a significant effect on the number of ideas generated per team member. Further, the quality, novelty, and variety are each significantly influenced by both the idea generation method chosen and the team member's location, but in different ways by the same level of each factor.

Concluding, both experiments in distributed engineering teams show these teams have unused potential that can be utilized using appropriate process, procedures and tools.

DEDICATION

To Markus, my love

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1. INTRODUCTION: GLOBALLY DISTRIBUTED ENGINEERING TEAMS

Globally distributed engineering teams are a reality in globally operating companies. The availability and affordability of the information and communication technology, foremost the World Wide Web, needed for distributed teams to work efficiently, has supported an increase in the number of globally distributed teams since about 1990. Information and communication technology in globally distributed teams mediates the team member's communication by simplifying data and information exchange among distributed team members. A multitude of software solutions has been developed with globally distributed teams in mind that facilitates the team members' work. Examples of such software include Voice over IP programs that allow video conferences, Product Lifecycle Management Systems, and screen sharing applications. Some of these solutions also prove beneficial when used in the collocated setting, for example Product Lifecycle Management Systems.

Three company developments promote the boost of global distributed teams: the expansion of multinational companies, the merging of businesses, and overseas collaborations to access natural and human resources. Each of these developments bears its own potential and risks. Not all companies have the ability for each development, with a company's financial possibilities causing the most restraint. The motivating factors driving globally distributed teams are the same factors driving local development; competitive advantage is sought through a reduction in time to market and costs while increasing or maintaining a product's quality

In this work, experimental research on two types of globally distributed engineering teams is presented: First, one instance of globally distributed teams performing computational fluid dynamics (CFD) is scrutinized. Second, experimental research on idea generation methods used in globally distributed teams during the idea generation phase of the product development process is presented.

This thesis follows the style of *Design Studies*.

The experiments for both types of teams are compared to a control condition, a collocated, or “traditional”, instance of the experiment, to identify possible discrepancies of in the generated solutions. In the virtual computational fluid dynamics experiment, these discrepancies might be due to the serialization of the project. In the idea generation experiment, the idea generation method and the shift in the familiar collocated human interaction of the team are seen as possible influences.

This distributed engineering research is an exciting step for teaming study. The majority of research on teams is done by psychologists, with a focus on general team building and working processes, and seldom on engineering teams and the challenges and benefits that are specific to them. In Addition, only a small part of current team research is dedicated to distributed teams.

For the computational fluid dynamics team experiment, no comparable or similar research has been found. To the best of the author’s knowledge, it appears that this is the first time a research team has attempted to spread out the computational fluid dynamics process through an in time distributed team. Key motivation for exploring this experiment is to offer the potential to reduce the overall time it takes to generate computational fluid dynamics solution. The obstacle for large computational fluid dynamics teams so far has been that the processes are hard to parallelize. But a globally distributed team works serial, with some possible overlap to facilitate the data and information exchange, thus offering a natural structure for creating computational fluid dynamics teams. Distributing a team in time and location, while implementing a 24 hour engineering process, could cut down the overall time to complete solutions by about two third based on a model that uses three sequential eight hour work cycles. This reduction in time to evaluate for example a novel design with computational fluid dynamics would lead to a shorter product design phase and ultimately in an earlier market availability.

For the experiment researching idea generation methods in distributed teams in the engineering design process, namely the concept generation phase, some research has been done in the area of brainstorming. Generally, using individuals in a distributed setting is not done with the intent to research distributed teams, but rather to see how individuals generate ideas and what synergy effects exist. This brainstorming research has given valuable ideas for the design of the experiment described in this thesis. Further research exists on engineering design teams, mainly indentifying challenges brought onto the team by its distribution, and on software tools developed to help distributed engineering teams. In this experiment, the motivation is not only the potential reduction of time spent during idea generation. Of course, cutting down on travel time will save time and money, and has benefits for the employer and for the employee. But if it can be shown with this experiment, that one or multiple idea generation methods can be used efficiently in globally distributed teams, this will allow input into the idea generation process from a broader audience with diverse backgrounds. Naturally incorporating input from diverse backgrounds through a locally immersed designer can be especially beneficial when a product for multiple markets is designed.

One common concern in both experiments is to find suitable tools to enable and hopefully support the processes. Each of the two experiments has specific needs that have to be met: the computational fluid dynamics team needs to be able to access large amounts of data from different computers. The computational fluid dynamics teams will be given the opportunity to share a screen and thus see each other’s work while having a telephone conference. Additionally, the computational fluid dynamics teams will be given the opportunity to keep a logbook that will allow each participant to note ideas and progress in a way accessible to all team members. In the idea generation, two idea generation methods will be scrutinized: brainstorming and a modified method 635. For brainstorming, a telephone conference and a shared screen are used. The modified method 635 makes it necessary to exchange sketches in a format that allows their editing.

A second concern is to develop procedures tailored to the needs of each project, but that are sufficiently flexible to allow modification if needed by the participants. Further, the procedures should be similar to common practice in industry. Establishing similar procedures will allow a prediction to be made about the possibility of implementing the methods into practice in the near future. As examples, the computational fluid dynamics team needs guidelines describing where and how often to save the data, how to perform the data exchange among team members, what parts of software to use, and how to communicate. The teams working on the idea generation will need to be guided through the idea generation method, and through the use of the equipment.

In the immediately following section, background information on computational fluid dynamics, distributed teams, and idea generation is presented. The next section contains the description of the research on using globally distributed teams in computational fluid dynamics. This is followed by the section describing the experiments scrutinizing two idea generation methods for their suitability in globally distributed teams in the engineering design process. The last section summarizes this work.

2. BACKGROUND

In this background section three topics are presented: First, computational fluid dynamics is summarized, as it is used in the VirtualCFD experiment presented in section 3 of this thesis. Second, distributed teams are defined and research on them is presented. Distributed teams are the common ground of the VirtualCFD and the dDesign experiments. The last topic is idea generation, which is significant for the dDesign experiment described in section 4 of this thesis.

2.1. Computational Fluid Dynamics

Computational fluid dynamics uses numerical methods to solve and analyze fluid flow problems. The computational fluid dynamic process consists of three general steps: 1) the generation of the geometry the fluid will flow through, 2) the meshing of the generated geometry which includes the problem set up, the implementation of boundary conditions, and the simulation of the problem often using a super computer, and 3) the post processing. Multiple software programs for different operating systems exist to assist the designer during each step. Which software program is chosen is a question of availability and compatibility. Having multiple programs for the same step of the computational fluid dynamic process is often prohibited by their cost. As the import and export formats between programs need to be compatible, and as the programs need to run under the given operating system, this further reduces the software suitable for a specific environment. The software used will influence how a step in the computational fluid dynamic process is executed, but should lead to the same results at the end of each step and of the process. The creation of the geometry can be done with any computer aided design program or with a tool specific to the analysis software. The designer creates a representation of the geometry the fluid will flow through. This may be only a section of the whole geometry for symmetric geometries. The accuracy of the geometry depends on the needs of the specific problem and is determined by the designer. In the second phase, the created geometry is portioned into elements, their nature depending on the planned analysis. A decision between finite elements and finite volumes has to be made and between different cell shapes for each method. The coarseness of the mesh is problem dependant may vary in the local geometry based on the needs of the engineer. Boundary conditions are added to the meshed geometry, for example the inflow velocity, wall temperatures, or similar. After the mesh and the boundary conditions are completed, the file is submitted for the actual flow calculation. This calculation may take seconds to months depending on the complexity of the problem and the available processing power. Post processing completes the evaluation of the data. Depending on what factors the designer is looking for, post processing might be done by using features available in the software that provided the flow analysis or a separate software or code written by the designer.

In this work, the focus is on the second and third step of the computational fluid dynamic process. In the meshing phase, the type or types of cells to be used is defined. Examples of three-dimensional cell types are tetrahedron, pyramid, prism with quadrilateral base (also called a hexahedron), prism with triangular base (wedge), or arbitrary polyhedron. Furthermore, the number of cells to be used overall, and the size and distribution of the cells in the geometry is established. After the mesh has been created, the problem is set up by modifying the solver settings according to the problem at hand. For example, boundary conditions are implemented, the discretization method is chosen, and the turbulence model to be used - if the flow is turbulent - is identified. The simulation is then run, requiring little input from the user. The results from the simulation are the basis of the post processing phase.

Each of the three phases is sequential, as the tasks executed in each one build on each other. Therefore, project duration cannot be minimized by employing more people at the same time. However, it is theorized that three to four persons distributed around the globe can work sequential on one design problem, reducing the number of days needed to finish a project but allowing the same number of work hours. In this study possible benefits and challenges of such a globally distributed computational fluid dynamic team are researched.

2.2. Distributed Teams

Distributed teams are teams that are dispersed geographically, in time, or in both dimensions, focusing on the physical presence of the team members as a label. Geographic dispersion can be as little as 50ft in the same building or as much as being located on a different continent on the other side of the world (Lipnack & Stamps, 1997).

Distribution in time spans everything between a team of nurses working different shifts to team members living in different time zones. Virtual teams are teams that “cross time, space, and cultural boundaries and do so effectively with the use of technology” (Johnson, Heimann, & O'Neill, 2001, p. 24), using the means of interaction as a descriptor. Virtual teams are a form of distributed teams that rely on information and communication technology to interact. A virtual team can be merely distributed in the same building as long as its interactions are mediated by information and communication technology. A global virtual team is a “temporary, culturally diverse, geographically dispersed, electronically communicating work group” (Jarvenpaa & Leidner, 1999, p. 792), adding the duration of the team cooperation, and the geographic distribution to the virtual teams. Global virtual teams, the focus of this work, are a specific type of distributed and virtual teams: they have members located around the globe, thus they are both geographically and in time distributed. The cooperation of global or virtual teams is generally tied to their project and ends with its fulfillment. Team members may never work together again. Global virtual teams may have three or more locations distributed around the globe to allow for some overlap of work time, and thus synchronous communication, between different locations. The term ‘global distributed team’ is used exchangeable with the term ‘global virtual team’ e.g. by McDonough and Cedrone (1999), assuming that a team dispersed around the globe is mainly using technology to communicate. In the remainder of this work, if the general term ‘distributed teams’ is used, it comprises its subcategories ‘virtual teams’ and ‘global virtual teams’.

Distributed teams have been researched in different disciplines. Researchers in psychology, sociology, and business management have researched processes in virtual teams drawing from their knowledge on co-located teams, and reevaluating concepts such as team building and trust development, communication, and management of a team (Baba, Gluesing, Ratner, & Wagner, 2004; Bell & Kozlowski, 2002; Coppola, Hiltz, & Rotter, 2004; Janssens & Brett, 2006; Jarvenpaa & Leidner, 1999; Lee-Kelley & Sankey, 2008; McDonough & Cedrone, 1999; McDonough, Kahn, & Barczak, 2001; Nemiro, 2004). Mathieu, Heffner, Goodwin, Salas, and Cannon-Bowers (2000) found a positive relation between shared mental models and team process and performance. A mental model is defined as “organized knowledge structures that allow individuals to interact with their environment. . . . mental models have three crucial purposes: They help people describe, explain and predict events in their environment" (Mathieu, et al., 2000, p. 274). Mental models are ever evolving constructs, which change for example during the team building process. To work effectively, each team member's mental model of the used technology, the task and the team has to evolve and be shared among the team members. As the study uses existing teams, it can be assumed that the team members' views of their team are congruent. However, as the idea generation technique and tools, as well as the problem are first presented during the experiment, it can be assumed that the team members' mental models in the technology and task area are diverging, even though the degree of sharing/ convergence is unknown and likely will differ between teams. Therefore it can be assumed that idea generation teams in industry that are familiar with the idea generation technique and tools, as well as had time to discuss the problem beforehand, will solve their design problem more thoroughly as in the experiments.. To foster shared mental models, teams should be given opportunity to discuss their project. This is not part of the experiment, but it can be and is applied in industry.

2.2.1. Motivation for Global Distributed Teams

The increase in the number of global distributed teams since about 1990 is mediated by the availability and affordability of the information and communication technology needed for the distributed team to work efficiently (Hung & Nguyen, 2008; Tavcar, Zavbi, Verlinden, & Duhovnik, 2005). Foremost, the now ubiquitous World Wide Web simplifies data and information exchange among distributed team members.

According to Friday (2007), the three developments of companies that promote the boost of global distributed teams are the expansion of multinational companies, the merging of businesses, and the interest in overseas collaborations to access natural and human resources. Each of these bears its own potential and risks, and not all companies have the ability for each development. A multinational company is able to create the same or a similar technology infrastructure and organizational culture at each branch, thus reducing conflicts due to file formats or lines of command. Merging businesses lead to change in each part of the merger. This dynamic of change might initiate innovative ideas and concepts, but it might also stifle them if employees feel insecure due to the changes. Once the merger is complete, the businesses build one multinational company. Overseas collaboration allows access to multiple resources, such as cheaper labor, to relatively small companies and establishes a company-supplier relationship. A drawback of these relationships can be that the commissioning company has only a relatively small influence on organizational culture and used information and communication technology, as well as on the general ongoings, such as a leadership change, of the supplier.

2.2.1.1. The Employer Viewpoint

Companies have multiple incentives for building global distributed teams. In general, the benefits of global distributed teams are an increase in efficiency, flexibility, and use of resources, as well as the reduction of costs in all areas of the company (Hung & Nguyen, 2008; Mowshowitz, 1997). In combination with allowing a company to involve the best suppliers and partners available around the globe this leads to an improvement in the competitiveness of the company (Tavcar, et al., 2005). Lee-Kelley and Sankey (2008, p. 51) describe these benefits as “resource maximization and corporate agility”. Reducing the product development cycle time is a further important reason for establishing global distributed teams, as they allow getting more serial work hours during a 24 hour day and responding quickly to local customer needs and customization request (Powell, Piccoli, & Ives, 2004; Yang & Jin, 2008). An engineer located in the sales market will be more familiar with customer needs and expectations for the product to be, and is thus able to integrate these earlier into the product, reducing overall development time (Anderl, Völz, & Rollmann, 2008).

Global distributed teams further reduce relocation costs, and travel time using the best suited employee in various projects independent from the location of the project head quarters (Geber, 1995).

2.2.1.2. The Employee Viewpoint

Distributed teams offer benefits for employees, too, as summarized by Johnson et al. (2001). All teleworkers working from home either full time or, more often, some of their overall work time, using technology to interact with colleagues and stay up to date on projects, are part of virtual teams. Teleworkers save everyday's commuting time and gain flexibility in their schedules, as all asynchronous tasks which do not require an active counterpart con be scheduled as the teleworkers pleases. Members of global virtual teams reduce the time spent traveling, will have to endure less jet lag, and can work regular hours most days. This allows gaining quality of life, for example by spending time with family, contributing to the community, or enjoying leisure activities. Less frequent relocations allow settling down and establishing social connections.

2.2.2. Challenges of Global Virtual Teams

Global virtual teams face additional challenges in comparison to local teams and to teams that are distributed in only one dimension. These challenges rise with the number of team members, the number of cultures represented by the team members, the number of locations, and the amount of data to be shared. Even though some of the challenges may exist in local teams and in teams that are distributed in one dimension, they are especially pronounced in globally distributed teams. Barczak and McDonough (2003) compare the challenges of traditional, local, face-to-face product development teams to global virtual teams (Figure 1):

Challenges Product Development Teams Face

Traditional Teams	Global Teams
• Building trust	• Building trust
• Working to plan	• Working to plan
• Meeting budget	• Meeting budget
	• Cultural diversity
	• Language barriers
	• Geographic distance
	• Incompatible technological infrastructures
	• Few face-to-face meetings
	• Different work norms
	• Different communication norms
	• Different decision-making norms

Figure 1 Comparison of challenges in traditional and global virtual product development teams (Barczak & McDonough, 2003, p. 16)

Whereas traditional teams have the challenges of building trust, meeting deadlines and their budget, global virtual teams face multiple additional challenges: A broad cultural diversity, communication barriers, overcoming geographical distance and time differences, problems due to differing technological infrastructures, fewer opportunities for face-to-face meetings, and different norms in multiple areas. These topics are discussed in the following paragraphs.

2.2.2.1. Cultural Diversity, Work and Decision Making Norms

Cultural diversity has two levels: The national culture and the culture of the organization. Work norms are correlated with national culture, whereas decision making norms are correlated with organizational norms, but some overlap exits. Hofstede identifies five independent dimensions to identify and describe national culture differences: Power distance, uncertainty avoidance, individual versus collectivism, masculinity versus femininity, and long-term orientation versus short-term orientation (Hofstede, 1984, 2010; Hofstede & Bond, 1984; Hofstede & McCrae, 2004). The first version of this framework was published in 1984 and has since become one of the most influential frameworks for describing national culture differences, its main weakness usually identified as it being a non-adaptive, static framework (Tang & Koveos, 2008). Hofstede, Neuijen, Ohayv, and Sanders (1990) develop a similar framework to describe organizational culture which is placed among different companies generally located in the same country, and distinguish it from national culture which comprises people, institutions and organizations spread out over different countries. The six dimensions are: process- versus results-oriented, job- versus employee-oriented, professional versus parochial, open versus closed systems, tightly versus loosely controlled, and pragmatic versus normative.

Each of these dimensions poses a potential challenge for members of global virtual teams. Each team member can be on a different position in one or more of the five national culture dimensions, and the organizational culture may be different, especially if not all team members work for the same multinational company.

2.2.2.2. Communication Barriers and Communication Norms

Communication barriers often result from language barriers. Grzega (2005) summarizes pronunciation stepping stones leading to intelligibility problems between native and non-native speakers, but also between two non-native speaker parties. In addition, he presents common grammatical errors, which negatively influence the understanding of two parties, one of them usually being a non-native speaker. L. E. Smith (1992) researched the understanding of English across cultures. He looked at ‘understanding’ from three aspects: 1) intelligibility, 2) comprehensibility, and 3) interpretability. Intelligibility consists of word or utterance recognition. Comprehensibility is concerned with the meaning of the word or utterance. Interpretability regards the meaning behind a word or utterance. He found that being familiar with different varieties of English (as spoken by people from different countries) positively influenced the interpretability. Further, he found that an increase in language proficiency in English influenced all three areas of understanding positively, but mostly comprehensibility. Other factors contributing to communication barriers are, for example, the loss in the richness of communication due to the use of information and communication technology (Anderl, et al., 2008), delays in communication due to technical difficulties or time differences, or the influence of national and organizational culture on communication (see section

2.2.2.1 Cultural diversity, Work and Decision Making Norms). Traditionally, face-to-face teams have “been found to outperform their virtual counterparts with respect to the ability to orderly and efficiently exchange information” (Powell, et al., 2004, p. 8). If team members are introduced to contemporary information and communication technology, these barriers can be overcome and even offer benefits to the team and the organization, but training is necessary (Thomson, Stone, & Ion, 2007). Data sharing on web-enabled shared workspaces for example encourages a close versions control of data items, and asynchronous communication is already in an achievable format. Jarvenpaa and Leidner (1999) present previous cultural exposure as a factor influencing communication, as a team member previously exposed to other cultures seems to be more confident when communicating with team members of other cultures and more inclined to bring up topics outside of the project scope.

The type of communication best suited for a virtual team depends on the project. To successfully conclude an open ended design process which benefits from visual stimulation and interaction, richer communication system, such as videoconferencing and screen sharing are needed. Other projects, such as a part development with exactly defined connections, may be sufficiently equipped with electronic mail. Generally, computer mediated asynchronous communication is often the main form of communication in an in time distributed team. Lowry, Roberts, Romano Jr., Cheney, and Hightower (2006) compared face-to-face with computer mediated communication. Teams of three and of six students worked in traditional face-to-face teams, computer supported face-to-face teams on in virtual teams with computer support heuristically evaluated web pages, which had been created for this purpose. They found that face-to-face communication was as effective as computer mediated communication. A similar experiment was carried out by Hammond, Harvey, Koubek, Compton, and Darisipudi (2005), as they researched media effects on the design process. They found that teams interacting using computer mediated communication perceived the mental workload to be higher, interacted less frequently, but for the same amount of time compared to face-to-face teams. .They proposed to engage a facilitator to reduce the mental workload not associated with the task itself, but with the virtual team setting. Further, training in the used information and communication technology is advisable, to reduce the mental barrier of its use.

2.2.2.3. Geographic Dispersion and Time Differences

Geographic dispersion might, but does not have to, include time differences. Teams can be distributed on a north-south axle with no or small time differences, as well as around the globe (east-west), which can entail time differences of +/- 12 hours.

The main challenge for teams dispersed geographically with no or small time differences among team members is that the members are not in physical contact with each other. Building trust in each other and establishing the team is harder than in collocated teams. Meeting times during regular work hours are relatively easy to arrange and synchronous communication methods can be used. Different seasons due to the north-south distribution require in general less accommodating than time differences and factors related to east-west distribution.

Members of geographically distributed teams with time differences face challenges scheduling meetings. A six hour time difference between team members seems like the biggest time difference that can be conveniently accommodated during regular work hours, if the work day is eight hours long and the team member is also engaged in local work. For bigger time differences in a team, accommodations –earlier start or later end time of the work day- are required to allow meetings of all team members. If a team is actually distributed around the globe with an eight hour time difference between each of three locations, this might mean one member being at work at 6am, one team member at 2pm and a third team member at 10pm to allow synchronous communication, for example a video conference. Pressure may be eased if team members can tend to work while not being in the office, for example a phone conference at home at 10pm, but still adds to the regular working time. Changes between summer and winter time in general and specifically their differing start days, differing workweeks (Saturday though Wednesday or Sunday through Thursday in many Muslim countries, Monday through Friday in many Western countries), and national holidays contribute further to the challenge of finding convenient meeting times.

2.2.3. Tools and Technology for Distributed Teams

Distributed team members are dependent on information and communication technology to bridge the distance among them. Researchers in computer science have developed computer based software to assist virtual teams, supporting development processes, data exchange and communication, so called product lifecycle management solutions. Teamcenter Community by Siemens for example is an internet based product lifecycle management Software tool, that among other things allows its users to share and exchange data, plan meetings and projects, manage project and group memberships, and create routing slips to guide documents or decisions though all team members.

Domain specific research in engineering has worked on providing process support during the product design process, and on generating or modifying methods for the use in virtual teams to accommodate the needs of different kinds of distributed teams. Even though both experiments described in this work are concerned with distributed engineering teams, they have very different requirements to the assisting technology. The Virtual CFD experiment requires a product lifecycle management system to exchange data, and a communication system to support the project handover process at the end and beginning of each shift. No communication between team members is needed during the actual work time, between handovers. The dDesign experiment is placed in the conceptual design phase of the product design process, a communication intensive phase. It consists of interdependent steps, which are generally passed multiple times before the phase is competed with the generation of one or multiple concepts. A continuous exchange of data and information should be available to engineering design team members to allow this interdependent process to take place.

Other challenges beside the presented data sharing exist and have been researched. Kraut, Gergle, and Fussell (2002) look at how a shared view of a problem influences its solution. The evaluated how dyads of participants solve a puzzle: one of the participants sees and knows the solution of it while the other participant has to actually manipulate the puzzle pieces. They are communicating through an audio connection. They suggest that the more complex a task is, the more the distributed team will benefit from a shared view of the work area. Kraut, Gergle, and Fussell (2002) showed this for a distributed team working on a rapidly changing task. This example is similar to a distributed brainstorming team that can see the notes of the team's note taker in real time. Related to the idea of shared views, Elsen and Leclercq (2008) recently published their work on developing ‘SketSha’, an innovative sketching tool. It digitalizes freehand sketching on a manipulated table top in real time within geographically distributed teams while at the same time allowing the team members to see the distant team members on the regular computer screens placed on the table. This leads to front-to-front interaction in the distributed teams very similar to the interaction in collocated teams. The natural sketching led to “impressive architectural results” (Elsen & Leclercq, 2008, p.26) in an educational study compromising of a three months project between French and Belgian architectural students. Elsen and Leclercq conclude that their study “confirms the relevance of sketch tools dedicated to remote collaboration in a formative design context” (2008, p.27). In regards of the dDesign experiment discussed later in this work, it raises the question how the use of tablet PCs compares to the presented SketSha tool, and if value is added to the processes and performance of the distributed teams if team members can see each other. David, Eoff, and Hammond (2010) also present a promising collaborative sketching environment called CoSke to promote sketching. The results of a user study with twelve participants revealed that the participants preferred having an individual sketch space on their computer screen versus sharing a piece of paper. In addition, the study found that spoken words are necessary when creating a shared sketch. A point of criticism is for both SketSha and CoSke is that both tools are only aimed at distributed teams working synchronously, and not suitable for teams distributed in time.

Shigenobu, Yoshino, and Munemori (2007) present GUNGEN DX II, a collaboration support system based on the Japanese KJ idea generation method, which is said to be similar to brainstorming. It assists teams in entering and grouping ideas, as well as in structuring these groups. The entering of ideas seems similar to electronic brainstorming and the grouping gives the impression of having some similarity to organizing ideas into a mindmap. Gungen DX II offers a quick way to organize ideas into similar groups of ideas, independently of other team members. It processes these groups and automatically shows consensus between groups of ideas of multiple users. It could simplify idea generation in distributed teams, as the typing of words should be quick and easy and independent of other team members. Further, it could ease idea categorization, and the evaluation of ideas, as a grouping into similar groups can be done independent of other team members. The groups of similar ideas can be evaluated as a package, saving time and effort of the team. Odd ideas not fitting in or ideas evaluated differently are identified and can be discussed to appraise their value. The research study focuses on the sorting aspect, not the entering of data, but it shows potential for the use in distributed teams. Unfortunately the system is not yet publicly available.

Molina, Aca, and Wright (2005) developed a product lifecycle management environment for global collaborative product development. In addition to the data sharing, the designed environment offers support for all four stages of the design process (idea generation, concept development, advanced development and product launching).

2.2.4. Success Factors in Distributed Teams

Multiple researchers have identified success factors for globally distributed teams. Barczak and McDonough (2003) present three suggestions for successfully managing virtual product development teams: To have a face-to-face kickoff meeting for each project that lasts at least three days, to increase the communication among team members, and to schedule and hold regular progress update meetings to help the team to remain focused on the project goals, maintain the commitment and enhance the motivation towards the project, and to strengthen the relationships among team members. Jarvenpaa and Leidner (1999) also proposed the last two points earlier and add that the team manager should be careful when selecting team members, as responsibility, dependability, and self-sufficiency are essential characteristics. But they found that a face-to-face meeting is not necessarily needed, as long as the communication in the team is frequent and detailed enough.

Based on two case studies, Thomson et al. (2007) developed a strategy for effective virtual design teams. The four key points identified are, first, the creation of a distributed process map, showing how to effectively design in a virtual team. Second, the introduction of a message management system to allow the sharing, storing and sending of messages as well as training of the team members in the use of the new system. Third, the introduction of “best practice” guides to streamline the appearance of exchanged information –sketches, protocols, methods- so it is instantly familiar and easier to understand. Fourth, to use the intranet of the company if assistance for the project is needed, as already many experts are part of the company and thus of the intranet, and at the same strengthening the appearance of virtual teams in the company. The strategy was tested in two more case studies its success was measured in the improvement in satisfaction of the team members. All case study participants worked for a mechanical and electrical consultant at various locations throughout Great Britain. Lee-Kelley and Sankey (2008) have similar suggestions, for example to raise cultural awareness, to foster the use of and making information and communication technology more available, and to encourage communication, as well as instating a clearly structured management.

Based on these studies, two main success factors emerge. Communication is the major issue to encourage and follow, to make sure one’s virtual team is on track and working productively together. Further, competent and knowledgeable management, which chooses its virtual team members carefully and is aware of the specific needs of a virtual team and ideally experienced in the area, makes a difference. A face-to-face kickoff meeting is beneficial to global virtual teams, but is no necessity for a successful team

2.3. Idea Generation

Following Pahl, Beitz, Wallace, Feldhusen and Blessing (2007), the engineering design process is traditionally divided into four phases: planning and task clarification, conceptual design, embodiment design, and detail design. Idea generation, which is part of the conceptual design phase, was chosen as the focus of this study as it sets the course for the following steps of the product development. In this early stage of product development, one aims at having as many alternative solutions as possible, building a wide basis for the following selection and development processes. This will save costs in the long run, as less iteration in the product development process result. Idea generation aiming at a large quantity and high quality of ideas benefits from access to a wide knowledge base. This access is usually achieved by doing the idea generation in teams, with the team members contributing ideas influenced by their areas of expertise.

There is a variety of methods to produce the preliminary solutions during the conceptual design phase, for example brainstorming, method 635, gallery method, c-sketch or functional analysis (Pahl, et al., 2007). Research in the area of idea generation methods, especially on brainstorming and its variations, is vast (e.g.; Adánez, 2005; Bouchard & Hare, 1970; Dillon, 1972; Gallupe, et al., 1992; Isaksen, 1998; Stroebe & Diehl, 1994; Taylor, Berry, & Block, 1958) compared to the amount of work on other idea generation methods. Examples for work on idea generation methods and techniques besides brainstorming are: Aiken, Vanjani, and Paolillo (1996) researching gallery writing versus poolwriting; Chiu and Shu (2007) researching the use of verbs as stimuli in concept generation; Geschka (1996) presenting several creativity techniques developed in Germany; and Shah, Vargas-Hernandez, Summers, and Kulkarni (2001) presenting a new technique called C-sketch.

The dDesign experiment presented in this thesis will specifically compare variations of brainstorming and a modified method 635.

2.3.1. Brainstorming

The following sections present background information on different brainstorming techniques and research on influential variables in brainstorming is presented.

2.3.1.1. Definition

According to the Merriam-Webster dictionary online, brainstorming is “ a group problem-solving technique that involves the spontaneous contribution of ideas from all members of the group [or also] the mulling over of ideas by one or more individuals in an attempt to devise or find a solution to a problem” (Brainstorming, 2009). This definition is broader than the method ‘brainstorming’ introduced by Osborn.

2.3.1.2. Osborn’s Brainstorming

Alex F. Osborn developed brainstorming to improve the creative problem solving process, especially the number of ideas generated, in the advertising agency he headed during the 1940s (Taylor, et al., 1958). He theorizes that if more ideas are generated, the chances of having “good” ideas among them increases. “Good” ideas would be ideas that are suitable to solve the given problem, also called useful ideas.

Osborn mentions brainstorming in his book “Your Creative Power” (1948), and described the technique in detail in the first edition of his book “Applied Imagination: Principles and procedures of creative thinking” in 1953. He developed four basic rules to be followed during a brainstorming session to make it successful:

1. *Criticism is ruled out*. Adverse judgment of ideas must be withheld until later.
2. *"Free-wheeling" is welcomed*. The wilder the idea, the better; it is easier to tame down than to think up.
3. *Quantity is wanted*. The greater the number of ideas, the more the likelihood of useful ideas.
4. *Combination and improvement are sought*. In addition to contributing ideas of their own, participants should suggest how ideas of others can be turned into better ideas; or how two or more ideas can be joined into still another idea. (Osborn, 1963, p. 156)

These rules aim to motivate the group to generate as many ideas as possible (rule 3), by letting their creativity flow (rule 2 and 4) as judgment is suspended and not interfering with creativity (rule 1). Osborn believed that holding back judgment leads to sparking or a chain reaction of ideas: When a member voices an idea it might lead to more ideas by other group members, as it triggers their creative potential.

In addition to the four basic rules, Osborn (1963) recommends the problem should be specific, rather than judgmental (p. 158), the size of the group should be about “a dozen” (pp. 159, 169), the group should have a leader who has prepared the problem and conducts the session (pp. 172-176), a secretary should be appointed to record all ideas (p. 177), and the duration should ideally be 30 minutes, with 15 minutes as a minimum and 45 minutes as a maximum (p. 178).

Even though Osborn praises the new method as leading to an increase in the number of generated ideas, namely twice as many when working in a group as an individual, he presents only anecdotal evidence. Neither his book “Applied Imagination: Principles and Procedures of Creative Problem-solving” (1963) nor his other work contains data from an experiment or a study to prove his point.

2.3.1.3. Verbal Brainstorming

Usually based on Osborn's basic rules, but often deviating from his recommendations, brainstorming evolved into a widely used group idea generation technique that is called verbal brainstorming in this article. In verbal brainstorming, a group of people, who have either been given Osborn's basic rules or a similar set of instructions, generates ideas verbally. Mongeau and Morr (1999) describe some of the changes to the procedure and team configuration that have been made and used in experiments. For example, the team size tends to be smaller, often four to eight instead of twelve members, the team composition is altered, a session leader or facilitator is seldom present, and a secretary might not be appointed or be the same person as the leader. Further, Osborn's recommended preparation for the problem both by the leader and the group members is often neglected, as is the training of the participants. The duration of the session might be in the recommended time frame, but does not have to be in it.

2.3.1.4. Electronic Brainstorming

The progress in technology allowed the development and implementation of electronic brainstorming in the 1980s, with the hope that computer mediated communication will enhance group idea generation and overcome shortcomings of verbal brainstorming that have been revealed in research (see section 2.3.1.5 Research in Brainstorming) since its introduction. Electronic brainstorming typically lets brainstorming participants enter their ideas into a computer using a keyboard. The ideas are then distributed via a network, and appear on the computer screens of all participants (Aiken, Krosp, Shirani, & Martin, 1994; Pinsonneault, Barki, Gallupe, & Hoppen, 1999). Sometimes, all ideas are accessible to the participants, sometimes only a random selection of the generated ideas is shown. The participants may or may not be in the same room.

According to Aiken et al. (1994), the benefits of electronic brainstorming over verbal brainstorming are the anonymity of the participants, the parallel communication as all participants can write at the same time, and the automated recording of the generated ideas. Research on brainstorming is presented in the following section.

2.3.1.5. Research in Brainstorming

Shortly after the publication of Osborn's book "Applied Imagination: Principles and procedures of creative thinking" in 1953, researches began examining the claims of an increase in the number of ideas when using brainstorming. What they researched however, was seldom Osborn's brainstorming, but usually some derivation, a verbal brainstorming as described above (Mongeau & Morr, 1999).

An early and often cited study by Taylor et al. (1958) is comparing if individuals or groups are more productive when generating ideas. The research question of the study is "Does group participation when using brainstorming facilitate or inhibit creative thinking?" which is tested by comparing results from groups and so called nominal groups. The concept of nominal groups is introduced by Taylor et al. A nominal group constitutes of individuals that solve the problem alone. After the experiment, the individuals are randomly compiled into groups with as many members as the real groups have. This allows a direct comparison of the amount of ideas generated in a (real) group versus by the same number of individuals in the nominal group. Taylor et al. used students in their experiments. The students had worked together and were no ad-hoc groups, but were sub groups of bigger teams. Each team had four participants. The experimenter stayed in the room and intervened if critical comments were made during the experiment. Three different problems were brainstormed, each one for twelve minutes. A sound recording of each experiment, both of groups and individuals, was obtained to later be transcribed, and no note taker was present. The brainstorming rules were provided to both the individuals and the group participants. The participants did not have time to prepare in advance and were not trained in brainstorming. The study found that the groups performed worse than the nominal groups in regard of he mean number of ideas, the mean number of unique ideas, and quality of idea measure and concluded that "group participation when using brainstorming inhibits creative thinking." (Taylor, et al., 1958, p. 1)

However, as both the individuals and the groups were given the same instruction and the four brainstorming rules from Osborn (1963, p. 156), the study by Taylor et al. (1958) did neither test the efficiency of brainstorming nor Osborn's claim that a real group will generate more ideas than an individual (Isaksen, 1998). According to Isaksen

(1998) and Litchfield (2008), the study by Taylor et al. (1958) was trend-setting for the future research on brainstorming, leading it into the direction if individuals or groups perform more ideas, even though this research was often perceived as researching the effectiveness of brainstorming. Isaksen (1998) examined 50 studies on brainstorming. He states that the guidelines of brainstorming were tested in 15 studies of these 50, and each of the 15 found support for brainstorming. Osborn's brainstorming was designed to overcome some of the problems arising from social interactions. By comparing group data to nominal groups, which have no social interaction, this important piece of the brainstorming is disabled.

Both Diehl and Stroebe (1987) and Mullen, Johnson, and Salas (1991) compared nominal to real brainstorming groups and confirmed the finding of Taylor et al. (1958), that nominal groups generate a higher quantity of ideas than real brainstorming groups.

2.3.1.5.1. Osborn's Basic Brainstorming Rules

In the year after the publication of the Taylor et al. study, Parnes and Meadow (1959) presented their work researching the influence of brainstorming instructions for trained and untrained participants. Undergraduate students were used as subjects; the untrained participants had no experience in creative idea generation, whereas the trained participants had taken part in a creativity lecture. The experiment was group administered, but all subjects individually wrote their ideas down. The study evaluated and compared good ideas, in contrast to comparing the pure quantity of ideas in other studies. The results show an increase in qualitative high ideas for untrained participants under brainstorming instructions as compared to untrained participants under non-brainstorming instructions and a significant increase in high quality ideas for trained participants as compared to untrained participants, both under brainstorming instructions. The findings indicate that Osborn's basic rules improve the idea generation performance, even though it is not yet shown how this transfers to groups. However, Litchfield (2008) notes that the influence due to the different instructions for the groups– the non-brainstorming group was instructed to only write down their good ideas, without them knowing how good was defined – should be kept in mind.

Putman and Paulus (2009) relied on the results by Parnes and Meadow (1959) and did not modify Osborn's rules. They added additional rules with the goal to improve the number of generated ideas. Paulus, Nakui, Putman, and Brown (2006) showed that additional rules aimed at facilitating the brainstorming process, increased the number of generated ideas both for nominal and real groups. The additional rules, modified form the 2006 study, are given to the participant in addition to the four rules from Osborn (1963). In the 2009 study, they are:

5. *Stay Focused on the Task*. Concentrate on the problem at hand and avoid engaging in irrelevant thought processes or discussions. When it is necessary to interrupt a group member, say something like, "Remember that we need to stay focused on our task."
    a. *Do not tell stories*. We are only interested in your ideas. Do not allow your group members to tell stories about their experiences.
    b. *Do not explain ideas*. Do not allow your group members to expand on why they think something is good or bad. Let them say an idea and then interrupt them.
6. *Keep the Brainstorming Going*. During a lapse of time when no one is talking, someone in the group should say something like, "Let's see what other ideas we can come up with for (restate the problem)."
7. *Return to Previous Categories*. When the group members are not talking very much, go back to categories of ideas that have already been mentioned and try to build on these previous ideas. For example say: "Does anyone have any more ideas related to (restate an idea already suggested)?" (Putman & Paulus, 2009, p. 39)

The additional rules increased the number of generated ideas both in the nominal and the real groups. In addition, Putman and Paulus (2009) found that the number of used words by a group in a condition might be an indicator of the performance of the group, as in the experiment similar word count indicated a similar performance level. Even though this study proved the usefulness of the additional rules, Osborn's rules have not been examined.

It seems that up to today the four basic rules developed by Osborn have not systematically been researched in regard of their benefits. Litchfield (2008) uses existing research to analyze the value of each of Osborn's rules and proposes their transformation from rules into goals. Overall, Litchfield (2008) shows that research examining any one of the rule for itself is scarce and proposes that a goal-based approach to creative problem solving would be beneficial for the number and quality of ideas developed. There is not sufficient data available to allow a reliable conclusion if Osborn's rules allow what they promise to do and if they are the best to use.

2.3.1.5.2. Does Quantity Produce Quality?

Parnes and Meadow note that subjects "give a larger number of ideas in response to brainstorming than to non-brainstorming instructions" (Parnes & Meadow, 1959, p. 173), which in combination with their findings of a higher quantity of good ideas in brainstorming conditions supports Osborn's theory that a higher quantity of ideas will lead to a higher quality of ideas. However, as Litchfield (2008) stated, the results need to be critically evaluated as the non-brainstorming groups received different instructions, telling them to only write down good ideas.

Diehl and Stroebe (1987) conducted four experiments to test reasons for differences in idea generation between real and nominal groups. Participants differed between experiments, in the first experiment high school students that were paid were used; in the experiments two through four, psychology students participated to fulfill part of their course requirement. In group conditions, participants were randomly assigned into four person groups. The results from the study support Osborn's hypothesis that quantity generates quality. The authors were so convinced with their findings that they "decided not to conduct quality ratings in further studies" (Diehl & Stroebe, 1987, p. 501). Adánez (2005) researched Osborn's hypothesis that quantity generates quality. In his experiments, 69 groups used brainstorming to generate ideas in twenty minute sessions. The group size varied between three and eight persons. Adánez (2005) found that his results fully support the positive relationship of quantity and quality.

Briggs, Reinig, Shepherd, Yen, and Nunameker (1997) researched if quality is a function of quantity in electronic brainstorming. The experiment used undergraduate students distributed into 58 five person teams. For the evaluation of the experiment, unique ideas were extracted from the session records. Each idea was rated by two raters on a four point scale considering economic, technical, and political feasibility, and the sum of the scores from the raters was the final value. A significant relationship between high quality and number of ideas produced was found. However, as the analysis was refined, it became evident that the higher the quality of an idea was, the less it was related to the quantity of generated ideas. This means, Briggs et al. (1997) found that if a team produces more ideas, it will produce more low quality ideas, but not necessarily more high quality ideas which led to the assumption, that other factors might be more influential on the number of high quality ideas produced by a team.

Contrary to the findings of supporting the quantity – quality relationship, Mullen, Johnson, and Salas (1991) inferred from the meta-analysis they conducted that brainstorming leads to both a quantitative and qualitative loss in generated ideas. They further state that the fewer generated by brainstorming groups are not of higher quality as some researcher had considered. Putman and Paulus (2009) also dispute the quantity – quality relationship proposed by Osborn, as their teams using the additional rules when brainstorming produced more ideas, but the quality of the ideas did not increase.

Isaksen (1998) advises to differ between quantity and quality when evaluating idea generation experiments in his review of brainstorming and not to average quality, as the number of silly ideas in brainstorming groups would automatically lower their average score compared to nominal groups.

On top of the potential problem due to averaging quality scores, there might be an underlying problem in how the quality was evaluated, which differs between studies. Sometimes the differences exist only because different raters were used, sometimes because quality might have been defined differently. For example, quality can be a score from one through four (Briggs, et al., 1997), or a quality score can be a composed rating of how good the idea is, how feasible, and how original (Diehl & Stroebe, 1987). Further, the author of this article thinks, that, even though the quality measure captures a snap-shot in time right after the idea generation, one should ask how this transfers to industry, where silly or initially disregarded ideas might spark a very innovative solution at a later time in the idea generation process. This questions the usefulness of quality measures in general. Overall, it seems that generating a higher number of ideas does not necessary lead to more high quality ideas. However, the circumstances under which the hypothesis might be true are not known yet and more research is needed.

2.3.1.5.3. Group Size

Group size was soon realized to have an effect in brainstorming groups. Bouchard and Hare (1970) created an experiment researching groups size in brainstorming. The first factor, group size, had three levels: five, seven and nine member groups. The second factor was the kind of team, either nominal or real verbal brainstorming teams. A third factor, experimenter one or two, did not show any significance. They hypothesized that the number of generated ideas in nominal and real brainstorming teams would converge with increasing team size, but could not support this hypothesis. Contrary, they found that the number of generated ideas diverged significantly, with nominal groups on the three levels examined producing about double the number of ideas than real brainstorming groups. It can be concluded form their research that nominal teams outperform real teams for up to nine team members

Aiken at al. (1994) compared verbal brainstorming in small (about eight members) and large (about 48 members) groups to electronic brainstorming. Note that the use of the adjectives small and large is highly subjective, only depending on the experimenter. They found a significant difference between small verbal brainstorming groups and large verbal brainstorming groups, with the small groups generating significantly more ideas. Further they found small electronic brainstorming groups performed significantly better than large verbal brainstorming teams, and that large electronic brainstorming teams outperform both small verbal teams and large verbal teams. Aiken et al. hypothesized that the breakeven point, at which electronic brainstorming becomes favorable over verbal brainstorming, lies at around eight people (Aiken, et al., 1994, p. 146). One difference between verbal and electronic brainstorming groups seems to be that in verbal brainstorming, the number of ideas generated deceased for an increase in team size, whereas the number of ideas generated increases with the number of team members in electronic brainstorming (Gallupe, et al., 1992; Valacich, Dennis, & Nunamaker, 1992).

Dennis and Williams (2005) performed a meta-analysis of group size comparing nominal groups, verbal, and electronic brainstorming groups. They find that group size is a significant factor when deciding which method will produce the most ideas. The gains of electronic brainstorming come already in small teams: With four and more participants electronic brainstorming groups outperform verbal brainstorming groups. For ten people, electronic brainstorming outperforms nominal brainstorming, too. This seems to be the point at which synergy effects, which do not exist in nominal groups, gain importance. It is interesting to see how in verbal brainstorming an increase in team size leads to a decline in the number of generated ideas, whereas in electronic brainstorming an increase in team size leads to an increase in generated ideas. However, for 2 or 3 members, verbal brainstorming leads to the most ideas.

2.3.1.5.4. Reasons for Productivity Loss in Verbal Brainstorming

After the divergence between Osborn's claim that brainstorming leads to the generation of more ideas and experimental findings indicating that nominal groups are superior generating a higher quality of ideas -generally using not Osborn's but verbal brainstorming in the studies- was discovered, researchers started looking for explanations why brainstorming groups generate fewer ideas than nominal groups. Dennis and Williams (2005) summarized the group processes identified by researchers (Diehl & Stroebe, 1987, 1991; Furnham, 2000; Gallupe, Cooper, Grisé, & Bastianutti, 1994; Mongeau & Morr, 1999; Offner, Kramer, & Winter, 1996; Paulus, Dzindolet, Poletes, & Camacho, 1993; Putman & Paulus, 2009) to positively and negatively influence the productivity in brainstorming groups: social facilitation and synergy lead to process gains, whereas production blocking, evaluation apprehension, social loafing or free-riding, cognitive interference and communication speed lead to process losses.

Social facilitation is the ability of the physical presence of others to affect one's behavior and performance. In brainstorming groups, even in nominal groups that work for themselves in the same environment, social facilitation is seen as a process gain (Pinsonneault, et al., 1999). Synergy occurs if an idea from one participant leads another participant to have an idea, which had not come to the participants mind without hearing or seeing the other idea first (Dennis & Valacich, 1994; Lamm & Trommsdorff, 1973). Osborn's (1963) fourth rule - *Combination and improvement are sought* – aims at increasing the synergy effect in a brainstorming group.

Evaluation Apprehension refers to the fear of the group member to be judged, to look incompetent or foolish when suggesting an idea (Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973). Osborn's (1963) first rule aims at inhibiting negative comments and judgment from other group members, which would eliminate evaluation apprehension. Unfortunately, it does not automatically eliminate the fear of being judged, especially in untrained groups. Dennis and Williams (2005) theorize that anonymity in brainstorming in an industrial setting might reduce evaluation apprehension, even though according to research with undergraduates is has either none or a very small influence. Social Loafing, often called free-riding, describes the situation when an individual contributes fewer ideas when working in a group than if working alone. The individual thinks that its efforts are not needed, it hides behind the group (Dennis & Williams, 2005; Furnham, 2000). According to Dennis and Williams (2005), social loafing can be minimized if each group members believes it will be evaluated by its contributions, rather than by the outcome of the whole group. Production Blocking was first mentioned by Lamm & Trommsdorff (1973), who were the first to state that verbal brainstorming might produce fewer ideas as only one person is speaking at a time. Diehl and Stroebe (1987) found through their experiments that the variable accounts for most of the variance in the quality levels of generated ideas of verbal brainstorming groups. Mullen, et al. (1991) concluded in their meta-analysis that not production blocking, a procedural mechanism, but social psychological mechanism are the main cause of process losses. According to Furnham (2000), a trained facilitator can reduce production blocking significantly. Researchers have also experimented with allowing participants to take personal notes during the brainstorming session, which seemed to reduce production blocking (Diehl & Stroebe, 1991; Madsen & Finger, 1978). Cognitive Interference can be described as the opposite of synergy. It occurs when an idea expressed by another participant interferes with other group members idea generation (Pinsonneault, et al., 1999). This might be that an idea is forgotten as it cannot be expressed immediately, or that a train of thought is interrupted. This effect is less pronounced in electronic brainstorming groups, as the written communication allows more than one train of thought at the same time and ideas are accessible after they have been written down, so they are not only available to be heard once as in verbal brainstorming (Dennis, et al., 1997; Dennis & Williams, 2005). Communication Speed refers to the fact the most people take longer to type or write their ideas down than to express them verbally (Dennis & Williams, 2005). This loss is specific to nominal or electronic brainstorming. It needs to be noted that the way of communicating ideas – writing, typing or speaking- has been used in both types of brainstorming and depends on the study.

Mullen, et al. (1991) categorize production losses as three different psychological mechanisms: 1) procedural mechanisms, for example production blocking, 2) social psychological mechanism, for example drive-arousal or self-attention, and 3) economic mechanisms, represented by for example social loafing and free-riding. The meta-analysis concluded that social psychological mechanisms are the most influential on productivity loss in brainstorming groups. Procedural mechanisms are marginally able to explain process losses and economic mechanisms do not explain process loses. Pinsonneault, et al. (1999) use the same three types of mechanisms from group and social psychology in their meta-analysis and find process gains and losses not yet identified in electronic brainstorming research. They apply them to four types of brainstorming: verbal, nominal, anonymous and non-anonymous electronic brainstorming. They indicate that these in electronic brainstorming research not yet examined gains and losses might lead to explanations for the mixed results when comparing nominal, verbal, and electronic brainstorming groups.

It needs to be determined which of the process gains and losses occur in the experiment presented in this article so that antidotal measures can be determined to be in tested in later experiment to maximize the quantity and quality of ideas produced. Dennis and Williams (2005) also indicate which effect will occur and to what extent in nominal, verbal, and electronic brainstorming groups. This could help in determining which gains and losses occur in the experiment presented in this article, as the verbal brainstorming condition is similar to earlier experiments and the brainwriting condition might have similarities with the nominal and electronic brainstorming conditions.

2.3.1.5.5. Research Centered on Electronic Brainstorming

Aiken et al. (1994) summarize three advantages and four disadvantages of electronic brainstorming in comparison to verbal brainstorming: Anonymity is easier to achieve and might prevent evaluation apprehension. Electronic brainstorming allows for parallel communication, which might reduce production blocking. Gallupe et al. (1992) describe the experience that individuals access the ideas of others especially when they themselves run out of ideas momentarily, which indicates it does not interfere with their own stream of thought. All ideas generated are automatically written down and thus automatically recorded and directly available to distribute for future use, without losing ideas that have not been spoken out and without needing a transcript.

Expression of ideas might take longer than in verbal brainstorming due to slow communication (called communcation speed in Dennis & Williams, 2005), as most people need longer to type or write their ideas than to express them verbally. Resistance to change might be fierce in a company, whoever, Gallupe et al. (1992) recorded a higher satisfaction in electronic than in non-electronic brainstorming groups, which they contributed to the curiosity for the new technique. This factor seems to be change with the setting of the brainstorming. The lack of media richness, the fact the in electronic brainstorming mimic, gests, and body language are missing, was also given as a disadvantage by Aiken et al. (1994). It seems, however, that this might be an advantage at times, as a group member might not be able to suppress a frown or a snarky remark, but is less likely to write down a negative remark. A further concern for electronic brainstorming groups is the possible increase in conflicts. As the team members are not having the group experience, they might find it harder to create a shared ownership of the generated ideas and a decision on which ideas to follow up on might be influenced by preferring the ideas created by oneself.

Another advantage of electronic brainstroming was identified and researched by Dennis, Aronson, Heninger, and Walker (1999). They provided participants three windows on their computer screen, each dedicated to a specific aspect of the problem at hand. The participants could enter ideas simultaneously for each aspect, without blocking or confusing their team members by switching topics. This improved the performance of the teams and opens up a possibility not existent in brainstorming.

2.3.1.6. Implications

What we today call brainstorming is often only loosely related to Osborn's brainstorming and is due to the many variations not defined by saying "we brainstormed". Many factors influence the outcome of a brainstorming session, and more research is needed if these factors should be classified on how much they impact the process and how they can be influenced.

Diehl and Stroebe (1991) propose to enable individuals to record their ideas privately in addition to the verbal brainstorming, which seems to lead to more generated ideas. Gripman (2009) presents team note taking techniques which might be beneficial for verbal brainstorming groups: first, using mindmaps to organize ideas while they are created. Second, he proposes to use one post-it note for each idea and to post the notes on a surface visible to all team members. His first premise is especially interesting, as mindmaps can be shared among participants at different locations and do not have to be manipulated synchronously, enabling a delayed idea generation process.

Offner et al. (1996) used a trained facilitator, a member of their research team, to ensure brainstorming groups stayed on task and found a significant effect on the number of generated ideas. Mullen et al. (1991) found that only the presence of an experimenter in the room enlarged the number of generated ideas.

Thinking of many experiments run with undergraduate students, the motivation of the participants to solve a problem in comparison to an industrial setting should be kept in mind. Dennis, Valacich, Connolly, and Wynne (1996) remarked that the presentation of the problem, both how much advance of the brainstorming session and how it is formulated and presented, might influence the outcome of a brainstorming session.

Most participants have not received a formal training in brainstorming, something Osborn advocated. This might make it harder to withhold judgment, again taking into account most participants in experiments are undergraduates. This leads to another point, the composition of brainstorming teams. Osborn advised for a heterogenic group, consisting of core team complemented by a diverse set of people. Experiments having been performed with the undergraduates might not fulfill this criterion.

In the study presented in this article, participants will not undergo extensive training, are a rather homogeneous undergraduate population, will not have a facilitator, and the experimenter will not be present at all times in the room. The group size will vary between three and four participants. They will not have the possibility to take personal notes, but a note taker for the team will be randomly selected. The problem will be not known before the experiment.

2.3.2. Modified Method 635

The second idea generation technique used in this study is a modification of the method 635. In the following sections terms concerning brainsketching will be clarified, a history of brainsketching is presented, and the modified method 635 as used in this study is explained.

2.3.2.1. Definition of Terms

Whereas brainstorming is used in many variations, the term is widely known and describes an idea generation session in which ideas are voiced. The term brainwriting is mostly used a generic term compromising all idea generation techniques that use written statements instead of spoken ones, as explained by Geschka (1996) or VanGundy (1984), sometimes with an emphasis on electronic brainstorming, for example by Heslin (2009). The method 635 is for example a brainwriting technique. Brainsketching is a modification of brainwriting, using sketches instead of or in addition to written words (Van der Lugt, 2002).

2.3.2.2. History of Brainwriting and Brainsketching Techniques

The following section contains a short history of the idea generation techniques underlying the modified method 635 used in the dDesing study presented in this thesis. These methods are method 635, the gallery method, and c-sketch. More methods of brainsketching have been developed, often incorporating some sketching into brainstorming, for example by Van der Lugt (2002), but are not presented here as they are not relevant to the method used in this study.

2.3.2.2.1. History of Method 635

The method 635 was developed by Rohrbach in the seventies (Rohrbach, 1969), then working in an advertising agency, to support slogan development and idea generation in marketing and advertising. In its original form it allows only the use of words (Rohrbach, 1969, p. 74), hence it is also called brainwriting. 635. It was developed for six participants, but can easily be adapted for a different number, though this changes the quantity of ideas obtained. Five minutes are suggested for each idea generation interval. Each participant is given a piece of paper, often a prepared worksheet, and asked to develop three initial solutions to a design problem, during the first five minute interval. Afterwards, the sheets of paper are passed on (either clockwise or anti-clockwise) to a neighbor. The participants then try to add to the existing solutions or to come up with new ideas. After five minutes the sheets are passed on again in the same direction as before, until everybody has worked on everybody's initial solutions. For six participants this means five exchanges. The name refers to the number of participants (6), the number of ideas generated per round (3), and number of rounds (5, not the duration of the round). The written ideas on the sheet are the only exchange among the participants during the idea generation session. A typical worksheet used during an idea generation session was developed by Rohrbach and is shown in Figure 2. The problem is noted in the top of the sheet, as are the time, date and the initial participant's name. Each participant fills in one line, consisting of three fields, one per expected idea. Extra lines in addition to the six needed for six participants are given to encourage idea generation and give space to write down more than three ideas per participant.

Brainwriting 6-3-5 Worksheet		
Job To Be Done:		Date:
		Team:
		Member:
1	**2**	**3**

Figure 2 Method 635 work sheet

Geschka (1996, 2008) equals the method 635 to the ‘ring-exchange technique’, but in the German literature ring-exchange technique (Ringaustauschtechnik) is mentioned by other authors without detailed description but shown in overviews as a technique distinct of the method 635 (Busch, Fuchs, & Unger, 2008; Leidig, 2004).

The method 635 has some benefits compared to brainstorming. Neither a moderator nor a note taker is needed. All participants can generate ideas at the same time and the generated ideas are automatically recorded. Ideally, an idea is more and more refined as the work sheet it is on circles through the participants, whereas in brainstorming an idea might be only voiced but not seized. It is possible to trace which participant created which idea. Arguments disrupting the idea generation process are less likely, as no discussion takes place. On the cost side, participants might feel more isolated and the stimulation through the written ideas might not be as intense as in voiced ideas.

2.3.2.2.2. History of Gallery Method

According to Pahl et al. (2007), the gallery method was presented by H. Hellfritz 1978. Unfortunately, as Hellfritz self published his book, no copy of this book is available. The gallery method is a 5 step method. First, the session leader presents the design problem. Then each participant has about 15 minutes to generate ideas individually and to express them in annotated sketches. The third step is the exhibition of all ideas generated so far, for example by pinning the pieces of paper to a wall. For 15 minutes, the participants will go around, look at the generated ideas and discuss them. The fourth step is a second individual idea generation session, in which the participants jot down all ideas which arouse through the previous discussion. The final step is a decision phase, in which the participants complete, categorize, and evaluate all created ideas. The gallery method has the same benefits regarding brainstorming as the method 635. In addition, it encourages sketches which work well in technical design problems and offers the discussion among the participants between idea generation sessions to interpret ideas and to get new suggestions. The discussion might benefit from a moderator, but none is explicitly asked for in the method description.

2.3.2.2.3. History of C-Sketch

Collaborative sketching (c-sketch), also known as 5-1-4 G, was first presented in 1993 by Shah and is based on the exchange schedule of the method 635, taking the sketching part from the gallery method (Shah, 1998; Shah, et al., 2001). In c-sketch, five (5) designers create one (1) sketch each on an initially blank sheet of paper and pass it on four (4) times. The G represents the graphic orientation of the method. Only sketching is allowed, no written or verbal annotations are intended. Shah et al. (2001) compared the method 635, the gallery method and c-sketch. They found that c-sketch produced more ideas than the method 635. Further, c-sketch let to the same quality of ideas as the gallery method, but the novelty and variety of generated ideas was superior.

2.3.2.3. Description of Modified Method 635

In this study, a modified method 635 is used. It is based on the method 635 exchange schedule and uses the idea of developing three ideas during each time interval. However, inspired by c-sketch and its superiority in comparison with the method 635 (Shah, et al., 2001), the participants are encouraged to sketch their ideas. Leaving the written words only restriction used in the method 635 and the sketches only restriction used in c-sketch behind, the participants are now encouraged to add annotations to their sketches. The modified method 635 is a brainsketching method. The sketch surface is partitioned in three similar sized parts, as shown in Figure 3, allowing the development of three ideas at the same time, each one in a spatially separated area. The origin of this partition could not be determined.

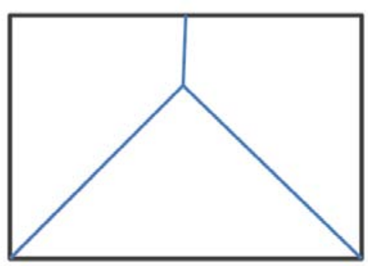

Figure 3 Sketching surface with partition lines

Whereas each participant has its own three fields to add comments or new ideas in the original method 635, in the modified method 635 the participants are encouraged to sketch and annotate three initial ideas in the first interval. In the subsequent rounds, the participants add to the existing solutions.

2.3.3. Incubation Period in Idea Generation

In 1926 Graham Wallas presented one of the first models describing the creative process in his work "The Art of Thought" expanding on reports by Helmholtz and Poincaré. Wallas presented four phases, Preparation, Incubation, Illumination, and Verification, introducing the term incubation as the second of four phases of the creative problem solving process, defining 'incubation' as "the stage during which [one is] not consciously thinking about the problem" (1926, p. 80).

More than 50 years later, Guilford defined incubation as "a period in the behavior of the individual during which there is no apparent activity on his part toward the solution of a problem, but during which or at the end of which there are definite signs of further attempts, with sometimes material progress towards a solution" (1979). S. M. Smith and Blankenship similarly explain incubation as a transpiring phenomenon: "After one has temporarily left an unsolved problem, an unexpected insight into the solution may occur" (1989). Based on these definitions, incubation in the realm of this publication is understood as the process happening while an individual is not actively pursuing a solution to a given design problem. Incubation period or incubation time refers to the duration of the non-pursuing state and an incubation effect describes progress towards a solution after resuming the active problem solving. Incubation periods have no prescribed minimum or maximum length, they can last years or only seconds.

2.3.3.1. Theoretical Background

During the research of incubation, different hypotheses aimed at explaining the phenomenon have been developed. Guilford (1979) presented the unconscious mind theory, the fatigue-dissipation theory and his own transformation theory. Kohn (2005) expands on those, adding the conscious mind hypothesis, the forgetting-fixation hypothesis and the autonomous-process hypothesis. Besides the conscious work hypothesis, Sio and Ormerod (2009) present three unconscious work hypotheses: activation spreading, selective forgetting and problem restructuring. In the following paragraphs, the hypotheses will be presented. The first distinction is made between the recovery from fatigue hypothesis and the incremental work hypothesis, with the latter being divided into the conscious and unconscious work hypotheses, and the attention-withdrawal hypothesis.

2.3.3.1.1. Recovery from Fatigue or Fatigue-Dissipation

The recovery from fatigue hypothesis, also called fatigue-dissipation hypothesis, has been described by Woodworth (1938). It is theorized that the individual tires from the problem clarification task and the attempts to solve the problem, so that a rest period is needed for recovery from fatigue. After the break the individual is refreshed and often able to solve the problem, leading to an incubation effect. Even though the recovery from fatigue theory can be true in some cases, multiple researchers (Murray & Denny, 1969; Penney, Godsell, Scott, & Balsom, 2004; S. M. Smith & Blankenship, 1991) have reputed this theory as general cause for an incubation effect, as in their experiments an incubation effect occurred even when the individuals were working on intense tasks during the incubation time, preventing the individual from resting.

2.3.3.1.2. Incremental Work

In the incremental work hypothesis, an individual, or rather the individual's mind, is composing a solution from fragments during the incubation period. This can be a conscious process, with the individual realizing it is working on a solution, or an unconscious process, with the individual unaware of its mind's activity. In addition to these two approaches, Segal (2004) proposes the attention-withdrawal hypothesis, which contains elements from both conscious and unconscious processes.

2.3.3.1.2.1. Conscious Mind

If the individual consciously keeps working on the problem during an incubation period even though it is told to relax, the process is called covert problem solving (Browne & Cruse, 1988). The incubation effect can be further increased by presenting a hidden hint for the problem solution to the individual, even though the individual needs to realize that there is a hint and how it relates to the problem.

Even though the individuals are aware of thinking about the problem at the time, they might forget later on that they thought about it during the incubation period. The forgetting of conscious work is more probable in extended incubation periods, wherein the individual follows automated routines, for example showering, which leave cognitive space for exercising the mind. The conscious mind hypotheses of problem solving has been disputed in some experiments for insight problems, as a significant incubation effect occurred, even though the individuals were occupied with thought intense filler tasks (S. M. Smith & Blankenship, 1991). However, the conscious mind hypothesis cannot be rejected for all incubation scenarios and should be considered when seeking to explain the phenomenon.

2.3.3.1.2.2. Unconscious Mind

In the unconscious mind hypotheses, the individual is not aware of its mind working on the problem. There are several hypotheses: the transformation hypothesis by Guilford (1979), the low-spreading activation hypothesis by Yaniv and Meyer (1987), the related set breaking hypothesis by Woodworth(1938) and the forgetting-fixation hypothesis by S. M. Smith and Blankenship (1989, 1991), and the problem restructuring hypothesis by Seifert, Meyer, Davidson, Patalano, and Yaniv (1995) and Knoblich, Ohlsson, Haider, and Rhenius (1999).

2.3.3.1.2.2.1. Transformation

Guilford presented his transformation hypothesis in 1979. It attributes progress during incubation mostly to unconscious transformation of information. In the beginning of the problem solving process, the individual retrieves and communicates the obvious solutions according to the individual’s internal search scheme. As time goes by, the individual runs out of obvious solutions and needs to extend the search scheme to less obvious memory items, transforming them into a solution. Both new information gathered and the creation of new connections between memory items, can lead to transformations of memory items into solutions. Guilford states that the transformation of memory items is more time intensive than the pure retrieval of the obvious solutions, thus the incubation time aids by allowing a longer time to create transformations. Further, the activities and experiences during the incubation period lead to an increased number of transformations of old memory items by new connections.

2.3.3.1.2.2.2. Spreading Activation

The partial activation of critical information for the problem solution is assumed in the spreading activation hypothesis by Yaniv and Meyer (1987). During the incubation period, the activation spreads, probably further activated by new experiences, leading to the solution of the problem, either during the incubation period or upon returning to the problem. This hypothesis has parallels to the transformation hypothesis presented by Guildford (1979) nearly ten years earlier, when one considers the act of transformation equal to the activation of information. It is consistent with the idea that nodes in the brain hold information and are activated through neural maps created prior to the experiment. The further one moves away from the original node –the problem- the less related are the ideas to it. They appear more unusual and creative to the environment.

2.3.3.1.2.2.3. Set Breaking

Besides presenting the fatigue-dissipation hypothesis, Woodworth (1938) presented a second possible explanation for incubation effects, called the set breaking hypothesis. He theorized that the incubation period allows the individual to forget misleading ideas or assumptions, and to start over when approaching the problem again.

2.3.3.1.2.2.4. Forgetting-Fixation or Selective Forgetting

S. M. Smith and Blankenship (1989, 1991) propose the forgetting-fixation hypothesis, deepening the set-breaking hypothesis. They propose the incubation effect is due to the forgetting of a ‘mental block’. The mental block, also called a fixation, emerges when an individual fixates on solutions during the initial solution generation phase. As this one idea is on the individual’s mind, it hinders the retrieval of different ideas or solutions and becomes more prominent the more the individual thinks about it. A break can lessen the prominence of this one idea, allowing the individual to forget the idea, and making room for other ideas, which might lead to the problem solution after the incubation period.

2.3.3.1.2.2.5. Problem Restructuring

Seifert et al. (1995) and Knoblich et al. (1999) propose that an incubation period allows the individual to restructure the mental representation of the problem the individual is trying to solve. The restructuring process might be triggered by the insight that a new approach towards solving the problem is needed, or from a renewed task clarification which might change the boundaries of the problem.

2.3.3.1.2.3. Attention-Withdrawal

In 2004, Segal (2004) presented a new hypothesis to explain incubation, expanding the attention-withdrawal hypothesis. Based on the observation that an incubation effect is mainly seen when using insight problems in the experiments, he defines two characteristics that discern insight problems from problems that need to be solved incremental: The impasse often encountered during the solution process and the “Aha!” experience when finding the solution. He then presents three occasions which allow incubation: First, directly after the individual encounters the impasse, when its mind begins to wander. Second, when encountering external cues during a break after an impasse has occurred. This situation constitutes the prepared-mind hypothesis. Third, the break allows forgetting or erasing of unhelpful assumptions. This is described as the returning-act hypothesis. The conducted experiments lead him to believe that only the prepared-mind hypothesis is true – nothing happens during the break in the individuals mind, the only reason for the break is the distraction from the problem.

2.3.3.2. Experimental Research

There is an ongoing quest in the experimental research community to prove the existence and to find an explanation of the cognitive processes driving incubation. The early research as presented by Browne and Cruse (1988), Sio and Ormerod (2009), and S. M. Smith and Blankenship (1991) succeeded sometimes in showing incubation effects, but all research was beneficial in leading to a better understanding of the effect and its causes, identifying factors influencing an incubation effect

2.3.3.2.1. Motivation

In 1979 Guilford identified motivation as a factor in incubation. If an individual is motivated to solve a problem, it is to be expected that the problem remains more prominent in the individual’s mind during the incubation phase. Guilford does not state if this process happens consciously or unconsciously, but rather states: “An unsolved problem can leave a more or less painful void that must be filled, and this could put pressure on the brain parts that are responsible for meeting the challenge." (Guilford, 1979, p. 5)

2.3.3.2.2. Problem Type

More than one research team (Segal, 2004; Sio & Ormerod, 2009; S. M. Smith & Blankenship, 1991) has identified that a so called "insight problem" is suited best to enable incubation effects. In contrast to other problems, insight problems are not solved gradually. Usually, the problem leads the solver to assume a false assumption, which leads to an impasse and prohibits the problem solution. Once this misleading information has been corrected –the impasse is overcome- the problem is solved with an "aha-effect" (Segal, 2004). An example of an insight problem is to cut a cake into eight equal sized pieces with three cuts. The information to use a cylinder instead of a cake usually helps the solver to imagine a horizontal cut and to solve the problem. Penney, et al. (2004) however were successful in using an anagram problem to show an incubation effect.

2.3.3.2.3. Cues

Some researchers (Browne & Cruse, 1988; S. M. Smith & Blankenship, 1991) present helpful cues during the incubation period, others misleading ones (S. M. Smith & Blankenship, 1989) in order to test the influence of external stimuli.

2.3.3.2.4. Occupation During the Incubation Period

In the experiments, the occupation of the individual during the incubation period under experimental conditions was varied between relaxation, an intense mentally challenging task and a medium challenging task (S. M. Smith & Blankenship, 1991). As an incubation effect occurred even after the intense mentally challenging task, the recovery from fatigue hypothesis was reputed for this experiment.

2.3.3.2.5. Length of Incubation Periods, Number of Incubation Periods

Offner, Kramer, and Winter (1996) tested the influence of the length and spacing of pauses in brainstorming groups and found only a marginally significant effect, which they accredited to the extra time the teams with pauses had. Paulus, Nakui, Putman, and Brown (2006) researched the same question, in a different set up. They found a small benefit for one break. Having no or two breaks in their experimental set-up led to a significantly lower number of ideas. Another experiment using individuals solving an insight problem (Segal, 2004) showed that a break is beneficial, but that its length does not significantly influence the problem solving.

2.3.3.3. Implications

Research as presented in this short review seems to indicate that incubation exists and that an incubation period is beneficial in creative problem solving. It is still unknown if any, or which, or which combinations of the presented hypotheses may be explanations of the phenomenon. The current work is not aimed at developing a hypothesis to explain the process, but at experimentally finding an incubation effect. The problem used in the presented experiments and the factors surrounding the experiments seem to determine if a significant incubation effect could be shown. For example the recovery from fatigue hypothesis might be true if a participant was tired from a full day of work, but might not be a valid explanation of most experimentally shown incubation effects.

The main obstacle besides designing and executing experiments to gain more insight into the incubation effect in a meaningful way is to transfer the results from the experiments to industrial settings. Industry seldom has to solve as narrowly defined insight problem and the surrounding factors are often out of control. The problems are often open-ended and have a much bigger scope. The incubation periods in industry will likely be longer -overnight periods- and thus longer than in most experiments, which usually use time periods of 5 to 10 minutes. This is reflected going to be researched in the current work, as the experiments use an open ended design problem and the incubation period is at least 24 hours.

3. VIRTUAL CFD EXPERIMENT

3.1. Introduction

Computational Fluid Dynamics (CFD) are valuable in the engineering design process, as they allow gathering data on fluid and heat flows of products without the need of building a functional prototype and time-consuming as well as error-prone measurements. In order to increase the competitiveness of CFD projects, it is proposed to save time and money by using globally distributed engineering teams to solve them. Most of the engineer's time in CFD projects is spent on meshing, problem set up, and post-processing. These are chronologically serial tasks that need to be executed in the given order. Each task itself does not parallelize well amongst a team of engineers. Thus, as it is proposed to sequestrate each task by distributing team members around the world. This allows three team members to work on a task successively. This pilot study is conducted to show the general feasibility of distributed CFD teams. The hypothesis of this study is that an in time and location distributed CFD team will reduce the number of days needed to finish a project. The research questions, which will illuminate aspects of the hypothesis, are:

1. Are there tradeoffs in comparison to a single person solving the problem?
2. Are the tools and methods developed to hand the project from one team member to the next team member suitable?
3. Are the defined metrics suitable to measure the team's effectiveness compared to the single worker?

3.2. Methods

To explore the feasibility of an in time and location distributed CFD Team, a pilot study is created. The pilot study is a between participants design, comparing the results for a specified CFD problem of one worker with the results of a three person in time and location distributed team. The study is split into two succeeding parts: The single worker solves the CFD case first, alone. A few days later the pilot study with the in time and location distributed team is conducted. The participants, the CFD problem, the experimental procedure, the metrics and the evaluation procedure are discussed in the following sections.

3.2.1. Participants

The four participants are graduate students from Texas A&M University. They are not randomly selected. They are members of the Fluids, Turbulence, and Fundamental Transport Laboratory and are selected for this pilot study due to their experience in CFD. They have no industrial experience in CFD, but have used CFD in the academic setting for 25 hours to 3 years. They have limited exposure to the used CFD software, StarCD, the minimum being 10 hours for one participant. The single worker is more experienced at solving CFD problems. He has worked about 3000 hours on CFD problems versus about 250 hours maximum among the participants forming the team. The single worker and the team participants had the same experience with StarCD, a three day workshop offered by the company. The single worker refined the problem in an iterative process while solving it. In addition, the single worker is involved in the development of the evaluation metrics as well as in the evaluation of the CFD data produced during the project. During the team experiment, the single worker is the technical support, monitoring the progress of the team in the project and ensuring that the hardware and software works correctly. All participants are aware of the general procedure of the experiment and the comparison group.

3.2.2. Problem Description

The CFD problem is a simplified three dimensional combustor simulation (Figure 4, Figure 5). The participants receive the geometry file of one combustor ring element and have to mesh it. They need to decide if and how to adjust the mesh for each of the four different cases of boundary conditions. Further, they need to solve each case. For this part of the problem, the baseline cell count was set to 200,000 cells with a range of plus or minus 10 per cent. This value provides a compromise between solving the problem accurately and having a short run time in accordance with the shift length of the project. The computational time needed to run the project with this cell count is less than one hour, allowing the participants to evaluate their solution in regards of convergence.

Virtual CFD Teams

Task for preliminiary study

To obtain realistic inlet conditions for turbine simulations in gas turbines, efficient combustor simulations are needed. In this project, we want to study and compare different cold combustor flow conditions and their impact on the flow towards the first stator turbine row. Making use of the rotational periodicity of the full, simplified ring combustor (see Fig. 1 left), only one segment (Fig. 1 right) needs to be computed.

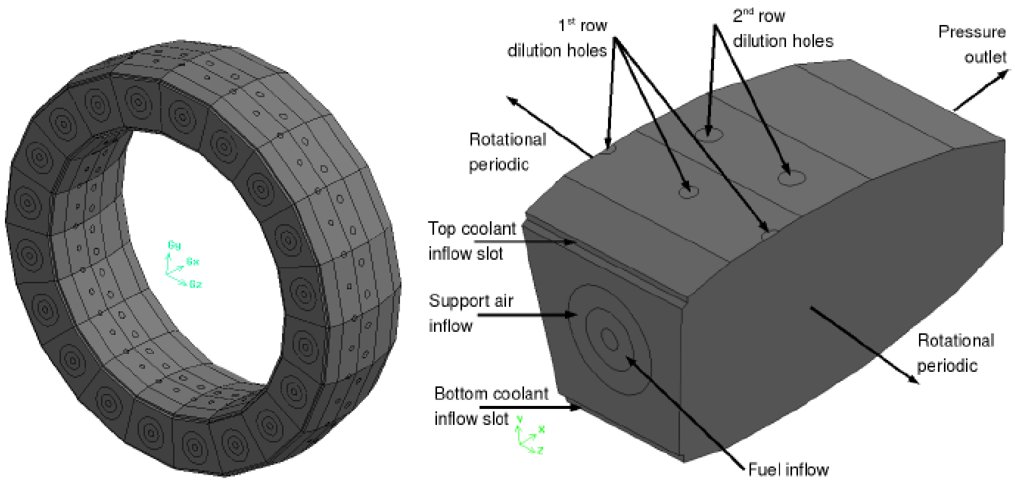

Figure 1: A jet engine ring combustor (left) and one 18° segment (right) with boundary conditions.

Specifically, the following items should be worked on:

- Open "~/teamrun/chamber.sim" in StarCCM and combine, name and fully define all boundaries (see Table 1) as shown in Fig. 1 right. All faces not labeled are no-slip walls. When a velocity inflow face is not used (zero velocity), it should be set to no-slip wall. Set the domain-wide reference pressure to 12.41 bar and the air density to $5.2\frac{kg}{m^3}$.
- Mesh the geometry using preferably hexaedral (quad) cells. The total number of cells should not exceed 200k within ±5-10%. The wall nearest cells should not be further from the wall boundary then 500 (within ±5-10%) wall units (check contours of "Wall y^+"). Refine the grid where necessary.
- Compute an isothermal, steady state, incompressible, turbulent solution for the following cases:
  - **Case 1:** Fuel and support air inflow normal to boundary (use only the axial component from Table 1), no slot coolant flow, no dilution flow (baseline).
  - **Case 2:** Fuel and support air inflow with swirl, no slot coolant flow, no dilution flow.
  - **Case 3:** Fuel and support air inflow normal to boundary, no dilution flow, coolant flow through slots. A finer mesh might now be required for the slot.

Figure 4 Virtual CFD design problem part I

- **Case 4:** Fuel and support air inflow with swirl, dilution flow through all holes and slot coolant flow.

To ensure convergence, all residuals should have dropped by 4 orders of magnitude. In addition, monitor turbulent kinetic energy area-averaged over the outlet plane and iterate until the value is stable.

- While cases are running, create a mesh for the baseline case with approx. 100k, 500k and 1000k cells for a grid independence study. Set all necessary parameters and boundary conditions so that the simulation is ready, but do not run these cases.
- Create two line plots at the outlet plane showing turbulent kinetic energy and axial velocity over radial coordinate (y) at $z = 0$ for all converged simulations.

Table 1: Boundary conditions

	V_{ax}, normal to boundary [m/sec]	V_{rad} [m/sec]	V_{Θ} [m/sec]	V_Y [m/sec]	V_X [m/sec]	Turbulence intensity [%]	Turbulent length scale [m]
Dilution holes, top				-150	35	10	0.01
Dilution holes, bottom				150	35	10	0.01
Coolant slot (top and bottom)	40					10	0.05
Support air inflow (outermost ring area)	30	20	15			15	0.1
Fuel inflow (middle ring area)	1	5	2			15	0.1

Remarks:

- For defining inflow in cylindrical coordinates, you may search for the combustor tutorial in the program help.

Figure 5 Virtual CFD design problem part II

In addition, the participants are asked to prepare a grid independence study, which shows that a computed solution is independent of the employed computational grid. In order to simulate that part of a real world project in the experiment and at the same time avoiding a long wait time for results, the participants are asked to only generate grids with approximately one half, two and a half, and 5 times the baseline cell count but not to actually run the simulation of the problem. The simulation is done by an experimenter during the data evaluation. Figure 4 and Figure 5 show the problem description as it was developed by the single worker and handed out to the three participants forming the in time and location distributed team.

3.2.3. Experimental Procedure

The pilot study takes place in the experiment room of the IDREEM Lab at Texas A&M University. The participants are alone in the room, and use one workstation. They are not supervised constantly and are free to take short breaks as in a regular work environment. The experimenter is available in an adjacent laboratory room if needed. For the handshake procedure, a second workstation is set up in an adjacent room. The incoming student takes this place during the handshake procedure and transfers to the experiment room after the previous participant leaves. They are not allowed to run over the allotted time, and the experimenter gives a warning five minutes before the time is up.

The software used is partly installed on the experiment workstation, partly available online, and partly accessible using Virtual Network Computing (VNC). This set-up resembles closely a real-life collaboration using one server to store the data and provide the license for the CFD program.

Camtasia Studio 5, a screen-recording software, is a locally installed software program. Throughout the pilot study, the screen the participants use is recorded. For the single worker, a new recording is started every three hours. For the distributed team, a new recording is started after each handshake. This keeps the file size manageable and allows quicker access to specific times of the recording. The second locally installed software is Putty, which allows the use of the secure shell (SSH) network protocol to connect to other devices in the network. In this case it allows to connect to the server in the Fluids, Turbulence and Transport Laboratory. RealVNC is tunneled through the SSH connection and provides the Virtual Network Computing environment needed to export the graphical user interface from the server to the experiment computer. Furthermore, RealVNC allows two participants to share a screen interactively during the handshake procedure. It also allows the technical support to look at the problem in real time while the team is working to ensure the software used is working properly and that the team is progressing in the problem solution. The team knew about the possibility of the technical support connecting to their screens to check on the project progress, but could not detect if or when it happened.

Saba Centra is the one software that is available online. It is designed to host teleconferences among distributed teams. It allows verbal real-time communication among team members. During the handshake procedure, the participants are instructed to exchange all information relevant to the problem. In this study, the participants cannot see each other, as no webcams are used. In addition to hosting the teleconference, it is used to record the verbal exchange during the handshakes.

A shared notebook is accessible to the participants at all times in the distributed team during the pilot study to protocol their work and to pass information on. It consists of a text file that is saved to the server. It is edited with the program notepad available on the computer the participants used during the experiment. Only one of the participants, Participant 2, who is situated in the manager's time zone, is allowed to contact the manager. This is done to reflect a company setting, where the manager might or might not share a time-zone with one of the team members. As the manager in a company is not working around the clock, only team members in the manger's time-zone can contact the manager using synchronous communication. The other team members need to rely on asynchronous communication if they want to contact the manager and on the information received from their team members. Asynchronous communication, such as email, is available to all team members at all times, but team members can only reply to their work email during their work time.

For both conditions, a script initiates a backup copy of the CFD files every 30 minutes in a write-protected directory to prevent data loss and to allow retracing of the progress after the study. The workers do not experience any delay due to this procedure.

The procedures for the single worker and the distributed team are detailed in the following two sections.

3.2.3.1. Single Worker

The single worker gives informed consent before starting the pilot study. The single worker uses the workstation in the experiment room exclusively. To minimize differences between conditions, the single worker uses the same software, Putty and RealVNC to stream StarCD, identical to the team. The single worker works eight shifts distributed over four days ranging from one hour to four and a half hour for a total of 15.5 hours, to complete the simplified combustor problem. This is the time needed by the individual worker to solve the CFD problem, and does not include time to refine the problem statement.

After the worker finishes the pilot study, the worker fills a survey and is interviewed by the experimenter on the worker's perception of the pilot study.

3.2.3.2. Distributed Team

The in time and location distributed team is simulated by three graduate students of the Fluids, Turbulence, and Fundamental Transport Laboratory. To lessen the workload of the participants and to allow all of them to participate during day time, it has been decided that one workday equals three hours The participants are not allowed to talk about the pilot study except during their respective handshake procedures.

The following two sections will present the preparation and the experimental procedure for the in time and location distributed team.

3.2.3.2.1. Preparation

The day before the start of the pilot study, the three participants forming the distributed team meet in the experiment room for one hour. They are introduced to the facilities, procedures, and software by the experimenter and the single worker, who at this point has finished the benchmark run. The three participants received a handout with rules regarding the pilot study, short instructions on how to use the software and a timetable for the pilot study. The document is shown in Figure 6 and Figure 7.

Virtual CFD Teams – Pilot Study

Chasing the sun with a globally distributed computational fluid design team

Rules

- You will not meet your team mates in person, Saba Centra will be used for synchronous communication. If you meet outside of the experiment location, please do not to talk about the experiment until it is finished (after Friday night).
- Each work session consist of a 30 minutes handshake, a 2 hour individual work time and a second 30 min handshake
- 30 minutes are allotted for each handshake. You may not overrun the 30 minutes. If you need less than 30 minutes, you will have idle time until the start of your individual work time.
- Please restrict each of your individual work time to 2 hours per session.
- Only one of you, P2, is able to talk directly with Dr. Duggleby, the project leader.
    - First, call him on his cell phone.
    - Depending on the needs, you may meet him in person.

  These interactions have to take place during your individual work time.
- Your simulations may run only during your work time (not over night).
- You may not pause or manipulate the recording software.
- You may use email for communication. However, you might not answer emails when it is not your turn. To prevent errors, all email has to be sent only to Susanna. When the recipients work session starts, Susanna will forward the message.
- To exchange information on your work or to protocol events, you have access to a shared text file.

Instructions

- VNC Viewer
  Double-click on the Desktop icon and connect to server "localhost::5903". Use the password provided. For the handshake, the person logging in from the extra workplace, remember to change the option to shared connection. For more detailed instructions, see documentation on Desktop.
- Putty
  Double-click on the Desktop icon and load "dugg5", then click "Open". Use the password provided. For more detailed instructions, see documentation on Desktop.
- VNC server restart
  After a VNC server crash, restart by typing "restartvnc" from anywhere in the command line. Make sure that a server on port 5903 is started.
- Backup script

Figure 6 Virtual CFD participants instructions part I

Every 30 minutes, the contents (including all subfolders) of "/home/virtualcfd/teamrun" is backed up into "/home/virtualcfd/teambackups". To manually initiate a backup, type "backup" from anywhere in the command line.

- Camtasia
  Please make sure that the recording is working – check from time to time if the symbol in the right corner of the task bar is still blinking red/green.
- Login and password for computers
  The login is VirtualCFD. The password will be given to you separately.
- Entering GRPH
  GRPH is locked by default. The door with the card reader on Ireland Street is open between 8am-5pm on weekdays. The door facing ENPH is often unlocked. If you cannot get in the building, call the researcher at 458-4293.
- Shared Notebook
  To access the shared notebook, type "writenotes" from anywhere in the command line.
- Saba Centra
  Saba Centra works only in Internet Explorer. You will have an email send to the experiment account (gmail). Please check the email before the handshake, click on the link provided and join the session.

Work Schedule

	P1, P2, P3, P4
Tuesday, May 12th 2009, 10:00 am	Meeting with P1,P2,P3, P4 at I-DREEM lab (119A GRPH) to look at workplace, talk about setup etc.
Wednesday, May 13th 2009	P2: 2 PM - 4:40 PM P3: 4 PM - 7:10 PM P1: 6:30 PM - 9:10 PM Note: Above times include 10 minutes for the consent process before each shift.
Thursday, May14th 2009	P1: 10 AM - 10:30 AM P2: 10 AM - 1 PM P3: 12:30 PM - 3:30 PM P1: 3 PM - 5:30 PM
Friday, May15th 2009	P1: 12 PM - 12:30 PM P2: 12 PM - 3 PM P3: 2:30 PM - 5:30 PM P1: 5 PM - 7:30 PM Note: Please add 10 minutes for an exit interview.

Figure 7 Virtual CFD participants instructions part II

3.2.3.2.2. Procedure of Pilot Study

The pilot study with the distributed team took place on three consecutive days. On each day, each participant worked a two hour shift. Each shift, besides the very first one and the very last one of the experiment, was anteceded and followed by 30 minutes for a real-time meeting between the leaving and the incoming participant. Thus, the total time of participation in the pilot study was three hours per day. During the 30 minute meetings, the so called ‘handshake procedure’, information on the progress was passed on to the next participant. The participants were not allowed to start working if they took less time for the handover. In total, the participants spent 18 hours of work time plus 4 hours of handshake time on the pilot study.

On the last day of the pilot study, after the end of their respective shifts, each participant of the distributed team filled a survey and took part in an interview (Figure 8 and Figure 9).

3.2.4. Metrics

Two sets of metrics are used to evaluate different aspects of this pilot study: CFD measures are used to evaluate the quality of the created mesh, and efficiency measures are used to evaluate the efficiency of the process both quantitatively and qualitatively.

3.2.4.1. CFD Metrics

The CFD measures consist of the number and kind of cells used, skewness, and the wall normal resolution.

The number and kind of cells used are read from the created meshes. Post processing time and the quality of a solution are strongly related to the number and kind of cells used. Ideally, the post processing time is minimized, but the quality of the solution is maximized. The problem description (Figure 4 and Figure 5) gives a target baseline count of cells (200k). This number is chosen as a compromise between solving the problem accurately and the run time needed to compute a solution. In this case study the goal was to create the best possible solution for the given cell number. The derivation from this baseline count is used as a measure, as the number of cells used influences the solution quality. In the problem description (Figure 4 and Figure 5) the participants are instructed to use hexahedral cells. Hexahedral cells were chosen as cell type by the technical consultant, as they are appropriate for the problem at hand. Generally a quality solution will only use one type of cells.

Skewness describes the deviation of cells from their ideal shape. For this problem statement, the ideal shape of a cell is hexahedral (as each cell has six faces), thus the cell should ideally be equiangular – all cell angels have 90 degrees. The solver, which is part of StarCD, provides the skewness measurement.

The wall normal resolution describes the distance of cell centers from the wall in wall coordinates. This distance correlates with the cell center of the cell closest to the wall being in the fully developed turbulent boundary layer region of the Law of the Wall. It the cell is too small, it is in the viscous sub layer, if it is too big, it is in the wake region of the Law of the Wall. These two regions require different boundary conditions than the fully developed boundary layer region condition assumed in the problem. For this problem, cell centers with a distance of more than 500 wall units were counted, as they influence the quality of the solution negatively. The wall normal distribution is important for the quality of the CFD solution as too small or too big cells will introduce error into the solution and reduce the quality of the solution. The used boundary conditions and the cell size need to be in agreement to allow a convergent solution that reflects actual flow.

3.2.4.2. Efficiency Metrics

The quantitative efficiency measures are the actual duration of the handshake in minutes and seconds and the number of entries in the logbook by each team member. As these measures do not occur for the single worker, they are unique to the in time and location distributed team.

The qualitative efficiency measure tools are the survey, pictured in Figure 8, and the interview, its questions provided in Figure 9, are completed by both the in time and location distributed team and by the individual worker. They are used to gain insight into the perceived effectiveness of the communication among team members and with their manager, and of the used software programs. Furthermore, the participants are asked about their opinion on the feasibility of a CFD project in an in time and location distributed team.

Question	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
I was comfortable using …					
… Putty.	1	2	3	4	5
… the VNC Viewer.	1	2	3	4	5
… StarCD.	1	2	3	4	5
… the backup script.	1	2	3	4	5
… Saba Centra.	1	2	3	4	5
… the shared notebook.	1	2	3	4	5
… the experiment email addresses.	1	2	3	4	5
I think the handshake procedure worked well.	1	2	3	4	5
I think the handshake procedure was efficient.	1	2	3	4	5
I am content with my team's performance.	1	2	3	4	5
I am content with my personal performance.	1	2	3	4	5
I felt that I could make decision regarding the project.	1	2	3	4	5
I wanted to undo my predecessor's work.	1	2	3	4	5
I think the CFD problem was appropriate for the experiment.	1	2	3	4	5
For me personally, the CFD problem was hard to understand.	1	2	3	4	5

Question	Amount:
Approximately how many problems –besides the training workshop in Houston- have you solved using StarCD?	
Approximately how many hours besides the training workshop in Houston- have you used StarCD?	
Approximately how many CFD problems have you solved using a different program than StarCD?	
Approximately how many hours have you worked on CFD problems using a different program than StarCD?	

Figure 8 Virtual CFD survey to be completed by participants

1. What do you think about the experiment?
2. Do you feel the overall process was efficient?
3. How would you evaluate your team's performance?
4. How do you feel about your participation in the experiment?
5. Did you feel like you had the ability to make decision regarding the project?
    a. Did you feel included in the decision making process?
6. How did you feel about working without the guidance of a team leader?
7. Did you miss the interactions of working in a collocated team?
8. Based on you experience, do you think CFD projects are suitable for distributed teams?
9. Do you think the handshake was efficient?
    a. What did you find annoying?
    b. What worked really well for you?
10. What would you suggest as handshake procedure for future experiments?
11. Were you comfortable using the different software programs?
    a. Was there one you liked a lot or one you did not like to use?
12. Were you comfortable following the procedures during the experiment?
    a. Were the procedures explained well before the experiment?
13. Was the training session before the start of the experiment beneficial to you?
    a. Why?
    b. What was good about, what should be improved?
14. Did you have the urge to undo your predecessor's work at any point? Please explain.
15. Is there anything you would like to add regarding the experiment? Any suggestions, critique or ideas?

Figure 9 Virtual CFD interview questions

3.2.5. Evaluation Procedure

The single worker, experienced in CFD, reads the CFD related measures from the files produced by both him and the team. This procedure entails looking at the produced data files and using basic functions built into StarCD to gain the desired listings for the overall number of cells and the number of skewed cells. Any person with a basic knowledge in StarCD can read out and check the results noted by the single worker.

The length of each handshake procedure is measured by listening to the recorded procedure and noting the time it took to exchange the project related information by the experimenter. The answers to the survey and the interview answers are summarized by the experimenter.

3.3. Results and Discussion

In the following sections the results are presented and discussed. The first section refers to the data on the quality of the CFD results, the second section the data connected to the efficiency of the process, and the concluding section covers the participants' perceptions and self-report.

3.3.1. Quality of the CFD Results

To evaluate the quality of the mesh, the number of used cells (Table 1) and their skewness angle (Table 2) are evaluated. It is obvious that for the single worker the number of cells for each case differs from case one through case four, whereas the number of cells remains constant for the distributed team. The same is true for the amount of cells with a skewness angle larger than 0.8 for cases one through four. These results reflect that the single worker created a new mesh for each case, whereas the distributed team used the same mesh for all cases.

Table 1 Virtual CFD number of cells used

		Overall number of cells used (% of derivation from goal value)	
		Single Worker	Distributed Team
Cases 1 through 4	1	221118 (10.56)	221655 (10.83)
	2	211416 (5.71)	221655 (10.83)
	3	216140 (8.07)	221655 (10.83)
	4	184359 (7.82)	221655 (10.83)
Grid Independence Study	100k	251967 (151.97)	102002 (2.00)
	500k	526318 (5.26)	496041 (0.79)
	1000k	1010785 (1.08)	1047728 (4.77)

The values in parenthesis in Table 1 reflect the percentage of derivation form the goal value and where calculated using Equation 1:

$$|goal\ value - actual\ value| \div (goal\ value * 100) = percentage\ of\ derivation\ from\ goal\ value \quad \text{Equation 1}$$

The largest derivation can be seen in the grid independence study of the single worker, where 151.97% more cells than desired were used for the goal value of 100’000 cells. Besides this one value, the deviation from the goal values remains within or close to the 10% allotted in the problem description, with a minimum of 0.79% and a maximum of 10.83%.

Table 2 Virtual CFD summary of results

		Number of cells with skewness angle >= 0.8; (% of number of cells used)	
		Single Worker	Distributed Team
Cases 1 through 4	1	1147 (0.52)	943 (0.43)
	2	1559 (0.74)	943 (0.43)
	3	1387 (0.64)	943 (0.43)
	4	598 (0.32)	943 (0.43)
Grid Independence Study	100k	965 (0.38)	896 (0.88)
	500k	2559 (0.49)	2790 (0.56)
	1000k	2978 (0.30)	3310 (0.32)

The analysis of the skewness angle of the cells reveals that in all cases less than 1% of the used cells are skewed beyond an angle of 0.8, which is a chosen based on experience. The value is mentioned in the Ansys FLUENT 12 user manual (ANSYS, 2009)

Overall, the meshes created by the single worker allows a converging solution of case one through four, whereas the meshes by the distributed team to solve cases one through four do not allow converging solutions, which means the solution created by the team violated physical laws. The non-existence of a converging solution made it impossible to measure the near wall mesh resolution based on normalized wall units, thus this criterion for mesh quality could not be used.

The use of the same mesh for all four cases by the team is to be evaluated critically. As the inflow and thus the boundary conditions change for each case, the near wall mesh generally needs to be refined at the new inflow location, to be able to account for the steeper velocity gradients at this location. The use of the same mesh for all cases might reflect lack of experience or a misunderstanding in the team. The communication during the handshake seems to indicate the first.

3.3.2. Efficiency of the Process

Data related to the efficiency of the progress is the handshake duration, the frequency and intensity of the use of the notebook, and the team's handling of the manager's intervention.

3.3.2.1. Work Time

The single worker works eight shifts distributed over four days ranging from one hour to four and a half hours for a total of 15.5 hours, to complete the simplified combustor problem. The distributed team uses all of its work time; a total of 18 hours distributed over three three-hour shifts for each of the three team members. In addition, the distributed team does eight handshake procedures, each one with two team members with a maximum allotted duration of 30 minutes, adding another eight working hours. This adds up to 24 hours the members of the distributed team would need to be paid for versus the 15.5 hours of the single worker. The single worker would needs close to 2 eight hour workdays to solve the problem, the distributed team three workdays. However, taking into account that the team would work around the clock, the problem would actually be solved within one calendar day, as each of three team members could spend close to eight hours consecutively on the project, lessened by the time needed to perform a handshake procedure. Of course the time should diminish, as not eight but only two handshake procedures would be needed. In addition, labor might be cheaper at different locations, allowing the project not only to be solved within 24 hours -thus within one workday of the supervising manager- but also with presumably lower costs.

3.3.2.2. Handshake Duration

The duration of the handshake procedure varies between a minimum of 11 minutes, 56 seconds for handshake 1 and a maximum of 27 minutes, 45 seconds for handshake 3 (Table 3). The recorded time of the handshake is entirely dedicated to communication on the project, eventual start up time or chatter is eliminated.

Table 3 Virtual CFD duration of each handshake in minutes and seconds

Handshake #	Duration [min:sec]
1	11:56
2	25:40
3	27:45
4	21:25
5	21:30
6	27:00
7	12:20
8	21:24

The participants use the handshake time effectively by concentrating on the problem at hand. The conversation is matter of fact and devoted to the exchange of information critical to the solution of the problem. The 30 minute time frame is found to be appropriately chosen to convey the notable events during the two hour work blocks for the degree of difficulty of the problem.

3.3.2.3. Use of Notebook

The distributed team uses its electronic notebook an average of 5.44 times per day and participant (Table 4). The values do not include the entries in the notebook which only state that a software program has crashed, as these entries do not add value to the solution for the design problem. There is an increase in the use of the notebook from Day 1, with an average of 4.33 uses, to Day 3, with an average of 7.33 uses over all three participants.

Table 4 Virtual CFD frequency of notebook use. Values in parenthesis reflect software crash related notebook entries

	Participant 1	Participant 2	Participant 3	Average per day
Day 1	3	5	5	4.33
Day 2	4	6(+4)	4 (+2)	4.66 (6.67)
Day 3	9(+1)	7(+2)	6	7.33 (8.33)
Average per participant	5.33 (5.67)	6 (8)	5 (5.67)	Average per day and participants 5.44 (6.44)

Besides information on the actions of each person, the participants write down when StarCD crashes. Furthermore, the technical support enters two comments on Day 2, letting the participants know about restarting the VNC server and changing a setting in StarCD, necessary due to crashing programs but costing about five minutes of work time each.

The notebook provides a place to record notes and to make them accessible to the whole team. The frequency of its use reflects the need of the team to communicate with each other, and the increase in its use over the duration of the pilot study reflects the need to exchange more information. However, as with three participants each participant talks to both its ante- and predecessor, it might not have been used to its full potential, as all information could have been communicated orally during the handshake.

3.3.2.4. Manager Intervention

One event that allows an estimation of the efficiency of the communication in the team was the manager intervention on Day 2, during Participant 2's shift. The technical support, which monitored the progress of the distributed team undetected by the distributed team using the VNC connection, realized that the distributed team had gotten stuck with a boundary condition which would ultimately prevent a converging solution of the given problem. Thus, the manager decided to go in to discuss the problem with the Participant 2, who was in the manager's time zone. The manager guided the participant by asking questions, but did not plainly state where errors had been made or what would need to be corrected. This intervention is captured in the notebook at the time it happened and a second time during the following handshake between Participant 2 and 3. It was discussed in both this handshake and the next handshake between Participants 3 and 1, but is not mentioned later on.

3.3.2.5. Correction of Errors

The observation of how the team handled errors in their work was interesting and allows some conclusion about the connection of knowledge and the ability to work a CFD problem in a virtual team successfully. The team found and fixed some errors made while creating the mesh and setting up the simulation, using each team member. It became clear, that more than one person working on the problem had a positive influence, as errors were often found and corrected by the following participant, for example one participant set the outlet pressure to gauge pressure as needed. Interestingly, this participant did not set the initial pressure to gauge pressure as well, which would have been correct. This could be due to the participant not checking this value or due to the participant not knowing that the value has to be gauge pressure. At this point, it can only be assumed that this is due to the relative inexperience with CFD problems.

After the manager intervention, the areas pointed out through the manager's questions were scrutinized by the participant. Some errors were recognized and corrected. One error, an incorrectly placed inflow coordinate system, was not corrected by the team, as after some discussion, were participant 1, the most experienced worker of the team, insisted of the coordinate system being placed correctly, the other two team members agreed. This reflects a problem with the unequal knowledge distribution.

Further, not all cells on the side faces were included in the periodic boundary zone. This is a main problem of the team generated solution, as it hinders convergence, and has not been detected by the team.

3.3.3. Participants' Perceptions and Self-Reports

The filled in surveys (Figure 10 Virtual CFD summarized survey results Figure 10) and the answers to the interview (summarized in Appendix A) allow conclusions how the participants perceived the experiment. All participants answered all questions they were asked. Some survey questions show four, others three responses, as some questions do only apply to the distributed team, the single worker did not answer them. Also the same is true for the interview questions, although less obvious, as they are summarized. All questions specific to and only answered by the participants of the distributed team are marked by an asterisk (*) before the question.

The survey responses showed that the single worker and the distributed team members agreed or strongly agreed that they were comfortable using all software needed during the experiment. Further, all team members agreed or strongly agreed that the handshake procedure worked well and they were content with their team's performance. One each of the distributed team members answered disagree, neither agree not disagree and agree to the question if they wanted to undo their predecessor's work and if the CFD problem was hard to understand for them personally. The answers reflect that the software side of the experiment worked smoothly and that the participants felt positive about their contribution.

Virtual CFD Teams – Survey

Chasing the sun with a globally distributed computational fluid dynamics team

Question	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
I was comfortable using ...					
... Putty.*				X	XXX
... the VNC Viewer.				XXX	X
... StarCD.				XX	XX
... the backup script.			X		XXX
... * Saba Centra.				XX	X
... * the shared notebook.				X	XX
... * the experiment email addresses.				X	XX
* I think the handshake procedure worked well.					XXX
* I think the handshake procedure was efficient.				X	XX
* I am content with my team's performance.				XX	X
I am content with my personal performance.				XX	XX
I felt that I could make decision regarding the project.				X	XXX
* I wanted to undo my predecessor's work.		X	X	X	
* I think the CFD problem was appropriate for the experiment.				XXX	
* For me personally, the CFD problem was hard to understand.		X	X	X	

Question	Amount:
Approximately how many problems –besides the training workshop in Houston- have you solved using StarCD?	0 - 3
Approximately how many hours besides the training workshop in Houston- have you used StarCD?	0 - 40
Approximately how many CFD problems have you solved using a different program than StarCD?	1 - 6
Approximately how many hours have you worked on CFD problems using a different program than StarCD?	20 – 3000

Figure 10 Virtual CFD summarized survey results

The interview questions were designed to allow the participants to speak about their experiences. Some interesting answers are the indirect identification of the learning curve, reflected in more than one statement:

> “Got easier with each session” and “Crappy 1st day, 2nd day good”

which showed that the student got accustomed with the procedure and the design problem.

The only two points mentioned coming close to critique on the experiment, were the slight dislike of the used telephone conferencing software, Saba Centra, due to its non-intuitive use, and the wish to have gotten the problem description before the start of the experiment.

Overall, the participants said they enjoyed the experience and could imagine the experiment in the real world.

3.4. Conclusions and Future Work

The study indicates the feasibility of distributed CFD teams. Even though the distributed team did not achieve a converging solution, this is attributed to their inexperience with CFD projects and not to the used procedures and programs. The feedback gathered from the interviews and questionnaires indicates that the procedures and programs generate an efficient and a comfortable work environment. This is in agreement with the observations of the experimenter. The only software indicated by the participants to be cumbersome to use is the videoconferencing software Saba Centra. A different videoconferencing solution can be used in a follow-up experiment. The participants reported that they had an overall positive experience, increasing from the first day which was perceived as the hardest day, to a good last day.

The first research question is concerned with possible tradeoffs comparing a single person to a distributed team solving the CFD problem. The results of the experiment indicate that these tradeoffs exit. It takes more work hours for the distributed team than for the single worker to solve the problem, but the solution would be available within one work day, whereas the single worker needs two workdays. The success of the project depends on an effective exchange of information among the team members, which can probably be optimized with training. If the information that needs to be exchanged for a successful project can be identified, a protocol could be created, instructing the team members to capture this information in some form. This could be optimized by providing a customized software solution guiding each team member through the information capture and exchange process.

The second research question, if the tools and methods developed for the handshake procedure are suitable is also answered with yes. The success of the handshake is indicated by the lively verbal exchange on topic during the handshake. The verbal exchange is positively supported by the use of the shared screen and further by the prompt continuation of the work after the beginning of each shift. Only little time is spent on 'catching up'. More advanced tools might exist and allow an even smoother or more comfortable exchange of the data. A different videoconference system and screen sharing software, needing less preparation and more intuitive to handle, might exist. This study showed however that the basic and cost effective tools used do work very well. The methods of restricting the handshake procedure time and of providing asynchronous communication in addition to the handshake, also proofed to be suitable. The time frame was long enough to allow all needed information to be exchanged; only twice did handshakes exceed 25 minutes. The notebook was described as a helpful tool to find information about actions taken by prior users, for example setting made in the analysis software.

The third research questions, if the defined metrics are suitable to measure the team's effectiveness compared to the single worker cannot be answered definitely. They seem a working set of metrics if both parties have similar results, but fail in the study as the distributed team does not generate a converging solution. This question needs to be revisited in a future experiment.

In the future, it is planned to run a similar experiment with more participants. The number of team members in the distributed team could be increased from three to four or more team members, so that not each participant will be speaking to each other participant. This will help to research the efficiency of information and communication structures. It seems that such a scenario puts more emphasis on asynchronous information exchange and might need more structured means beside the notebook used in this study.

To allow for a convergent solution, which will allow an in depth data analysis, the CFD problem used in the experiment needs to be matched more accurately with the knowledge of the participants. It is proposed to test the participants' knowledge some time in advance to the participation and based on the results, to formulate the problem in a way that each participant could solve it on their own.

4. dDESIGN EXPERIMENT

4.1. Introduction

Globally distributed engineering teams are a common sight in today's worldwide corporate networks. Multiple reasons motivate companies to employ globally distributed teams. By not having to relocate employees, but making them available through the world wide web, a company saves on moving costs and can use the employee's expertise in multiple, globally distributed projects at once. The employee is independent of location, and can live in a place with lower living costs, potentially earning less but being able to spend more.

Up to date not all aspects of globally distributed engineering teams have been researched. The research described in this section is trying to shed light on one of these aspects, experimentally exploring idea generation during the conceptual design phase in globally distributed engineering design teams, asking the question how a global distribution might influence ideation.

The distributed design (dDesign) research project is composed of three consecutive experiments: The pilot study, the low control study, and the final study. They are presented in the following sections.

4.2. Pilot Study

The pilot study is the first experiment in the dDesign experiment series. It took place in fall 2009. The purpose of the pilot study was to identify any problems that could lead to problems during the conduction of the experiment and test the experimental design for the studies to follow.

4.2.1. Pilot Study Research Questions

Of the six conditions (see section 4.2.2.1 Pilot Study Experimental Design) scrutinized in this research study, only collocated brainstorming has been researched extensively. No literature on distributed brainstorming or on any of the four modified method 635 conditions could be found. Linsey et al (In Review) researched Brainsketching and C-sketch, which are idea generation methods similar to the modified method 635, but not identical. As this study aims at researching globally distributed engineering design teams, it is decided to use the technology needed to communicate in them to realistically simulate the information exchange in the study. This adds complexity to the experiment in comparison to an experiment using pens and paper, but very little or no electronic equipment. Electronic brainstorming research gives some information on methods used in technology rich experiments, but the used equipment differs from the electronic brainstorming description, mainly the use of tablet screens (see section 4.2.2.2 Pilot Study Materials). Therefore the first research question in the pilot study is:

> Do the experimental methods for each condition and the used technology enable idea generation?

The second research question is concerned with the design of the experiment and asks how the chosen factors (as explained in section 4.2.2.1 Pilot Study Experimental Design) influence the idea generation:

> Do the idea generation method (brainstorming, modified method 635 synchronous), the location (collocated, distributed), or their interaction influence the number of generated ideas?

The number of generated ideas is chosen as a measure as it is a reliable metric according to current research (see section 4.2.2.5 Pilot Study Quantity Metric).

4.2.2. Pilot Study Methods

4.2.2.1. Pilot Study Experimental Design

The experiment is a between subjects 3x2 factorial study, with two independent factors: idea generation method (brainstorming, modified method 635 synchronous, and modified method 635 time delayed) and location (distributed and collocated) (Table 5).

Verbal brainstorming is chosen as an idea generation method as it is a commonly used method and extensively researched (see section 2.3.1 Brainstorming). This allows a comparison between existing research and the current experiment. Even though participants usually like to use verbal brainstorming, it is often not the most efficient idea generation method (Diehl & Stroebe, 1987; Mongeau & Morr, 1999). The modified method 635 (see section 2.3.2.3 Description of Modified Method 635) is chosen as the results from Linsey et al. (In Review) and Shah et al. (2001) can be used for comparison. The modified method 635 seems to be a very efficient procedure and is promising at producing a higher quantity of ideas. Furthermore, as the modified method 635 is based on sketches and written words, it can be implemented in an asynchronous, time delayed fashion. In a globally distributed design team not all team members are available synchronously (see section 2.2 Distributed Teams). The time delayed version of the modified method 635 allows one participant to contribute to the idea generation before passing the contribution on without the need of synchronous communication. The resulting time delay in the idea generation process generates an incubation period (see section 2.3.3.2.5 Length of Incubation Periods, Number of Incubation Periods). An incubation effect is said to increase the number of ideas. However, it also seems to be related to the motivation of the idea generator towards solving the problem. The collocated or distributed arrangement of the team mimics the physical distribution if team members in collocated and distributed teams.

Table 5 Pilot study experimental conditions. Three idea generation methods and two possible geographic locations

	Brainstorming (always Synchronous)	**Modified Method 635, Synchronous**	**Modified Method 635, Time Delayed**
Distributed	Brainstorming, Synchronous and Distributed	Modified Method 635, Synchronous and Distributed	Modified Method 635, Time Delayed and Distributed
Collocated	Brainstorming, Synchronous and Collocated	Modified Method 635, Synchronous and Collocated	Modified Method 635, Time Delayed and Collocated

Based on the assigned condition, the team works either as a collocated team, in one room and seeing each other, or as a distributed team, dispersed in two rooms. In the distributed team, the team members cannot see each other. Therefore, the participants use screen sharing and headsets to communicate with each other (see section 4.2.2.4 Pilot Study Experimental Procedures).

In the study, the modified method 635 as presented in section 2.3.2.3 is further altered. First, the teams are smaller, consisting of three or four members. Second, the five minute time span is considered to be too short, both for the initial interval and the following exchanges. Because the design problem is rather complex and no task clarification has happened prior to the modified method 635 session, the initial interval is set to fifteen minutes, and all following intervals to eight minutes. This allows time to understand the design problem during the first interval and to understand the ideas generated by the previous participant(s) during the following intervals. Third, instead of paper the participants sketch on tablet screens, which reflect the reality of distributed teams. Fourth, some teams will experience a time-delay.

4.2.2.2. Pilot Study Materials

The experiment takes place in windowless rooms on the campus of Texas A&M University. The conference room used is approximately 5m x 3m and solely used for the experiment. For the distributed brainstorming condition one or two team members, depending on team size, use work places in a windowless office adjacent to the conference room. The office is approximately 4m x 4m and was shared with the experimenter during the experiment. Other people were not present. The students use Wacom Cintiq 21UX pen displays instead of writing and sketching on paper. This allows an uninterrupted capture of all cursor movements and executed commands on the screen by recording it with Camtasia, a screen recording program. Microsoft Office OneNote is used as sketchpad. As the screens offer only limited viewing angles from the side, a projector is used for co-located teams to allow all team members to see the notes being taken. Camtasia is also used to capture the conversation of the co-located teams. Even though the focus of the data evaluation is on the produced concepts, this recording allows a more in depth analysis if needed. Distributed teams use the Saba Centra conferencing tool to share desktops and make conference calls. Each participant uses a headset with headphones and microphone, allowing Saba Centra to voice record any communication which took place among the distributed team members.

4.2.2.3. Pilot Study Participants

Thirteen teams with either 3 or 4 members participate in the experiment. All participants are students of a mechanical engineering senior design class at Texas A&M University. Three mechanical engineering senior design classes are offered at Texas A&M University: The first course in the sequence is called ‘Introduction to Mechanical Engineering Design’ and focuses on the design innovation process. It is labeled MEEN 401 in the course catalogue. The follow up course is called ‘Intermediate Design’ and has the course number MEEN 402. These two courses form a two semester capstone design course in which the student teams experience the development of an industry sponsored product from its idea to its prototype stage. The third mechanical engineering senior design class at Texas A&M University is an ‘Engineering Laboratory’, labeled MEEN 404. The student teams identify their experimental research project by themselves. The course focuses on its design, the conduction of the experiment, and the interpretation as well as the reporting on it. The first course in the series, ‘Introduction to Mechanical Engineering Design’ or MEEN 401 is a prerequisite for the two other mechanical engineering design classes. The students participating in the pilot study are participating either in MEEN 404 or MEEN 402. No statistical information on the participants’ sex, age, professional experience or the like were obtained. However, the affiliation with one of the mechanical engineering senior design classes provides some consistency across subjects. Each of these classes has the students assigned into teams, and all members of a team have to sign up to enable the students to participate in the experiment. All experiments take place in weeks 9 to 14 of a 15 week semester, allowing the team building process to be mostly completed. Participation is voluntary. Disbursement is either extra credit in the student’s design class or monetary, each participant could decide independent of their team members’ decisions. The participants are told that extraordinary results will lead to a bonus to provide additional motivation, but all receive the same maximum amount of disbursement. After the teams sign up, they are randomly assigned to one of the conditions. The participants are asked to not share any information about the experiment with anybody in the mechanical engineering department in order to minimize the hazard of contamination of experiments taking place in the future, as students who know the design problem before the experiment will likely generate a different amount of solutions than students who are new to the problem.

4.2.2.4. Pilot Study Experimental Procedures

The experiments are run one team at a time. The experiment starts with informed consent. Afterwards, the participants are randomly assigned a computer workplace, equipped with a tablet screen. If the teams are in the distributed modified method 635 condition, all team members are in the conference room and dividers are used to prevent any team member seeing any other team member. In addition to these measures, in the distributed brainstorming condition one or two team members, depending on team size, use work places in a windowless office adjacent to the conference room to minimize acoustic interference. In the collocated modified method 635 condition, the tables are arranged in a diamond, so that the participants can see each other but cannot look at each others' screens. In the collocated brainstorming condition, the team sits around a round table. In the synchronous idea generation conditions (brainstorming and modified method 635 synchronous), the participants did the experiment in one session, whereas the participants in the modified method 635 time delayed condition had two appointments with a 24 hour to 48 hour delay in between sessions.

As the participants have no experience with the use of tablet PCs, a 10 minute training session followed consent. The students are asked to sketch a Coca-Cola bottle and to try writing on the screen to get a feeling for the pen. Afterwards each participant turns an instruction sheet placed on the top left corner of the participant's workplace around. The instruction sheet shows a short explanation of the idea generation technique which is read to the participants by the experimenter. Underneath the information sheet, the individuals receive the design problem (Figure 11). The design problem is read to the participants. During the process the participants are repeatedly asked if any questions have arisen. Questions are answered without giving answers to the idea generation task. After all questions are answered, the idea generation is started.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

Figure 11 Pilot study spice composing design problem

The experimenter is keeping track of the time and gives the participants a timely warning. At the end of the idea generation process, the participants have a five minute break before they work on two more design problems. The experimenter scripts and participant instructions of the pilot study are reproduced in Appendix B. At the end of the three hour experiment the participants all sit together around a table with the experimenter and are asked three questions with emphasis on the first design problem: how they found the experiment, if they found the timing appropriate and if they had any difficulties following instructions or using equipment.

4.2.2.5. Pilot Study Quantity Metrics

For measures, the rating was done following the procedures proposed by Linsey et al. (In Review). The two measures used were the quantity of unique ideas per team and the quantity of unique ideas per individual. The quantity measure is used to compare the effectiveness of each of the six idea generation processes. To be an idea, a sketched or described component has to fulfill one function in the functional basis. For example, solar energy was not counted as an idea, as this is not a function. A solar panel is counted as an idea, as it changes solar energy into electricity, fulfilling a function. Uniqueness for the team is reached by counting an idea only once for the whole team, so if three team members have the idea to use a scale, scale is counted as one unique idea.

To be a unique idea for a team member, the team member has to have the idea during the first idea generation round. These ideas are called initial ideas. To these initial ideas all ideas that the participant contributes in later rounds are added, if the participant has not had a chance to see the idea previously. The number of unique ideas per team does not equal the sum of all unique ideas per team member, as some team members had the same ideas during the initial idea generation phase. For example, many participants used containers to store spices. In the team count, all containers were counted as one idea. In the participant count, each participant's container was counted as one idea for that participant.

To analyze who generated an idea, and if the team member had a chance to see an idea before sketching it themselves, the recordings taken during the experiments are evaluated. The recordings consist of screen recordings of each participants screen, allowing to replay what each participants sketched when, and voice recordings, allowing to identify which participant uttered which idea verbally in the brainstorming conditions.

4.2.2.6. Pilot Study Data Validity

Of the thirteen teams participating in the pilot study, ten use the spice composing design problem, and three use a different design problem. Of these ten possible valid data points for the spice composing device, one is invalid due to failures of Camtasia, which makes more than one of the tablet screens turn green repeatedly. In this case, a computer needs to be rebooted to restart Camtasia, but as more than one Computer was affected, the participants had to wait. This disturbs the flow of thoughts of the participants and leads to pauses in the idea generation process. The pauses are long compared to the idea generation time of 15 minutes in the first round and 8 minutes in the following rounds. Unfortunately, this was the only team in the collocated modified method 635 time delayed condition, which left one cell in the 2x3 factorial experiment empty. In one team in the modified method 635 time delayed distributed condition one screen turned green. This team's data is used in this pilot study, as the participant was able to switch to an unused but ready computer with only minor -less than 30 seconds-interruption.

In one of the brainstorming cases, the experimenter forgot to start the voice recording. The data is valid, but only the team quantity counts can be done, as the missing voice recording makes it impossible to identify who generated an idea.

Camtasia remained a source of problems during the data evaluation, as some screen recordings would only play on the computer they were recorded on and some would not replay at all. This does not influence the results from the quantity count for the teams, but it posed a problem when trying to allocate each idea's generator, as data had to be interfered form the other recordings. Due to these technical problems, the recording of one team in the distributed brainstorming condition is missing, so that the team's data cannot be analyzed per team member. This reduces the original 31 data points to 28 for the unique ideas per participant analysis.

Of the three teams using a different design problem, one run is invalid as the projector required for the collocated brainstorming did not work.

4.2.2.7. Pilot Study Number of Unique Ideas per Condition

The valid runs, consisting of all four brainstorming teams, the three modified method 635 synchronous teams, and two modified method 635 time delayed distributed as presented in section 4.2.2.6 Pilot Study Data Validity, produced an average of 17.89 unique ideas per team (Table 6). The highest quantity of ideas per team is generated by the synchronous modified method 635 teams, across location the mean value is 22.33 ideas. The lowest value is generated by the brainstorming teams, across location the mean value 14.5 ideas.

Table 6 Pilot study number of unique ideas per team

	Brainstorming (always synchronous)	Modified Method 6-3-5, synchronous	Modified Method 6-3-5, time delayed
Distributed	13; 9	23	19[a]; 17
Collocated	13, 23	20, 24	~~14[b]~~
Average over all valid teams: 17.89			
a: reduced idea generation time (disruption of less than 30 seconds for one participant) due to technical problems			
b: invalid run due to technical problems (disruptions of more than one minute for multiple participants); value shown for completeness			

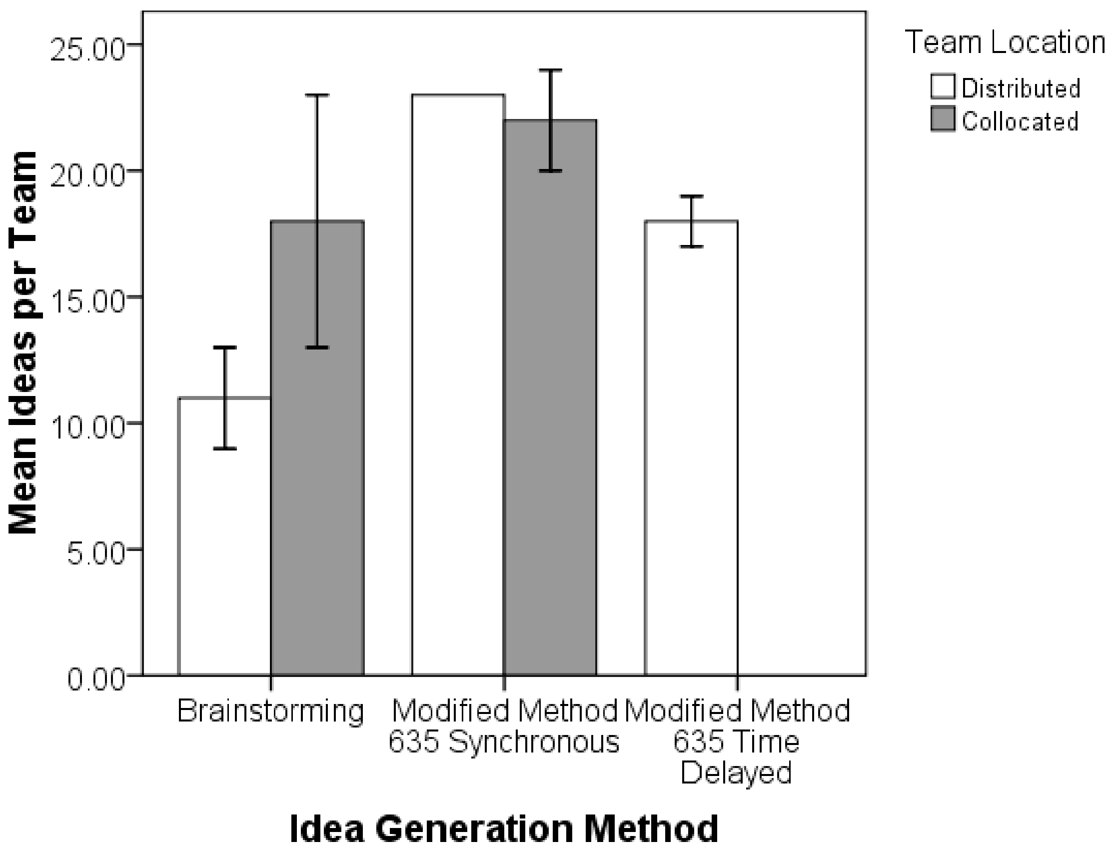

Figure 12 Pilot study mean number of generated ideas based on the unique ideas per team in dependence of idea generation method and location

The ANOVA for the number of unique ideas per team did not yield significance on the p=0.1 level for the location, the idea generation method, or the interaction (Location: $F(1,8)=0.85$, $p=0.41$; Idea Generation Method: $F(2,8)=3.25$, $p=0.15$; Interaction: $F(1,8)=1.51$, $p=0.29$, $MS_{error}=17.00$; Table 7). The bar chart (Figure 12) shows the mean values of generated ideas based on the number of unique ideas per team in relation to the idea generation method used and the location. This might be influenced by having only nine data points total and by the unequal distribution of the data points, especially in the modified method 635 time delayed condition.

Table 7 Pilot study ANOVA results for unique ideas per team

Source	df	F	p
Location	1	.85	.41
Idea Generation Method	2	3.25	.15
Location x Idea Generation Method	1	1.50	.29
Error	4	(17.00)	

Note. Value enclosed in parenthesis represents mean square error.

To strengthen the reliability of the data analysis, it was decided to multiply the data points by counting the number of unique ideas developed by each participant. This approach focuses on each participant instead of on the team. It also allows to take the different number of team members into account and shows if one team member was less or more productive than the average team member. The results of the per participant analysis are presented in the next section.

4.2.2.8. Pilot Study Unique Ideas per Participant

The number of unique ideas per participant is evaluated following the approach presented in section 4.2.2.5 Pilot Study Quantity Metric. The quantity data, 28 data points, for the individual participants is shown in Table 8. A bar chart shows the mean values per team member and condition (Figure 13).

Table 8 Pilot study number of unique ideas per participant and condition

	Brainstorming (always Synchronous)	Modified Method 635, Synchronous	Modified Method 635, Time Delayed
Distributed	8, 3, 6; X[c]	6, 7, 14	7, 5, 8, 9; 12[a], 9[a], 3[a]
Collocated	5, 4, 4, 2; 10, 8, 8	7, 7, 8, 8; 11, 13, 10, 6	
Overall Average: 7.43			
a: reduced idea generation time (t<30s) due to technical problems c: recording from 2nd team malfunctioned, no individual analysis possible			

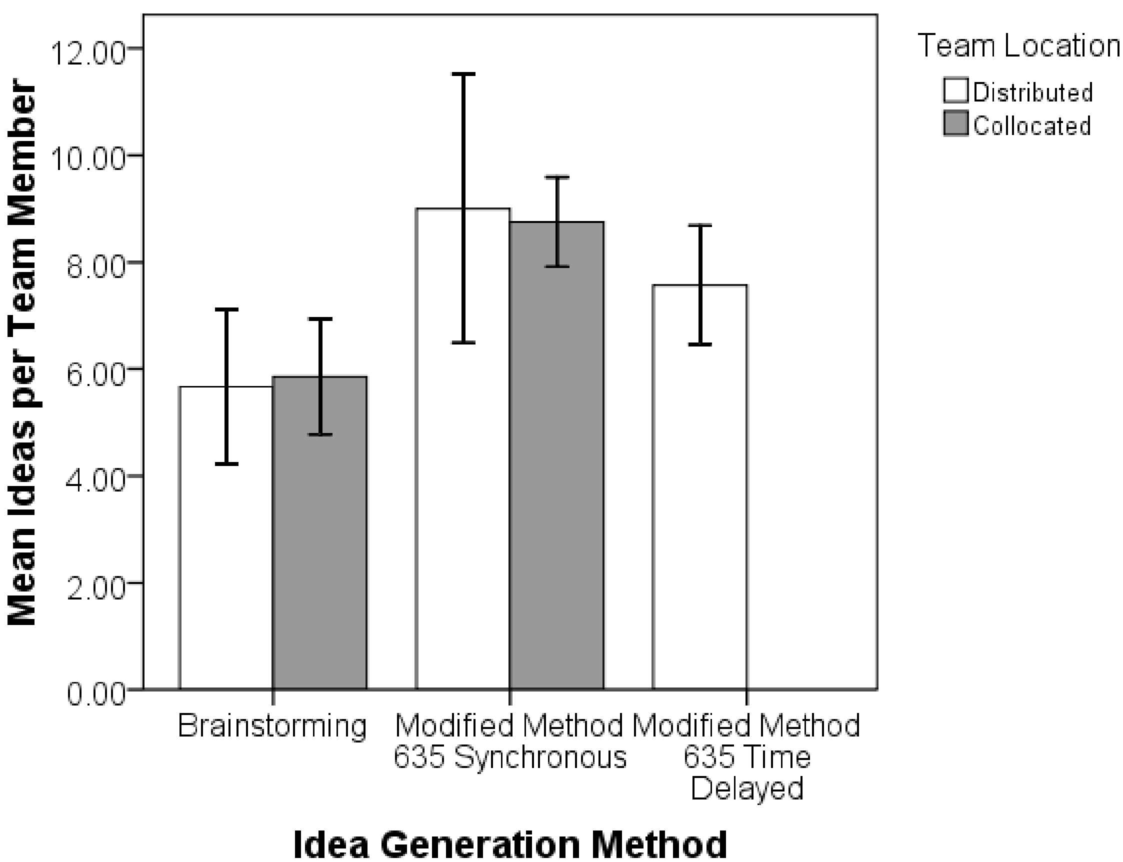

Figure 13 Pilot study mean number of unique ideas per participants and condition (+/-1 SE)

ANOVA is used to analyze this data set. No significant effect for the interaction or the main effects on the p=0.1 level is found (Location: F(1,27)=0.25, p=0.98; Idea Generation Method: F(2,27)=2.51, p=0.10; Interaction: F(1,27)=0.03, p=0.88, MS_{error}=8.29; Table 9).

Table 9 Pilot study ANOVA results for unique number of ideas per team member

Source	df	F	p
Location	1	.00	.98
Idea Generation Method	2	2.51	.10
Location x Idea Generation Method	1	.03	.88
Error	23	(8.29)	

Note. Value enclosed in parenthesis represents mean square error.

As the imbalance of the data set due to the missing data point in the modified method 635 time delayed collocated condition might negatively influence the overall analysis, it is decided to only analyze the brainstorming and the modified method 635 synchronous data. The data of these six teams, leading to 21 data points per team member (Table 8) is used in the ANOVA analysis. This analysis shows a significant effect for the idea generation method, but not for location or the interaction (Location: F(1,20)=0.00, p=0.98; Idea Generation Method: F(1,20)=5.07, p=0.04; Interaction: F(1,20)=0.03, p=0.88, MS_{error}=8.18; Table 10).

Table 10 Pilot study ANOVA results unique number of ideas per team member

Source	df	F	p
Location	1	.00	.98
Idea Generation Method	1	5.07	.04
Location x Idea Generation Method	1	.03	.88
Error	17	(8.18)	

Note. Value enclosed in parenthesis represents mean square error.

The results are visualized in a bar chart (Figure 14), showing the mean number of ideas based on the unique ideas per participant count in relation to the idea generation method and the location.

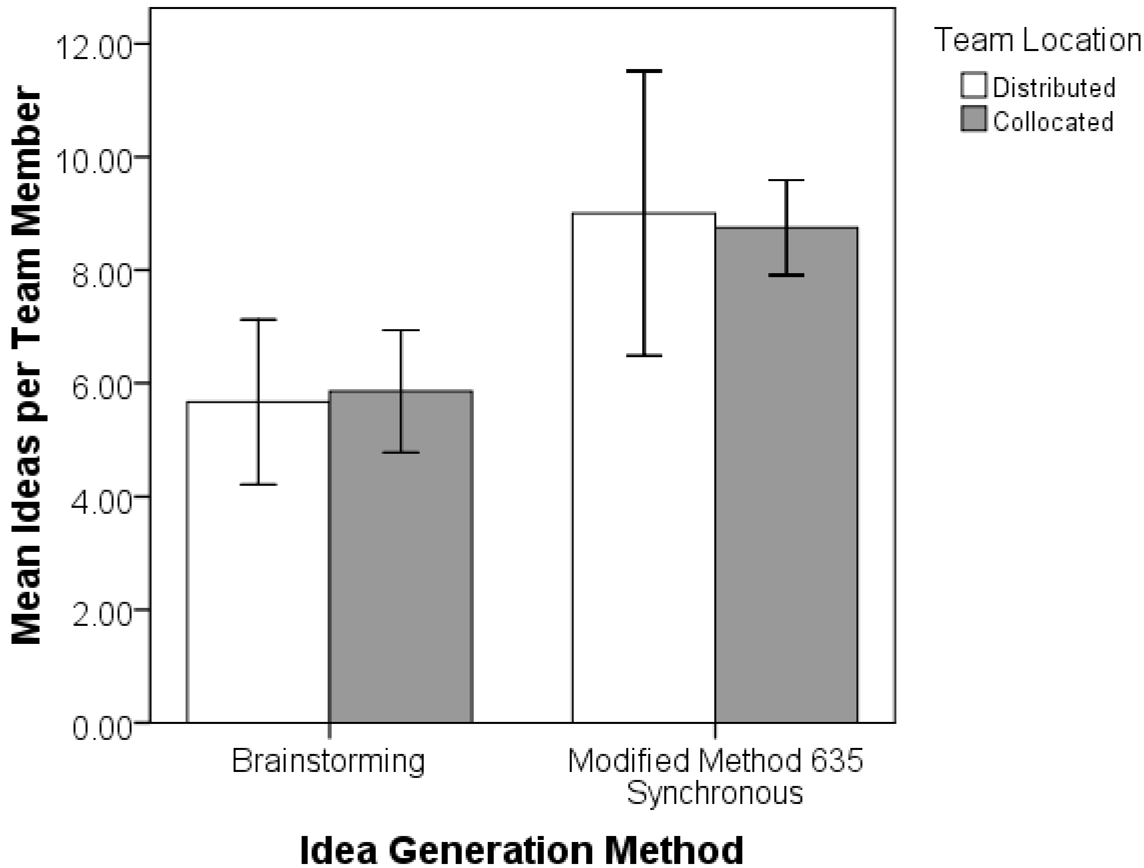

Figure 14 Pilot study quantity of ideas per team member, brainstorming and modified method 635 synchronous (+/-1 SE)

For the follow up T-test, the data is collapsed over the factor location, as there is no significant effect of location for the data set. This can be done, as the mean values of the distributed and collocated conditions for each idea generation method are similar and their difference is well below the standard error. The T-test confirmed a significant difference (p=.019) between the two tested idea generation methods, brainstorming and the modified method 635.

4.2.2.9. Pilot Study Design Problem Issues

The design problem used for the majority of the experiment, the spice composing device, does not produce the desired output. The participants are asked to sketch how the device measures, combines and dispenses spice mixtures. It was expected that the participants create sketches showing how a device accomplishes this, or that the participants describe in detail how these functions are fulfilled or executed by the device. However, participants tended to sketch a big box with random buttons without adding detail to their idea. The problem had been pilot tested in a graduate design class and had produced promising results. For an unknown reason, even though the problem statement read “your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices”, the participants did not specify these three functions. It was rather common to draw a large machine and add a comment specifying that “the spices are measured” or “dispensed here” without identifying how. It is possible that the students did not identify with the problem, as they might not be into cooking. Due to the small number of available teams it was not suitable to completely switch to a different design problem after this issue with the spice composing device design problem became evident. However, three teams participated using the peanut sheller design problem, which produced higher quality data and is recommended for a possible continuation of this experiment.

4.2.2.10. Pilot Study Characteristics of Brainstorming Results

During the analysis of the brainstorming sessions it was noted that the note takers in two of the three conditions wrote down their own ideas without voicing them to their team members at the moment. They would usually come up later on, when the specific topic, for example how to measure spices, came up again. Overall, the quality of the note taking surpassed the experimenter’s expectations, as the notes were conclusive and complete. It was also interesting to see that one collocated brainstorming team handed the pen to another team member, so the team member could draw an idea that the team member could not communicate verbally. In addition, in two of the three brainstorming cases, the note taker used sketches to clarify ideas.

4.2.3. Pilot Study Conclusions and Implication for Future Work

In general, it was interesting to see that the note taker in the brainstorming conditions noted the note taker's own ideas before voicing them. It will be interesting to see if this occurs again.

The pilot experiments have been helpful in answering the first research question, which is: Do the experimental methods for each condition and the used technology enable idea generation? The experimental methods worked, allowing a successful experimental run if followed and not interrupted by technical problems. One technical aspect did not work as planned. The chosen screen recording software Camtasia failed repeatedly and thereby interrupted the experimental runs. It was necessary to go back to an older version of it to remedy the crashes of the program. Other technical aspects worked very well: The use of tablet screens in combination with Microsoft Office OneNote® as a shared sketching pad and the exchange of sketches in the modified method 635 conditions using computer network did not disappoint.

The presented results indicate that the idea generation method is influencing the number of ideas generated in distributed teams, at least when looking only at brainstorming and the modified method 635 synchronous. The modified method 635 synchronous seems to allow the team to produce more ideas than the teams in the brainstorming conditions. The current data set however is not sufficient in size to reliably make a statement about the reason for this. Brainstorming has been shown to lead to fewer ideas than electronic brainstorming, which has some similarities with the modified method 635. So far, no significant effect of location on the idea generation of the teams has been found. This is somehow surprising, as the general expectation would be that distributed teams produce fewer ideas than collocated teams. Thus, the second research question is answered only partially and preliminary. More experiments are needed, probably at least three teams should participate per condition with three to four participants per team, to allow a thorough testing of the hypothesis. Especially both the collocated and the distributed time delayed modified method 635, which is expected to have some incubation effects, needs to be tested.

For future experiments it is suggested to incorporate both an evaluation and a refinement phase, in which the team itself will be encouraged to rate their concepts and to generate three promising concepts solving the design problem, as detailed as possible, in the time given. This is expected to level brainstorming and modified method 635 to some extent, as the brainstorming solutions were often only partial, solving only a single aspect of the design problem, or noted too unclear, as to not allow a conclusion about how the device would operate. It needs to be decided if each phase should take place in the team or individual.

It is further suggested to add a survey at the end of the experiment to gather statistical information on the experiment and to get the opinion of each participant on the timing, procedure and technical feasibility of the experiment.

Overall, the experiment is ready to be run with a larger number of participating teams. The pilot study shows a glimpse of the bigger picture, and all conditions could be rerun and promise interesting results. One might consider extracting the 635 time delayed conditions into a separate experiment, as the length of the incubation period, the number of incubation periods, and the number of participants at one location at a time, are variables that are not varied and researched in the current experimental set up. Instead of the time delayed conditions, an electronic brainstorming variation where all participants type their ideas and send them to an idea pool could be incorporated. This would allow comparing electronic brainstorming to verbal brainstorming and the modified method 635 in collocated and distributed teams. Electronic brainstorming seems a good choice of idea generation method to include in the study as its implementation requires only a regular computer and no tablet screens. Further, it seems possible to use a version of it that could be modified for a time delayed test, too, if desired. If this electronic brainstorming permitted only written words, a comparison of all experimental conditions will allow to see if the quantity, quality, novelty, and variety of generated ideas are correlated with the sketches used in the modified method 635.

4.3. Low Control Study

The low control study is the second experiment in the dDesign experiment series. It took place one year after the pilot study, as this was the next time a part of the capstone design course, ‘Introduction to Mechanical Engineering Design’ (MEEN 401), was offered in the distributed setting with students participating from Texas A&M University in College Station and Qatar.

4.3.1. Low Control Study Research Questions

The low control study builds on the pilot study. The different context of the low control study leads to modifications of the conditions tested in the pilot study (see section 4.3.2.1 Low Control Study Methods). The focus is on the distribution of the team. Therefore, the first low control study research question differs significantly from research questions presented in the pilot study:

> Does the location (collocated, distributed) influence the solutions generated in the modified method 635 time delayed?

A difference between the pilot study and the low control study is that the teams know their design problem before the actual experiment takes place (see section 4.3.2.3 Low Control Study Experimental Materials and Procedure). This leads to the second low control study research question:

> Do the results indicate in any way the fact that the teams in the low control study knew their design problem before the experiment?

4.3.2. Low Control Study Methods

A globally distributed mechanical engineering design class (MEEN 401) is offered to students at Texas A&M in College Station and in Qatar. This design class offers a possibility to try the distributed, modified method 635 time delayed in a setting closer to real life. The class consists of three teams; two of them are actually distributed teams with team members on the Qatar campus. Team one has five team members, three in college station and two in Qatar. Team two has four team members, two at each location. Team three has three team members, all in college Station. The teams used the design problem they work on in class for the idea generation.

4.3.2.1. Low Control Study Experimental Design

The experiment is an in between subjects one factor study. The independent variable is the location of the teams (distributed or collocated). The definition of collocated is the same as in the pilot study. The distributed condition is modified due to the situation in the class. It is not possible to separate team members at the same location with dividers as in the pilot study. Therefore, the team members of the distributed teams that were at one location were in one room and able to see each other during the experiment. The dependent variable is the number of unique ideas per team. The experimental conditions are presented in Table 11.

Table 11 Low control study experimental conditions

	Modified Method 6-3-5, time delayed
Distributed	Modified Method 6-3-5, Time Delayed and Distributed
Collocated	Modified Method 6-3-5, Time Delayed and Collocated

4.3.2.2. Low Control Study Participants

The participants match the general profile described in section 4.2.2.3 Pilot Study Participants. However, all of the low control study participants are students of the same workshop section in the first course of the capstone design sequence “Introduction to Engineering Design” (MEEN 401), not of the second course (MEEN 402) or the mechanical engineering laboratory course (MEEN 404). The experiment took place during the sixth week of classes. At this early point in the semester, the teams might not have been completely established, but as the experiment was related to the work the students did in class, it needed to fit the class schedule.

4.3.2.3. Low Control Study Experimental Materials and Procedure

Some changes to the materials presented in section 4.2.2.2 Pilot Study Materials, and to the procedure presented in section 4.2.2.4 Pilot Study Experimental Procedure, are made to accommodate the class. The students in Qatar do not have access to tablet screens, thus the students use pens and paper, which is later scanned in and emailed to the other campus. Class time is used to conduct the experiment. A videoconference system is used to instruct the students in Qatar, and a local professor assists with the procedure.

One team works on the so-called wheelchair simulator, team two and three work on the development for a rigless abandonment tool for the oil industry. The goal of the wheelchair simulator is to facilitate the learning of operating a wheelchair. Besides all-day activities, as how to open doors or navigate a building, the system should provide the possibility to train for more challenging situations, such as rough terrain.

The problem description for the rigless abandonment tool to be developed by team two and three, as provided by FMC Technologies, reads as follows: “This project requires the design of a Rigless Abandonment Tool that interfaces with an existing mechanical retrieval tool, Tubing Hanger Emergency Release Tool (THERT), has independent guidance, is installed and retrieved via a down-line from a multi-service vessel and enables the independent hydraulic unlock and recovery of a subsea-installed Tubing Hanger from its mating component.”

As the students are familiar with their design problem and the teams participating at the same time have different problems, it is not read out loud. The first idea generation session takes place in the student’s respective classrooms, both in Qatar and College Station. The second session in College Station takes place at different times for each team and in a windowless conference room. The second session in Qatar takes place in the same class room as the first session and the two teams participate one after another. The experimenter script and the participant instructions are shown in Appendix C.

As one team had five team members, it is decided to not count the ideas of on randomly selected team member in College Station to have an equal team size.

4.3.2.4. Low Control Study Quantity Metrics

The evaluation follows the approach presented in section 4.2.2.5 Pilot Study Quantity Metrics. Instead of doing a count of the unique ideas per team member, the average number of ideas per team member is calculated by dividing the number of ideas generated by the team through the number of team members. This is done because the number of data points is too small to be used in a conclusive ANOVA analysis.

4.3.3. Low Control Study Results and Discussion

The results are presented and discussed in two sections, one for the quantity counts and one providing a qualitative review of the results.

4.3.3.1. Low Control Study Quantity Counts

The ideas generated by each team are counted following the approach presented in section 4.3.2.4 Low Control Study Quantity Metrics. This leads to the number of unique ideas per team and to the average number of ideas per team member. The team developing wheelchair simulator created 25 unique ideas, leading to an average of 6.25 ideas generated by each of the four team members. From the two teams working on a solution for a rigless abandonment tool the collocated team provided the control condition to the distributed team working on that problem. The distributed team created 32 unique ideas, whereas the collocated team generated 33 unique ideas. Even though their number of unique ideas per team differs by only one idea, their average numbers of ideas per team member are more distinct: 8 in the distributed team versus 11 in the collocated team. This is due to the distributed team having four team members and the collocated team having three team members. The unique ideas per condition and team are presented in Table 12. The average values of unique ideas per team member are presented in Table 13, with the number of team members shown in parenthesis for each team.

Table 12 Low control study number of unique ideas per team

	Wheelchair Simulator	Rigless Abandonment Tool
Distributed time delayed modified method 635	25	32
Collocated time delayed modified method 635	-	33

Table 13 Low control study average number of unique ideas per team member

	Wheelchair Simulator	Rigless Abandonment Tool
Distributed time delayed modified method 635	6.25 (4)	8 (4)
Collocated time delayed modified method 635	-	11 (3)

Neither the quantity counts found for the spice composing device nor for the peanut sheller can be numerically compared to the data of the class, as the design problems are too different. The same is true in this study: The wheelchair simulator problem cannot be compared with the rigless abandonment tool, as these two design problems are too different. Furthermore, the students in the low control study of distributed, time delayed modified method 635 know there design problem long before the idea generation experiment, which is a substantial variation of the experimental procedure used in the pilot study.

4.3.3.2. Low Control Study Qualitative Results

An interesting observation is that from the initial 6 solutions for the wheelchair simulator, two solutions on one sheet are very similar to two solutions on a second sheet (Figure 15, Figure 16, darker pen color).

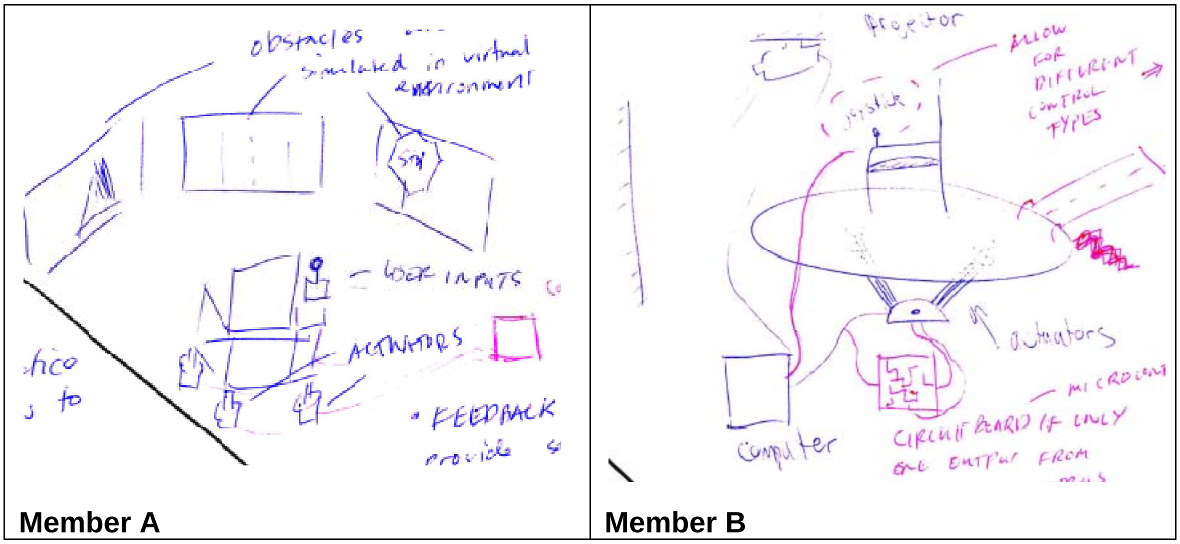

Figure 15 Low control study 1st example of a similar solution

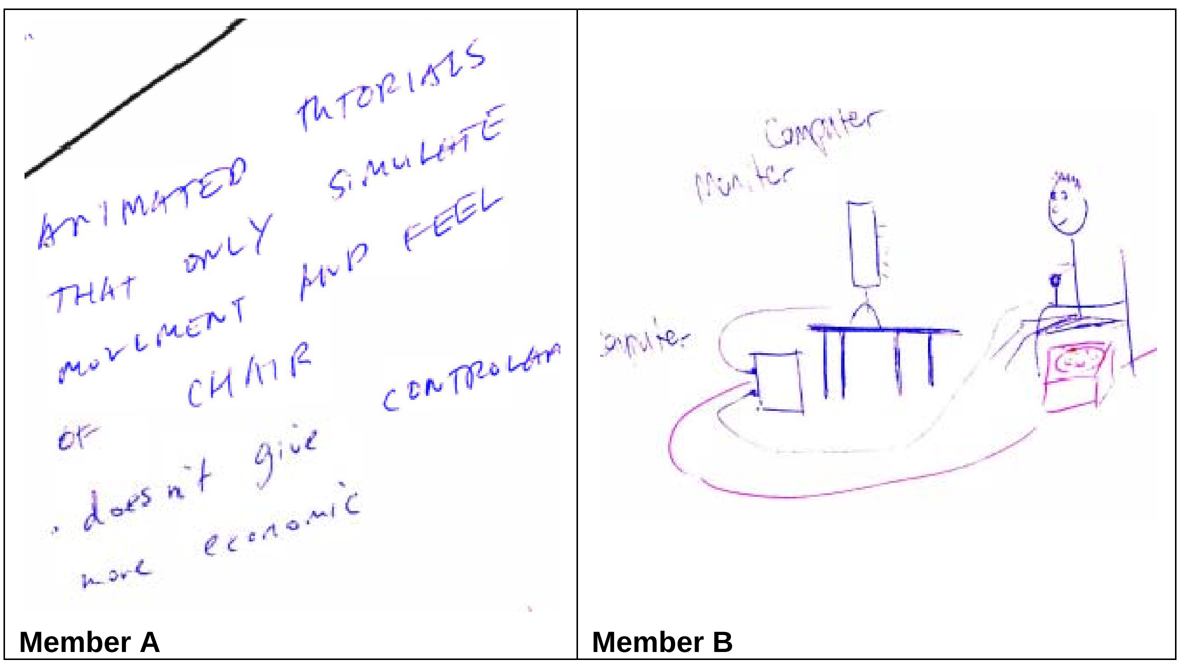

Figure 16 Low control study 2nd example of a similar solution

The first solution (Figure 15) uses actuators underneath a platform, on which the wheelchair is to be placed. A joystick is used as input device, and projections on the surrounding walls are used to simulate a virtual environment. The second solution

(Figure 16) was written by participant A, and sketched by participant B. It is a simplified simulation, similar to a video game. The similarities in the solutions can be due to the solutions being obvious or to the team members having talked about solutions during the earlier problem clarification phase, which was unsupervised for the teams.

4.3.4. Low Control Study Future Work and Conclusions

The low control study allowed testing the distributed, time delayed modified method 635 in two distributed student teams. One collocated team form the same class was used as a collocated, time delayed modified method 635 control group. The findings from this study are qualitative, as the low number of data points does not allow a reliable ANOVA or different statistical analysis. Addressing the first low control study research question, an influence of the factor location can neither be confirmed nor eliminated.

The participants have known the design problem for a few weeks and had done an extensive problem clarification prior to the experiment. The similar results of two team members presented in section 4.3.3.2 Low Control Study Qualitative Results may be due to the knowledge of the problem and the resulting possibility of talking about solutions. Further contributing might be that these solutions are relatively obvious to somebody trying to solve the problem. Knowing the design problem before the experiment and going though the task clarification prior to the idea generation experiment might have had an influence on the solution or it might not. Hence, the second low control study research question cannot be answered conclusively.

The results show that the modified method 635 is a suitable idea generation method for in time and location distributed teams. It can be realized with paper, pens and scanners and does not need to rely on electronic equipment, as for example the tablet screens. It bridges the time gap between participants as no synchronous communication is required. The sketching ability of the participants does not seem to differ substantially between pen and paper or tablet solutions, but this comparison is lacking as the design problems are different and require different detail, compare Figure 15 and Figure 16 of the low control study to the figure on page 103 of the final study to build your own opinion.

Based on the similar solutions in one of the teams, the biggest concern for future use is the window of opportunity for the idea generation method. The idea generation method should be employed after the problem is clear to each team member, but before possible solutions are discussed, to avoid a contamination of each team member's idea space. In an industrial setting it seems feasible to train employees towards recording their ideas without voicing them during the task clarification phase, so as to retain the ideas for later use but to keep everybody's mind open for the idea generation.

4.4. Final Study

The final study took place one and a half year after the pilot study and a half year after the low control study.

4.4.1. Final Study Research Questions

The final study research questions are based on the second pilot study research question and follow the same reasoning. They extend the scope of the question by including all metrics presented by Shah et al. (2001) and used by Linsey et al. (In Review). Besides quantity, these metrics are quality, novelty, and variety (see section 4.4.2.5. Final Study Metrics). The first final study research question is:

> Do the idea generation method (brainstorming, modified method 635 synchronous), the location (collocated, distributed), or their interaction influence the *quantity*, *quality*, *novelty*, or *variety* of generated ideas?

Further, once this question is answered, the connection between the measures is of interest, as this allows predicting the outcome of an idea generation process. On variable instance might be significant to generate high quality ideas, whereas another variable instance might be significant to generate a high number of ideas. The variable instances can be the same, but do not have to be the same. Therefore the second final study research question is:

> Is there a connection between the values of the measures? If yes, between which measures and how are they related?

4.4.2. Final Study Methods

This section shows the methods used in the final study. The experimental design, the materials, the participants, the procedure and the metrics are presented.

4.4.2.1. Final Study Experimental Design

Based on the results from the pilot study, the experimental design presented in section 4.2.2.1 Pilot Study Experimental Design is reduced from six to four conditions, removing the two time delayed modified method 635 conditions (distributed and collocated).The quantity results from the pilot study indicate no significant influence of the added incubation period when comparing the synchronous and the time delayed modified method 635 in the distributed setting (data presented in Table 8), and a bar chart indicates no significant effect as the error bars representing one standard error are overlapping (Figure 17).

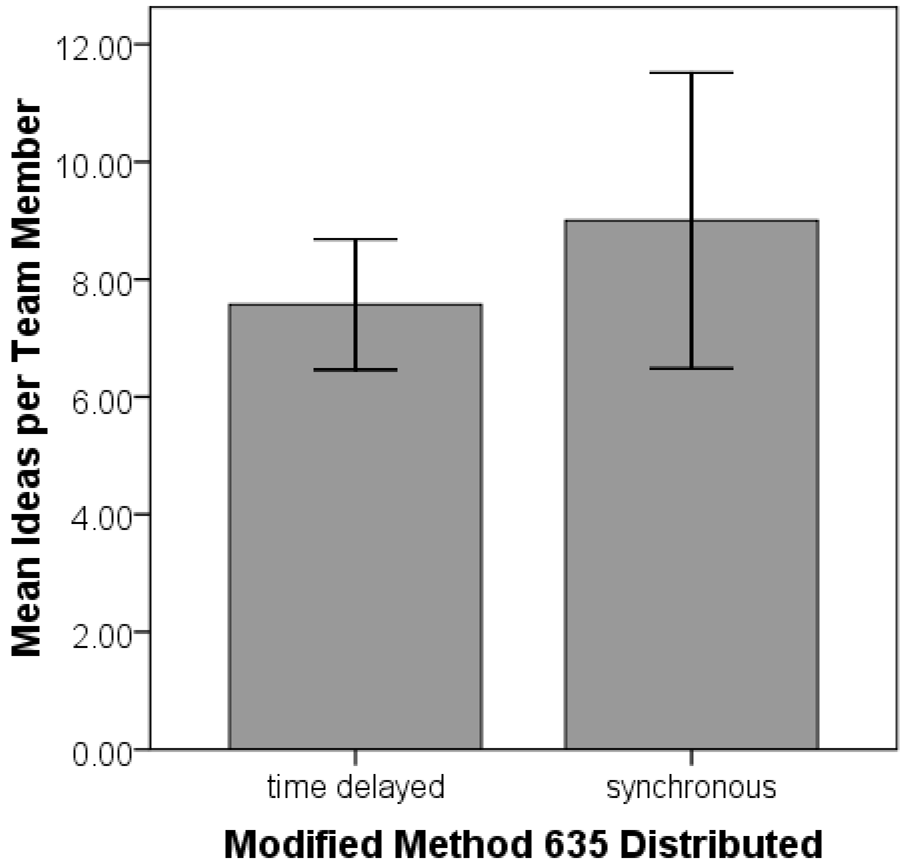

Figure 17 Pilot study modified method 635 distributed mean number of unique ideas per participants and condition (+/-1 SE)

Further, the literature review revealed many factors that influence an incubation effect, for example the motivation of the participants, the problem type, the occupation during the incubation periods and the length of the incubation period (see section 2.3.3.2 Experimental Research for details). Most of these factors are unfavorable in the dDesign experiment. The participants are not overly motivated, not “into it”, as the experiment is only a small part of their daily activities. It is unlikely that they think about it during the two idea generation sessions, especially taking into consideration that the design project has little relation to their everyday activity and might not be ingrained after just 35 minutes occupation with it. As they are undergraduate students, their schedule is probably busy, and their occupation with homework and classes will likely leave not much brain capacity for additional activity. This may or may not be similar to an engineer working on multiple projects at a time. Further, the length of the incubation period is substantial longer than in all studies reviewed, days as opposed to minutes. The sum of these unknown variables requires a more detailed research study than can be accomplished under the dDesign umbrella. Therefore, the modified method 635 time delayed conditions are not tested further. For now, the knowledge that the method itself is operational and that there is no substantial difference between the time delayed and the synchronous condition is sufficient.

The remaining four conditions used in the final study are presented in Table 14.

Table 14 Final study experimental conditions

	Brainstorming	**Modified Method 6-3-5**
Distributed	Brainstorming Distributed	Modified Method 6-3-5 Distributed
Collocated	Brainstorming Collocated	Modified Method 6-3-5 Collocated

4.4.2.2. Final Study Materials

The materials used are consistent with the materials presented in section 4.2.2.2 Pilot Study Materials.

4.4.2.3. Final Study Participants

The participants are in general consistent with the description given in section 4.2.2.3 Pilot Study Participants. All differences from the description given in that section are described in this paragraph. The participants are students in the second semester of the capstone design sequence (MEEN 402). As they are working in the same teams they worked in during the previous semester, one can assume that team structures are established, even though the experiment took place during the second through fifth week of the semester. Eight teams are recruited. Participants have to sign up in the team they are assigned in the design class. Teams with only three members are tested. If a team has more than three members, the additional team member is randomly selected to participate in an equally demanding, different experiment to keep the number of team member in the final study consistent. This experiment is led by a different experimenter in a separate room.

A survey at the end of the experiment shows that the average age of the participants is 22.45 years, the youngest being 21 years and the oldest being 26 years of age. All participants are male. 17 participants had industrial experience, including internships; 16 of them worked full time for an average of 7.8 months, the shortest time period being 3 months, the longest 24 months; four of them had additional part time industrial experience. One participant had only part-time industrial experience, working for 10 hours a week for 10 months. Three participants indicated that they had seen the design problem before. Questioning revealed that one of them had seen TV coverage on industrial peanut shelling. The other two misunderstood the question and had seen the idea generation method (modified method 635) before, but not the design problem.

4.4.2.4. Final Study Experimental Procedure

In the final study, the same procedure as presented in the pilot study (4.2.2.4) is used, but the design problem is changed to the so-called peanut sheller design problem (Figure 18).

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Figure 18 Final study peanut sheller design problem

The participant instructions and the experimenter scripts for each condition of the final study are presented in Appendix D.

4.4.2.5. Final Study Metrics

In the modified method 635 conditions, a solution to a design problem refers to one sketch and its annotations. In the brainstorming conditions, a solution is either the content of the note page or, if the team clearly indicated segments, one segment of the page. All solutions of a team are a ‘set of solutions’ or the ‘team’s solutions’. A solution can consist of multiple ideas, for example a conveyor belt may consist of the ideas belt, stands, and guide rolls.

The pilot study and the low control study were evaluated only quantitatively. The data from the final study is evaluated using four criteria: quantity, quality, novelty and variety.

4.4.2.5.1. Final Study Quantity Metric

The approach used to evaluate the quantity of the generated ideas per team is based on the counting technique used by Linsey et al. (In Review) as presented in section 4.2.2.5 Pilot Study Quantity Metrics. However, based on the knowledge gained in the pilot study, some alterations of the counting procedure are necessary. The updated counting rules are presented in Appendix E, and the changes are described in the following paragraphs.

First, as brainstorming conditions not only produce a list of keywords but often also contain sketches, the following rule is added:

> In brainstorming, if the note teller sketches ideas, count the components in them as you would count other sketches.

Then, because the tablet screens allow erasing of sketched components and because the voice recordings allow capturing all verbally expressed ideas, the following rule is instated:

> Count all ideas that have been generated. This includes erased (brainsketching) or verbally communicated but not written down (brainstorming) ideas.

Third, the ‘reframing the problem’ category is expanded by these examples:

> - General principles, for example high impact or solar energy, if no more specific instance is given and if it is not clear what function they are supposed to fulfill.
>
> - Crazy ideas as trained monkey, spaceships, magic…

In addition, rules that did not apply to the study are deleted. They can be found at the bottom of the counting rules in Appendix E.

The approach to evaluating the ideas per team member is altered from the one used in the pilot study to match the approach described in Linsey et al. (In Review). If team members have the same idea during the same time period, they share the credit for it. This means if two team members have the idea of a conveyor belt during the initial idea generation period, each team member gets 0.5 ideas accounted. For three team members having the same idea, this reduces to 0.33. Further, if an idea occurs during an earlier idea generation cycle, no points are awarded for it again, even if the person had not had a chance to see this idea. This means if participant X is the only participant who sketches a lever during the initial idea generation, no other participant will receive credit for a lever in a later cycle, even if they have not seen participant X’s sheet.

4.4.2.5.2. Final Study Quality Metric

Shah et al. define quality as "a measure of the feasibility of an idea and how close it comes to meet the design specifications" (Shah, Smith, & Vargas-Hernandez, 2003, p. 117). Quality is to be measured using domain specific rules, for example design for weight reduction by employing a hollow structure. If a hollow structure then appears in a solution, it receives a score of +1; if it does not appear, the solution receives a -1. All rules are decided upon for a design problem before evaluating the solutions. After all have been evaluated and scores are established for each solution, the scores of all solutions in a set are added up and normalized to a scale of ten. Kurtoglu et al. (2009) found that this unanchored rating scale was harder to use than an anchored rating scale, leading to smaller inter-rater agreement. Based on these findings, Linsey et al. (In Review) used an anchored three point rating scale with satisfactory results. This rating scale will also be used to evaluate the experiments presented here.

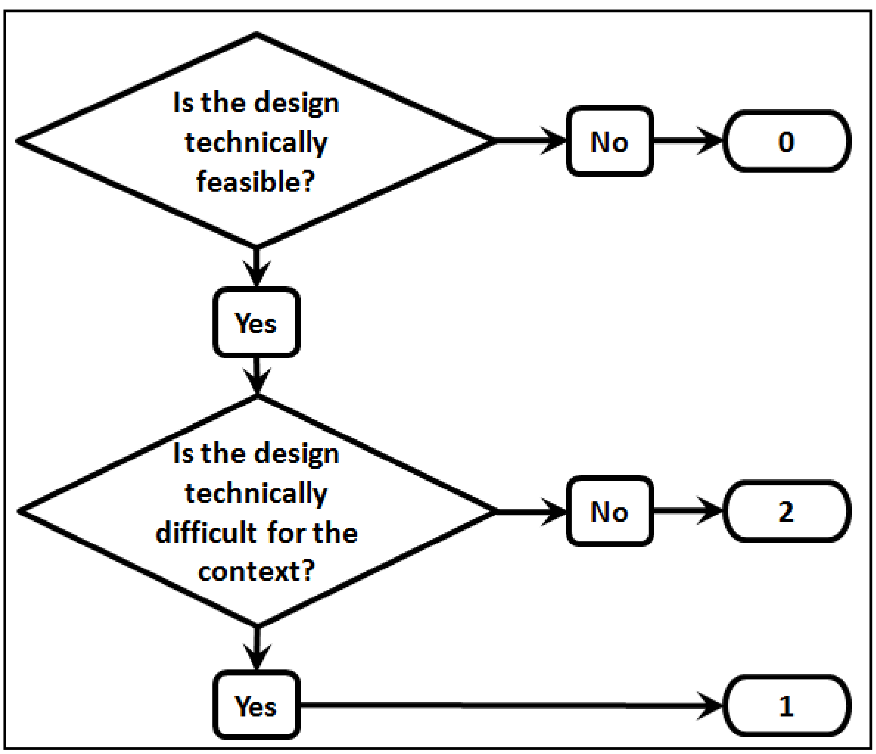

Figure 19 Final study quality evaluation three point rating scale

The used rating scale (Figure 19) asks first if the idea is technically feasible. If this is answered with no, zero points are awarded and the rater proceeds to the next idea. If this is answered yes, then the next question is asked: Is the idea technically difficult for the context? If this is answered with yes, one point is awarded. If the answer is no, two points are awarded. Then the rater moves on to the next idea. All sketched components and words that have been identified as ideas during the quantity counts are evaluated for quality. This rating scale is employable for a wide range of design problems. Depending on the specific design problem, the presented three point rating scale can be refined by adding more questions and expanding the point range. The quality rating of an idea measured as described is independent of other ideas, and thus can be evaluated while the series of experiments is in progress.

4.4.2.5.3. Final Study Variety and Novelty Metric

Novelty reflects how unusual or unique a solution is in comparison to the other generated solutions. Variety shows how diverse the team's solutions are, or how much of the solution space spanned by all solutions generated by all teams is covered by one team's solutions. The method used to evaluate the experiments at hand is presented in Linsey, et al. (In Review). Both measurements can only be evaluated after the series of experiments has been concluded. Novelty and variety are evaluated on the idea level, not on the solution level. Each generated idea is separated onto a single page. These pages are given to an independent rater, who sorts the solutions into groups of similar ideas. Each rater constitutes himself what similar means in the rating. The groups are sometimes referred to as bins.

4.4.2.5.3.1. Final Study Variety Metric

The variety of one team's ideas is defined as the number of groups the team's ideas are a part of. For example, if a rater creates 25 bins (or groups) and a team's ideas are found in five of those bins, the team's variety score is 5/25 = 0.2 or 20%. The team's ideas span 20% of the solution space created by all ideas of all teams who participated in the experiment.

4.4.2.5.3.2. Final Study Novelty Metric

The novelty metric measures the frequency of the occurrence of the idea. For one idea, it is measured by subtracting the number of concepts in a group divided by the number of concepts generated by all teams from one. For example, if a rater places an idea in a group that contains 5 ideas, and all teams produced a total of 200 ideas, then the idea's novelty score equals 1- 5/200=1- 0.025=0.975.

The Novelty score of all of a team's ideas is calculated by averaging the novelty scores of the team's ideas.

4.4.3. Final Study Results and Discussion

4.4.3.1. Final Study Data Validity

The screen recordings for the second distributed modified method 635 team were started about 2 minutes into the initial idea generation phase due to a neglect of the experimenter, suspending each participant for less than 30 seconds thus reducing their idea generation time. The evaluation of the results for quantity and quality of the generated ideas showed no effect on the idea generation, so that the results from the team are deemed valid data and are used with the other data collected.

4.4.3.2. Final Study Qualitative Results

The following section presents the results from the final study. It is interesting to see how results from brainstorming and modified method 635 teams differ. The brainstorming teams generally use keywords to capture their ideas and sometimes add small sketches to illustrate a specific point. In the instructions the brainstorming teams receive, they are neither encouraged nor discouraged to sketch (see Appendix D for the participant instructions and experimenter scripts). The modified method 635 teams are told to sketch and explain ambiguities with keywords or short phrases. Figure 20 shows 2 typical solutions to the peanut sheller design problem from modified method 635 teams on the left and 2 typical solutions from brainstorming teams on the right.

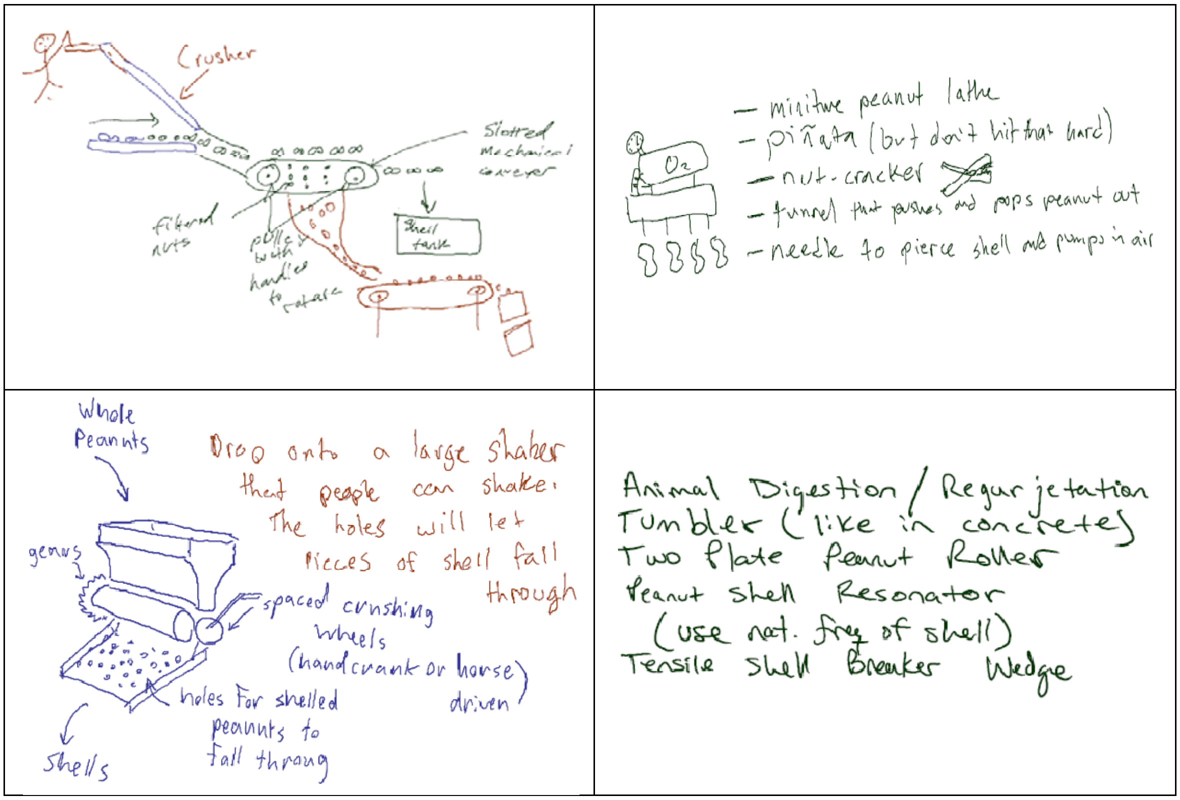

Figure 20 Final study typical solutions. Left: modified method 635; Right: brainstorming

For the modified method 635 condition, the different colors represent contributions from different team members. Solutions including how to import the peanuts, how to shell them, and how to separate the nut from the shell are common in the modified method 635. In brainstorming it is more common to find keywords without further explanations describing one of the functions or analogous products, for example “cotton gin”.

4.4.3.3. Final Study Quantity Results

A summary of the results per condition is given in Table 15. The average number of ideas per team member, presented in the middle column, is based on the counts of unique ideas per team member. These counts of unique ideas have been summed up and averaged with the number of participants. The number of ideas per team is presented in the right column. The detailed counting procedure is presented in section 4.4.2.5.1 Final Study Quantity. The biggest variation in the quantity of ideas per team can be seen in the brainstorming distributed condition, with one team generating 40, the other team generating 20 ideas (Table 15). The inter-rater agreement using Pearson's Correlation is 0.85 for the unique ideas per team member (shown in Table 16) and 0.66 for the ideas per team counts.

Table 15 Final study overview of quantity results

Condition	Average number of ideas per team member	Ideas per Team
Modified Method 635, Distributed	12.00	34; 32
Modified Method 635, Collocated	13.5	39; 40
Brainstorming, Collocated	9.5	26; 27
Brainstorming, Distributed	10	40; 20

The eight data points resulting from the quantity analysis on the team level form a too small sample size, prohibiting a reliable ANOVA analysis. Therefore it is decided to count the unique ideas per team member according to the procedure presented in section 4.4.2.5.1 Final Study Quantity. A count per team member takes the individual abilities of the participants into account, which are likely slightly unequal as they are randomly chosen. Using the individual counts triples the number of data points in comparison with the team counts, leading to six data points per condition, for a total sample size of 24 data points. The detailed quantity analysis per team member, consisting of the number of unique ideas generated by each participant, is presented in Table 16.

Table 16 Final study quantity of unique ideas per team member

Condition	Number of Unique Ideas for Each of the Three Team Members				Average Number of Ideas per Team Member & Condition
		1st	2nd	3rd	
Modified Method 635, Distributed	Team 1	9.7	12.7	16.7	12.2
	Team 5	9.0	11.5	13.5	
Modified Method 635, Collocated	Team 2	13.0	11.5	14.5	13.5
	Team 6	12.0	12.5	17.5	
Brainstorming, Collocated	Team 3	8.0	10.0	11.0	9.5
	Team 7	6.0	8.5	13.5	
Brainstorming, Distributed	Team 4	8.5	11.0	20.5	10.0
	Team 8	4.0	6.5	9.5	

An ANOVA analysis with the 24 data points representing the unique ideas per team member and condition (Table 16) shows a significant influence of the idea generation method on the number of ideas generated per team member (Location: $F(1,23)=0.08$, $p=0.78$; Idea Generation Method: $F(1,23)=4.40$, $p=0.05$; Interaction: $F(1,23)=0.39$, $p=0.54$, $MS_{error}=12.98$; Table 17). This is an interesting result, as one can conclude that the number of ideas generated is only dependent on the idea generation method (brainstorming versus modified method 635) used and independent of the location of the team for these two methods. For distributed teams, this implies that the lack of face-to-face meetings and electronic communications as used in the experiment has no effect on the number of ideas they generate. This result is good, as it implies that distributed teams can have as many ideas available for the future phases of the product development process as collocated teams; they are as effective –or ineffective- as collocated teams using the same of the two tested idea generation methods. They could also be more productive than collocated teams but be hindered by the communication technology used.

Table 17 Final study quantity per team member ANOVA results

Source	df	F	p
Location	1	.08	.78
Idea Generation Method	1	4.40	.05
Location x Idea Generation Method	1	.397	.54
Error	20	(12.98)	

Note. Value enclosed in parenthesis represents mean square error.

A graphical representation of the average values of unique ideas per team member per condition and their standard errors are shown in Figure 21, revealing that one standard error in the distributed brainstorming condition (1 S.E.=2.32) is more than twice as big as the next biggest standard error in the distributed modified method 635 condition (1 S.E.=1.14). This reflects that one team member in the first distributed brainstorming team dominated the two team mates and came up with half of the ideas generated in total by the team (20.5 versus 11.5 and 8.5 ideas per team member, see Table 16). One standard error for the collocated brainstorming condition (1 S.E.=0.90) and for the collocated modified method 635 (1 S.E.=0.94) are close in size to the standard error of the distributed modified method 635 condition.

Generally the results on the team member level should be reflected on the team level and vice versa. Because of the small sample size of only eight data points on the team level (values presented in Table 15), this is unlikely for this experiment. To test if the relation exits, an ANOVA analysis based on the unique idea counts of each team is performed. The ANOVA analysis shows that neither the idea generation method (brainstorming or modified method 635) nor the location of the team (distributed or collocated) has an influence on the number of ideas generated per team. There is no interaction effect of the two factors, either (Location: $F(1,7)=0.09$, $p=0.78$; Idea Generation Method: $F(1,7)=2.52$, $p=0.19$; Interaction: $F(1,7)=0.99$, $p=0.38$, $MS_{error}=50.75$; Table 18). Therefore the results of the per team member analysis are not reflected on the team level.

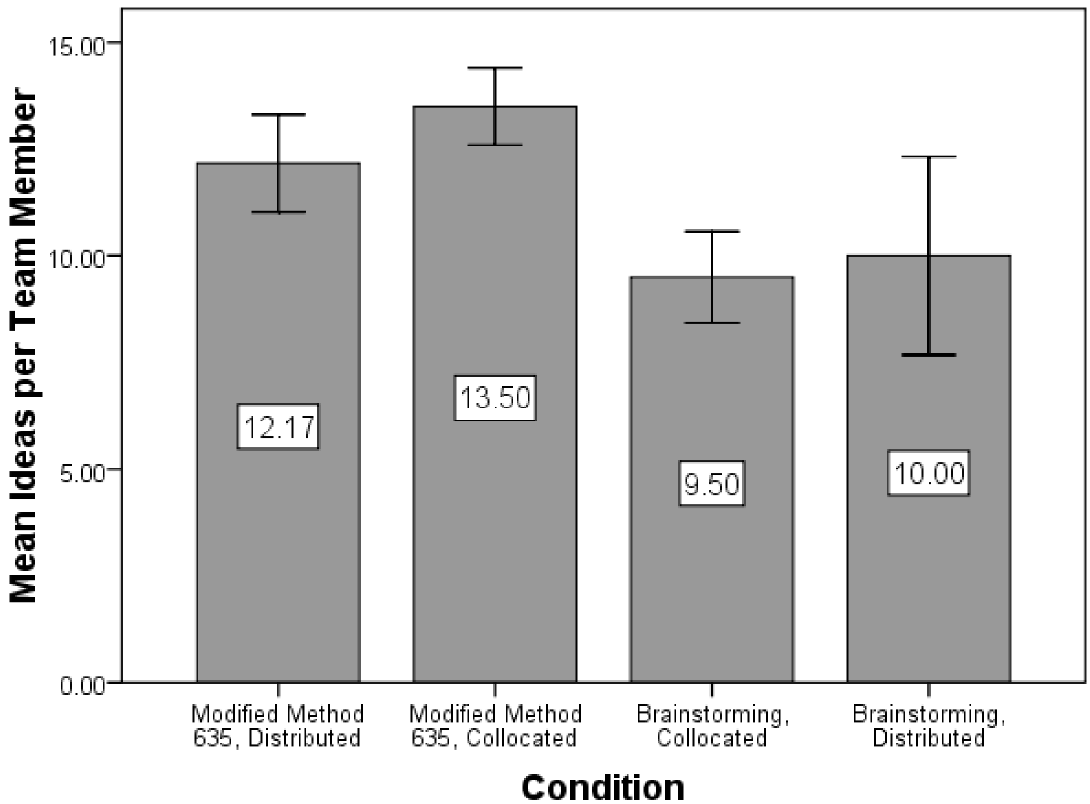

Figure 21 Final study average of unique ideas per team member over condition (+/-1 SE)

Table 18 Final study ANOVA quantity results per condition based on team values

Source	df	F	p
Location	1	.09	.78
Idea Generation Method	1	2.52	.19
Location x Idea Generation Method	1	.99	.38
Error	4	(50.75)	

Note. Value enclosed in parenthesis represents mean square error.

The bar chart presenting the average number of ideas per team depending on the factors location and idea generation is shown in Figure 22. The standard error for the distributed brainstorming condition might influence the results on the team level, as the non-overlapping other standard errors suggest a significant effect.

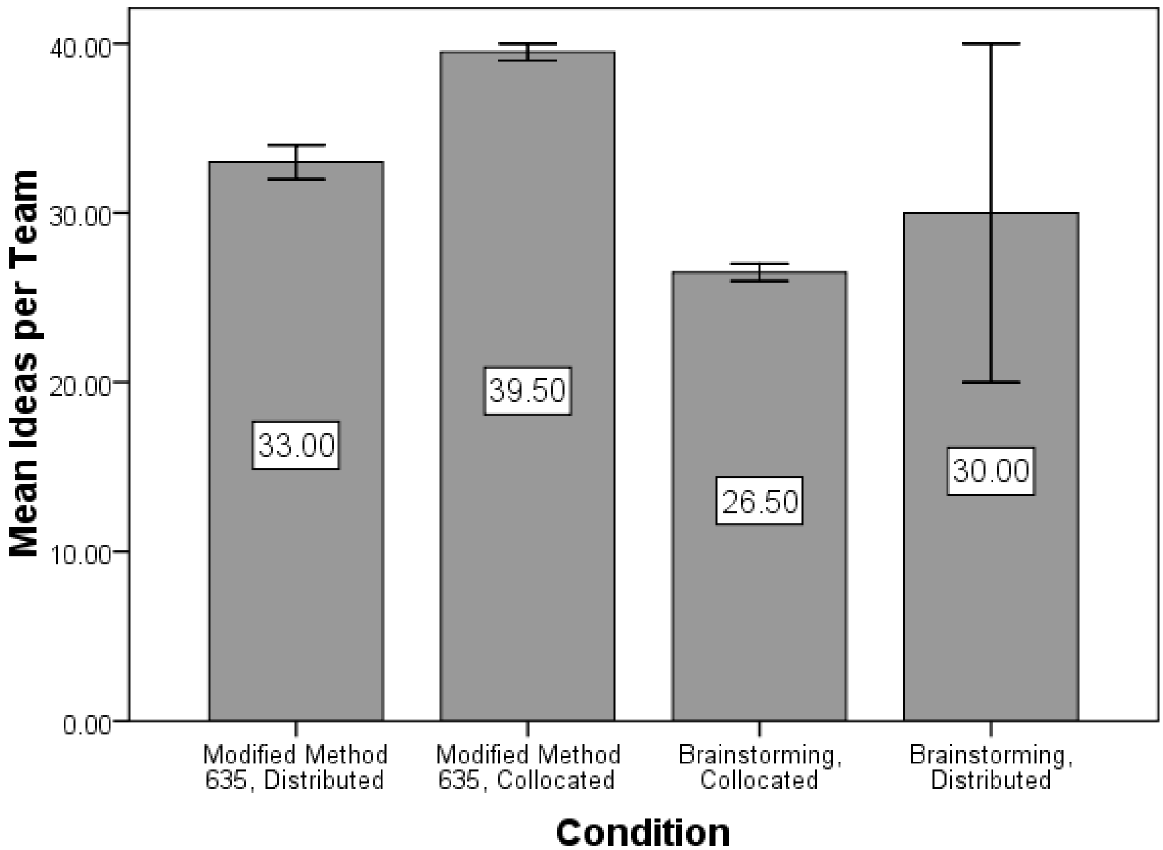

Figure 22 Final study average number of ideas per team (+/-1 SE)

4.4.3.4. Final Study Quality Results

All ideas are evaluated for quality following the three-point rating scale presented in section 3.2.4 Metrics. The first rater, the author of this thesis, evaluated all 373 ideas. Two more raters evaluated 40 randomly chosen ideas, 5 of each participating team. The inter-rater agreement calculated using Cohen's Kappa is 0.50 between the first and the second rater, a moderate agreement. The raters agreed on 28 out of the 40 compared observations, equaling 70% of the solutions, versus 40.44% of the observations expected by chance. For the second and the third rater Cohen's Kappa equals 0.26, with the raters agreeing on 24 out of the 40 observations, reflecting 60% versus the expected 45.88% of the observations. The first and the third rater reach a Cohen's Kappa of 0.35, with an agreement on 25 out of the 40 observations, 62.5% versus the expected 42.50% of the observations. The kappa values of 0.26 and 0.35 indicate fair agreement. Unfortunately all three kappa values are deemed too weak for a reliable inter-rater agreement, as the threshold for reliability testing for Kappa is generally assumed to be equal or bigger than 0.70.

Multiple theories for this weak inter-rater agreement are scrutinized: First, it was thought that the raters misunderstood the rating procedure. This could be out ruled after a conversation with each rater, who showed understanding of the method. Next it was theorized that the conditions of the experiment, especially the earlier mentioned differing results between brainstorming and the modified method 635, might have led to a differing judgment of ideas. Rater one and two agreed perfectly or with only one idea difference on teams 1, 5 and 6, all modified method 635 teams. Rater one and three agreed perfectly or with only one idea difference on team 3, 4, and 5, two brainstorming and one modified method 635 team. Rater two and three agreed perfectly or with only one idea difference on team 4, 7, and 8, all brainstorming team. However, no explanation could be detected for the results. Then, the ideas were categorized to be either a component (lever), an assembly (conveyor belt), or a method (pressure), as it was thought that the different levels of ideas might influence their rating. Again, no pattern could be detected for the disagreement. The ideas raters disagreed on were spread out evenly across the categories. At this point it was decided to go ahead with the analysis based on the first rater's (the author of this thesis) data and to add the quality evaluation method to the future work.

Based on the first rater's results, the average quality scores per team and condition are summarized in Table 19. The average quality value over all teams is 1.42, with each team's value using the modified method 635 quality being above or about this value and all team's quality values using brainstorming being below this value.

Table 19 Final study overview of quality results, 1st rater

Condition	Average Quality of Solutions per Team
Modified Method 635, Distributed	1.88; 1.72
Modified Method 635, Collocated	1.66; 1.47
Brainstorming, Collocated	1.18; 0.86
Brainstorming, Distributed	1.29; 1.29

An ANOVA analysis yields a significant dependence of the quality of a team's ideas on the $p=0.1$ level for both factors examined, but not their interaction (Location: $F(1,7)=6.22$, $p=0.07$; Idea Generation Method: $F(1,7)=27.13$, $p=0.01$; Interaction: $F(1,7)=0.03$, $p=0.87$, $MS_{error}=0.02$; Table 20).

Table 20 Final study ANOVA quality results 1st rater

Source	df	F	p
Location	1	6.22	.07
Idea Generation Method	1	27.13	.01
Location x Idea Generation Method	1	.03	.87
Error	4	(.02)	

Note. Value enclosed in parenthesis represents mean square error.

This implies that both the location, or rather the distribution or collocation of the team, and the idea generation method, respectively brainstorming and the modified method

635, have a significant influence on the quality of a team's solutions. The bar chart showing the quality values averaged over the location confirms the indicated significant effect of the factor idea generation method, as the error bars are not overlapping (Figure 23). The bar chart showing the teams' quality values average over the idea generation method however does not indicate a significant effect of the location, as the error bars are not overlapping (Figure 24).

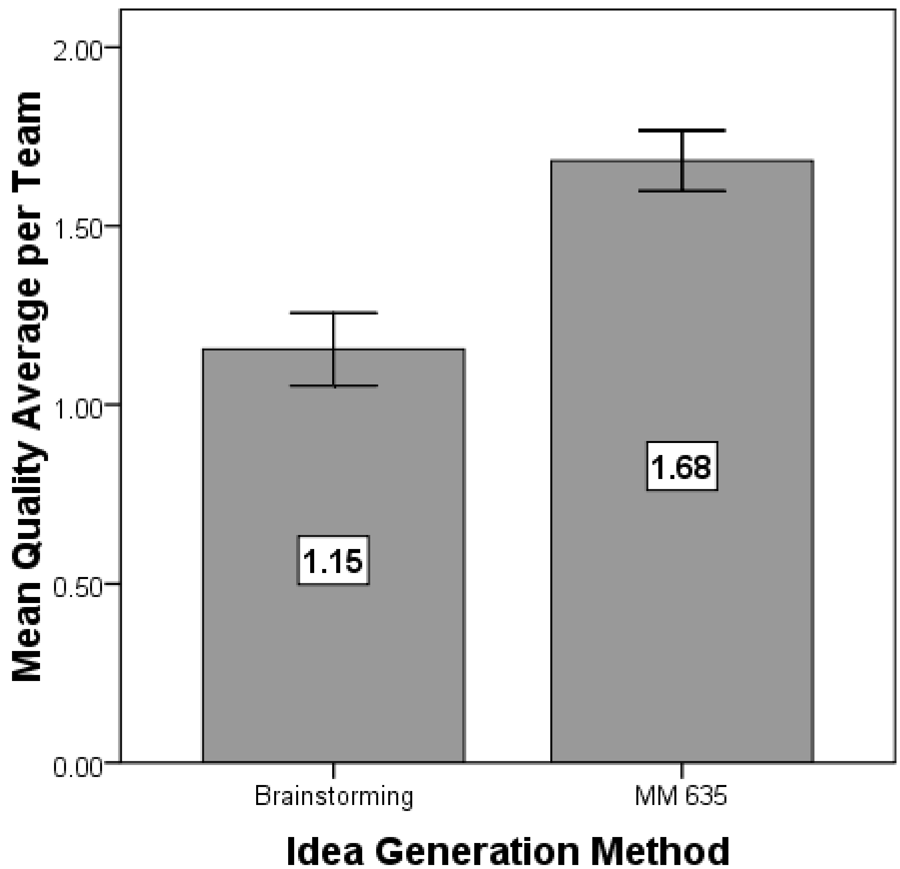

Figure 23 Final study quality 1st rater means averaged over the factor location (+/-1 SE)

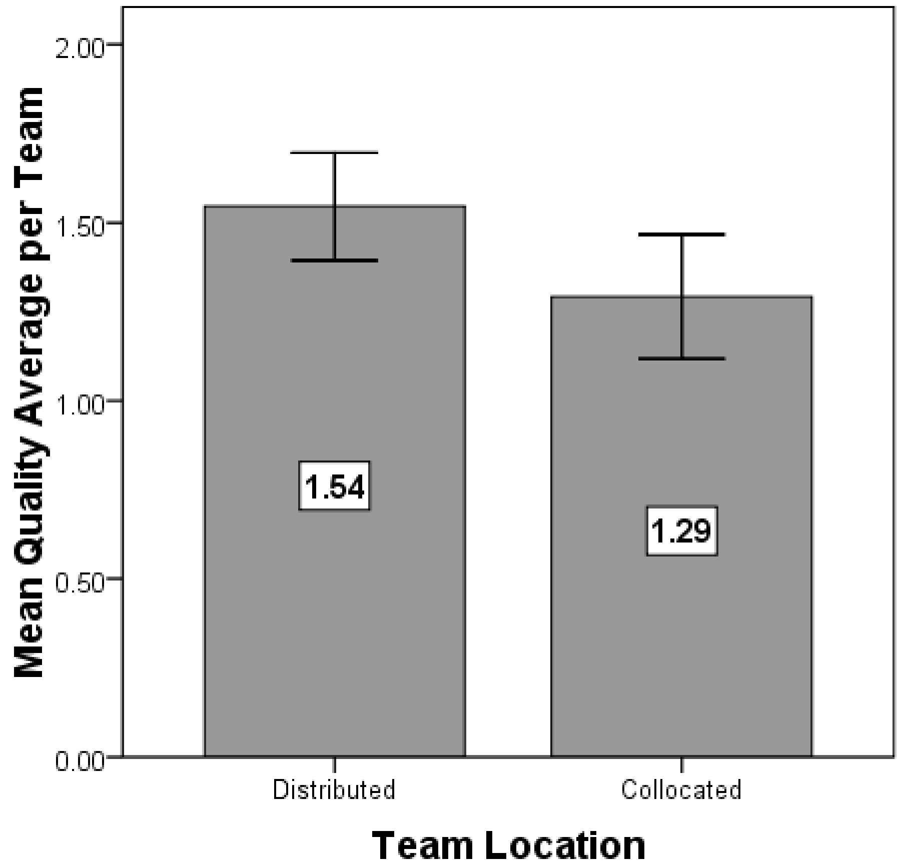

Figure 24 Final study quality 1st rater means averaged over the factor idea generation method (+/-1 SE)

Overall, teams using the modified method 635 in a distributed setting produce the highest quality of ideas. Teams using the collocated modified method 635 produce the second highest quality of ideas. Third are the distributed brainstorming teams, and the least quality ideas are generated by collocated brainstorming teams (Figure 25).

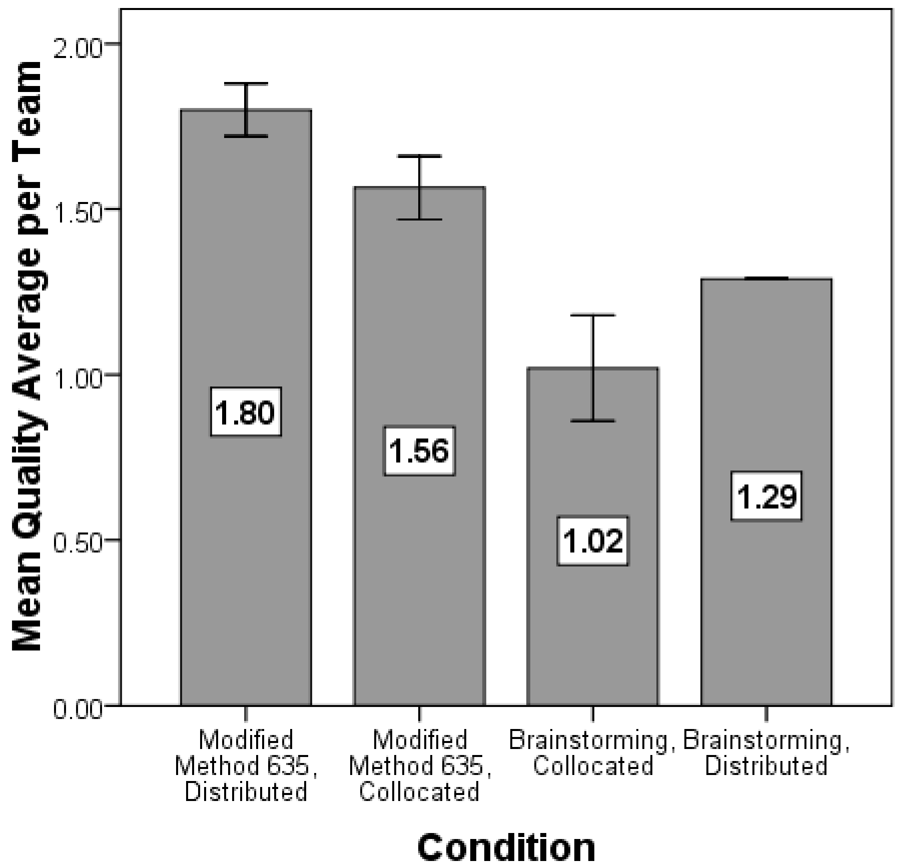

Figure 25 Final study mean quality per condition 1st rater (+/-1 SE)

A comparison of the distribution of quality scores across conditions gives the impression of an increase in feasible and appropriate ideas (two points awarded) solutions in the modified method 635 conditions (Figure 26). The modified method 635 teams produce a higher number in ideas, as each component or method sketched or written down is evaluated separately. For example, a table consists of a table top and legs, which are rated separately for quality. Furthermore, not only unique ideas are evaluated for quality - if a second table is drawn, it is evaluated in the same way as the first one. As these results are hard to compare due to the unequal number of ideas among teams, a second chart shows the distribution of quality ratings averaged over the condition with each condition's score being normalized to 100% (Figure 27).

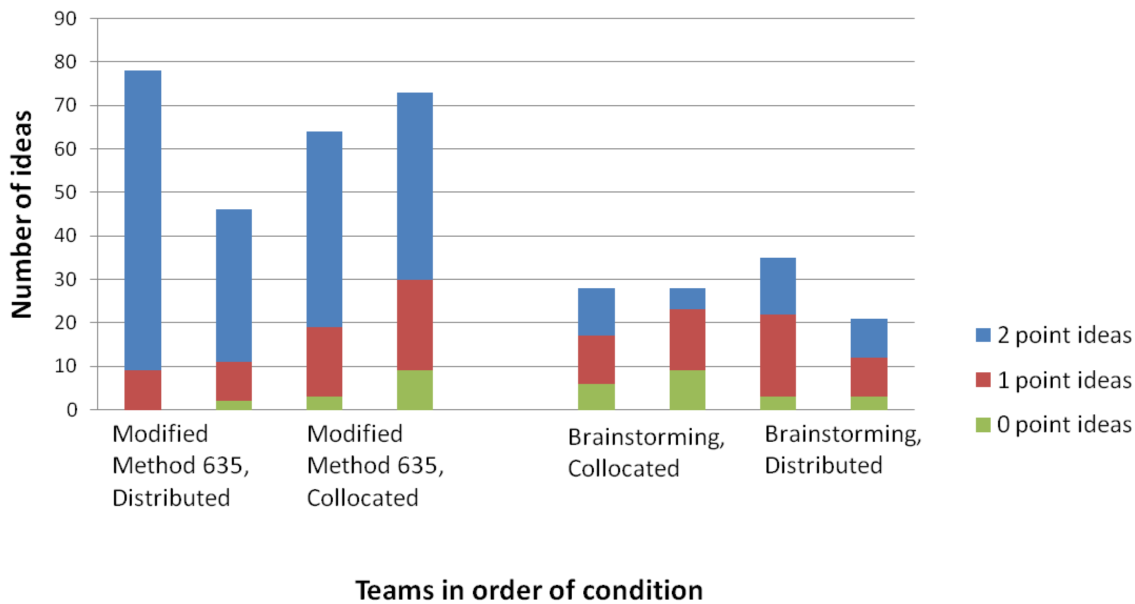

Figure 26 Final study number of quality ideas per team

The percentage of infeasible ideas is very small in the modified method 635 distributed condition, far less than 5 % of all ideas. The first collocated brainstorming condition has the highest percentage of infeasible solutions, slightly more than 25%. The modified method 635 collocated and the distributed brainstorming conditions both have around 10% of infeasible ideas. The brainstorming conditions have between 45 to 50% of feasible, but unsuitable ideas for the context (one point awarded), higher than the modified method 635 method conditions with 15 and 25%. These ideas might still inspire a solution in a real product development setting, but was not evaluated in this context.

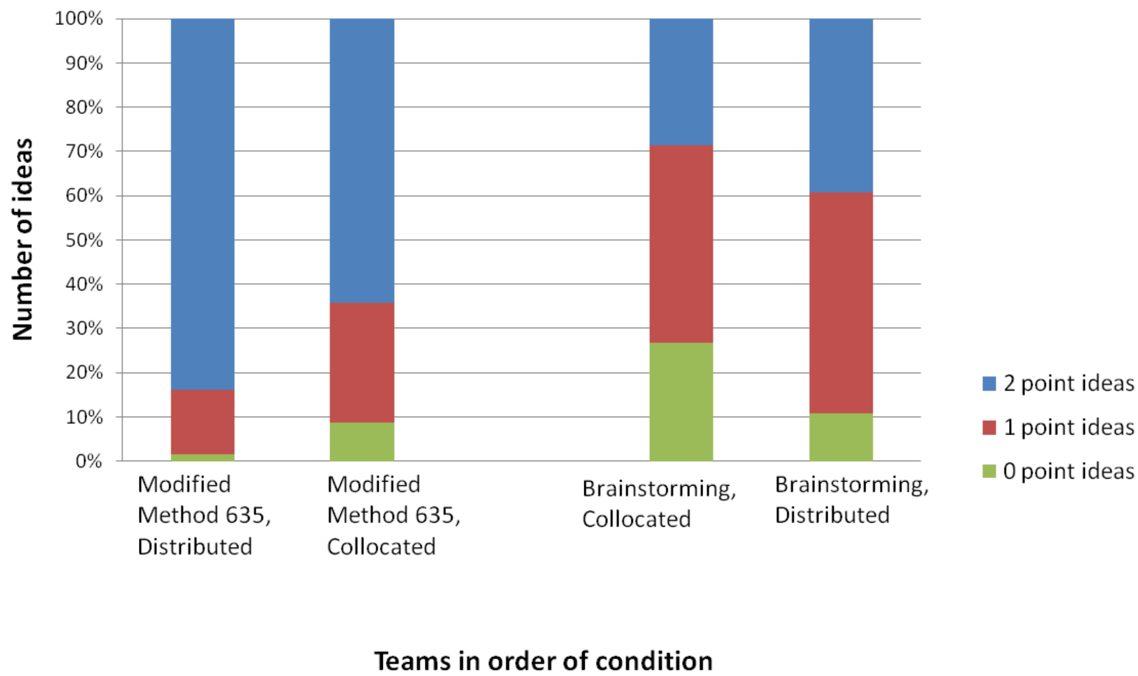

Figure 27 Final study percentage of quality ideas averaged over condition

The distributed 635 teams have the highest percentage of solutions that work in the context of the design problem (2 points awarded) about 65 and 80% compared to slightly less than 30 or 40% in the brainstorming conditions.

4.4.3.5. Final Study Novelty and Variety Inter-rater Agreement

Two raters sorted the solutions of the eight teams to allow the calculation of novelty and variety. The 373 ideas were sorted into 75 bins by the first rater and into 78 bins by the second rater. The inter-rater agreement is calculated using Pearson's Correlation and is large, with PC=0.9. The level of correlation allows the use of only the 1st rater's (the author of this thesis) evaluation data in the analysis, as only minor changes are expected when using the data of the second rater or the average of both raters.

The variety evaluation is related with the novelty relation, as the same sorting is used. The inter-rater agreement between the two raters is calculated using Pearson's

Correlation and is 0.9, which is considered to be high. As with the novelty analysis, only the evaluation results of the first rater (the author of this thesis) are used in the following analysis, as the large inter-rater agreement suggests only small changes for using the average of the two raters or the other rater's data. An overview of the rater's results is included in the appendix.

4.4.3.6. Final Study Novelty Results

Using the novelty values of the first rater in the ANOVA analysis, both factors have a significant main effect (Location: $F(1,7)=26.18$, $p=0.01$; Idea Generation Method: $F(1,7)=52.55$, $p=0.00$; Interaction: $F(1,7)=1.64$, $p=0.27$, $MS_{error}=0.00$; Table 21).

Table 21 Final study ANOVA novelty results, 1st rater

Source	df	F	p
Location	1	26.18	.01
Idea Generation Method	1	52.55	.00
Location x Idea Generation Method	1	1.64	.27
Error	4	(.00)	

Note. Value enclosed in parenthesis represents mean square error.

Two bar charts showing the cell means per condition allow a visual check of the significance of the main effects (Figure 28, Figure 29). The non-overlapping error bars indicate a significant effect for the factor location in the first and for the factor idea generation in the second figure.

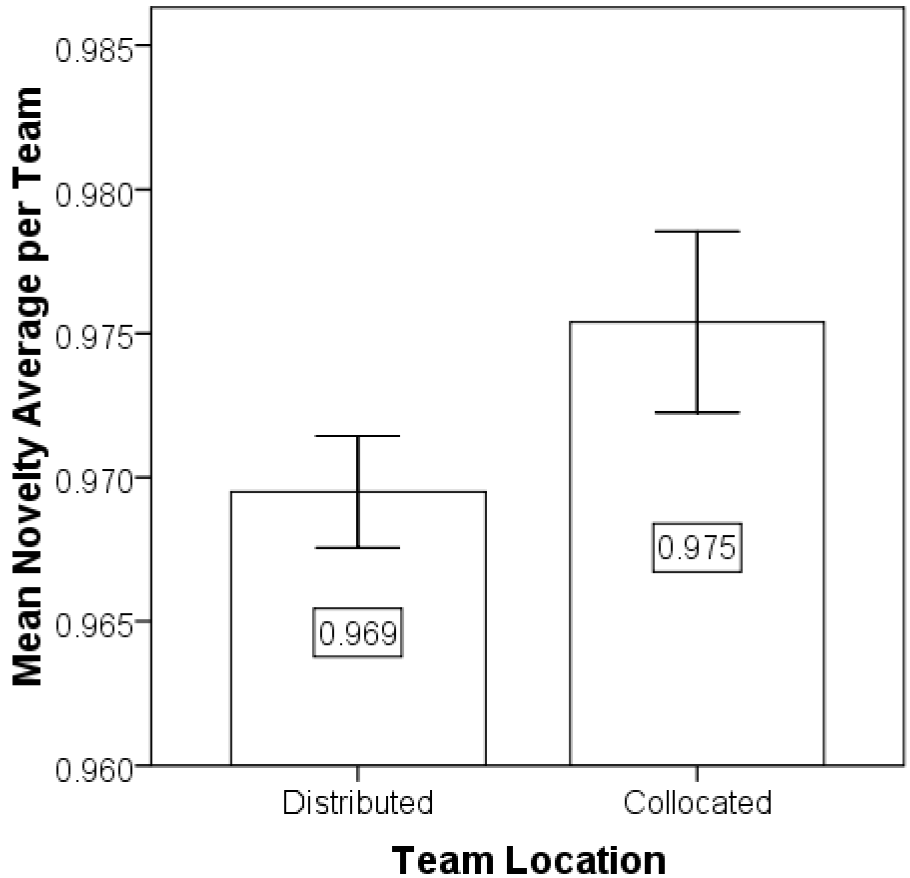

Figure 28 Final study novelty 1st rater means averaged over the factor idea generation method (+/-1 SE)

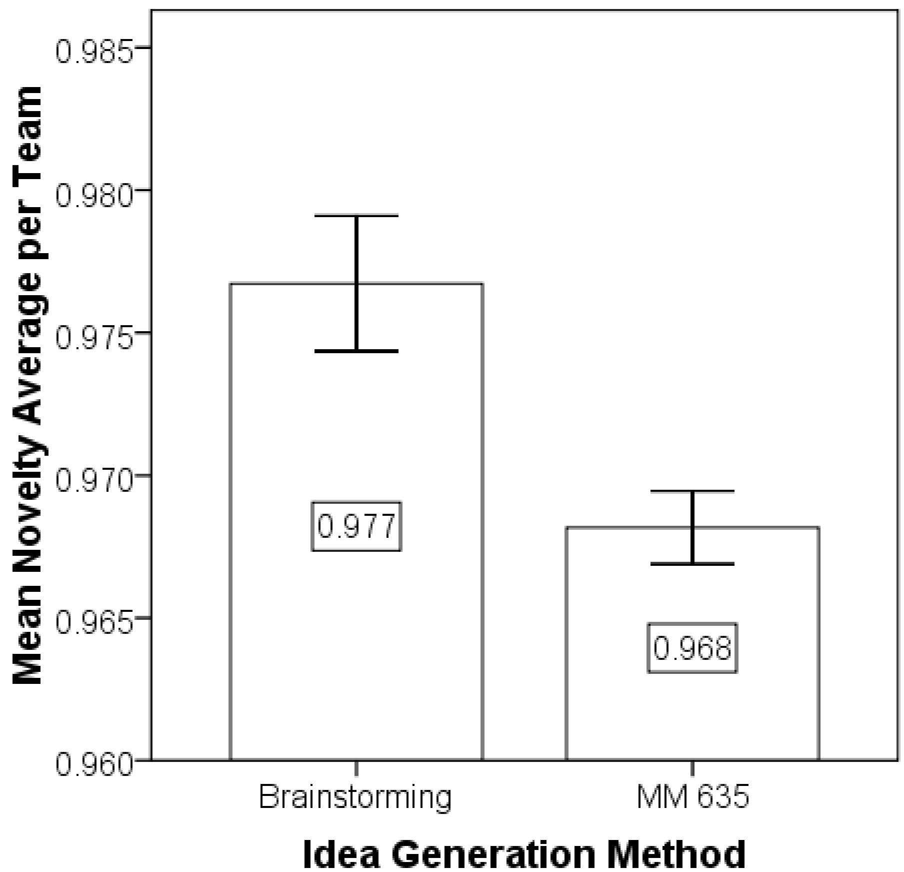

Figure 29 Final study novelty 1st rater means averaged over the factor location (+/-1 SE)

According to these results, the ideas generated by collocated teams produce are significantly more novel then the ideas generated by distributed teams, independent of the used idea generation method (brainstorming, modified method 635). Additionally, teams using brainstorming produce significantly more varied ideas than teams using the modified method 635, independent of the location of the team members. Teams in the collocated brainstorming teams generate the most novel ideas, followed by distributed brainstorming teams. The third position is occupied by the collocated modified method 635 teams and the distributed modified method 635 produce the smallest number of novel ideas (Figure 30).

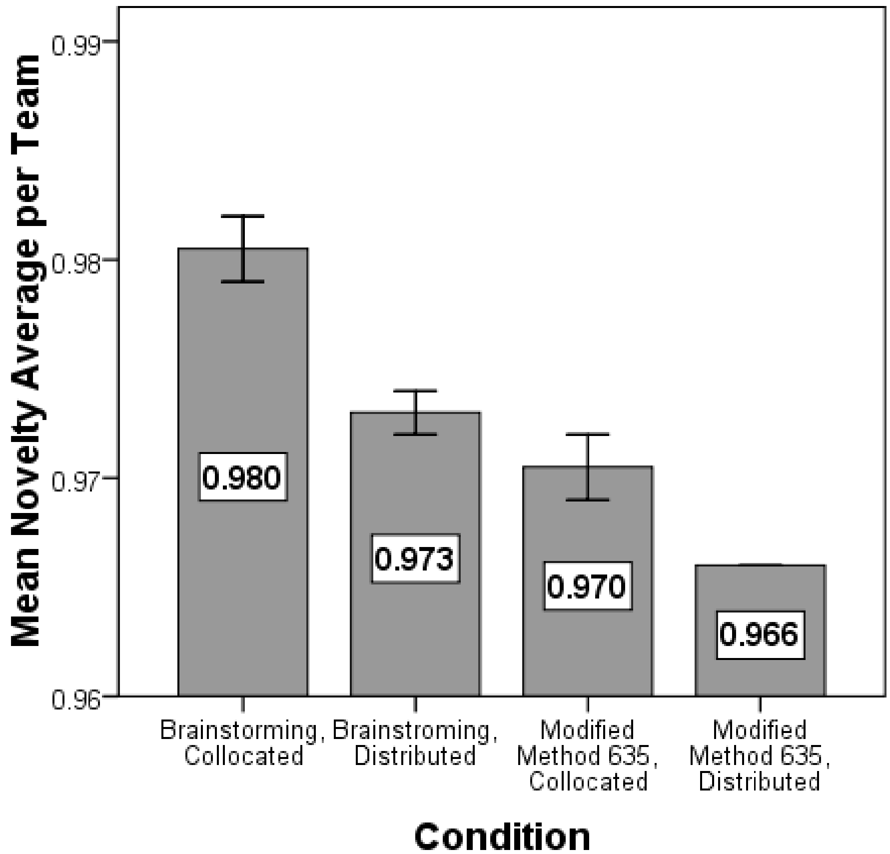

Figure 30 Final study novelty 1st rater mean values per condition (+/-1 SE)

4.4.3.7. Final Study Variety Results

Using the variety values of the first rater in the ANOVA analysis, both factors have a significant main effect (Location: F(1,7)=10.18, p=0.03; Idea Generation Method: F(1,7)=17.28, p=0.01; Interaction: F(1,7)=3.37, p=0.14, MS_{error}=0.00;Table 22).

Table 22 Final study ANOVA variety results, 1st rater

Source	df	F	p
Location	1	10.18	.03
Idea Generation Method	1	17.28	.01
Location x Idea Generation Method	1	3.37	.14
Error	4	(.00)	

Note. Value enclosed in parenthesis represents mean square error.

Two bar charts showing the cell means per condition allow a visual check of the significance of the main effects (Figure 31, Figure 32). The non-overlapping error bars indicate a significant effect for the factor location in the first and for the factor idea generation in the second figure.

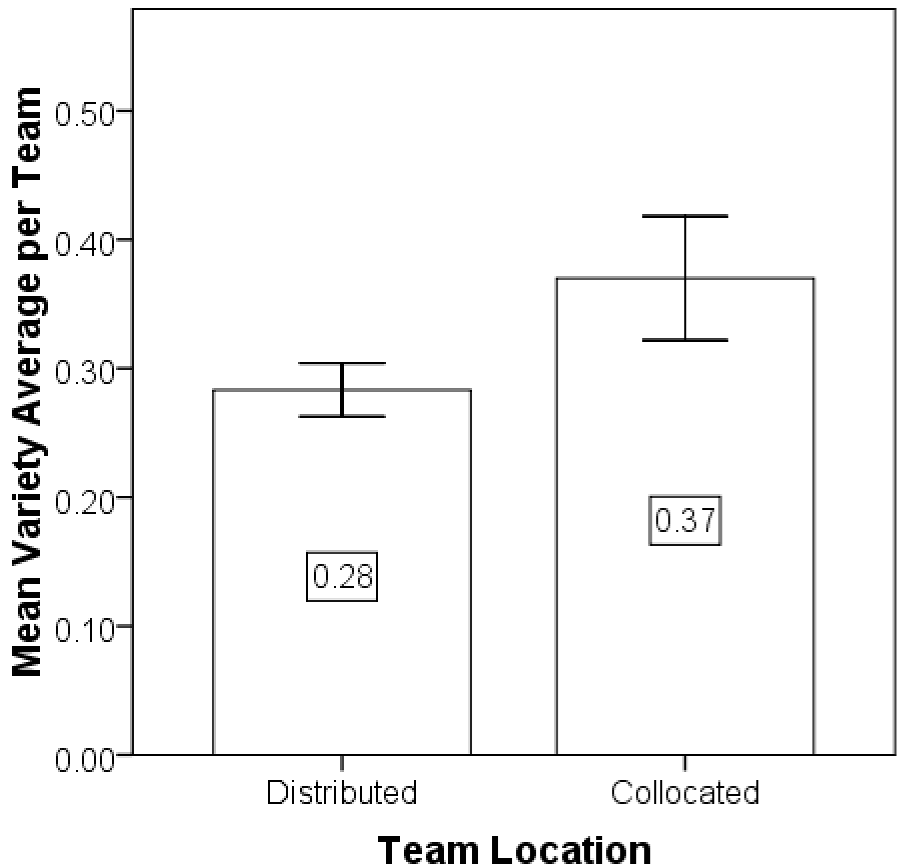

Figure 31 Final study variety 1st rater means averaged over the factor idea generation method (+/-1 SE)

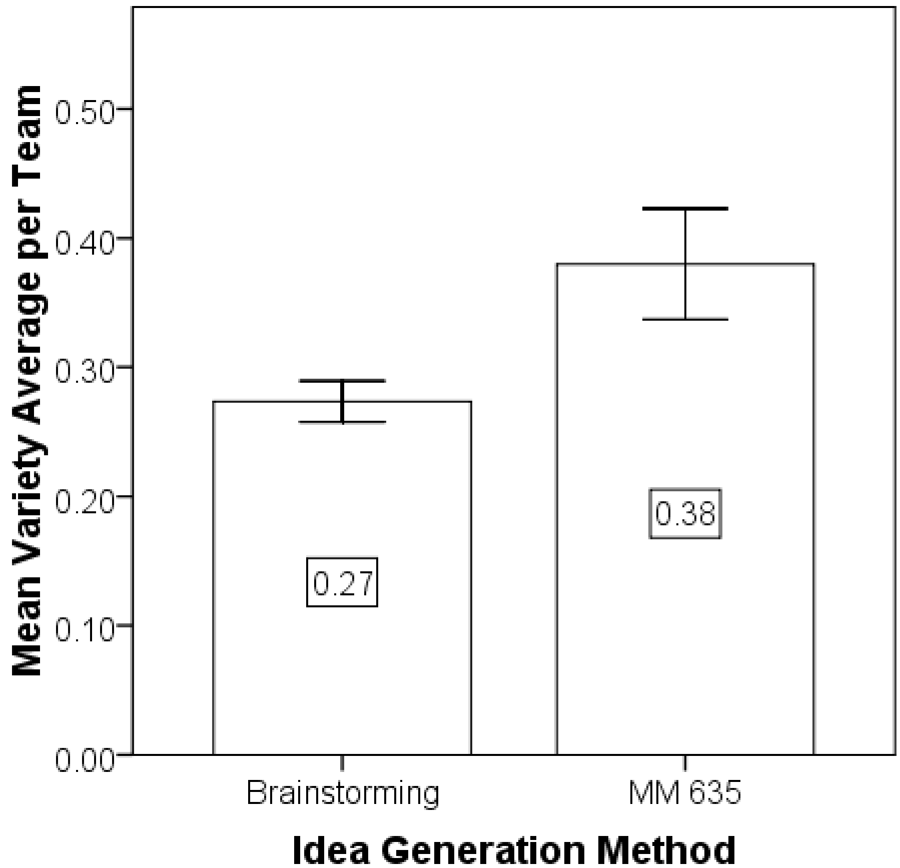

Figure 32 Final study variety 1st rater means averaged over the factor location (+/-1 SE)

Collocated teams produce ideas with a significant greater variety than distributed teams independent of the used idea generation method. Additionally, teams using the modified method 635 generate significantly more varied ideas than teams using brainstorming, independently of the location of the team. The teams using the modified method 635 in a collocated setting generate ideas with the greatest variety. The second biggest variety is achieved by the teams using the distributed modified method 635. The third and fourth places are occupied by the teams using brainstorming, with the collocated teams generating a greater variety than the distributed teams (Figure 33).

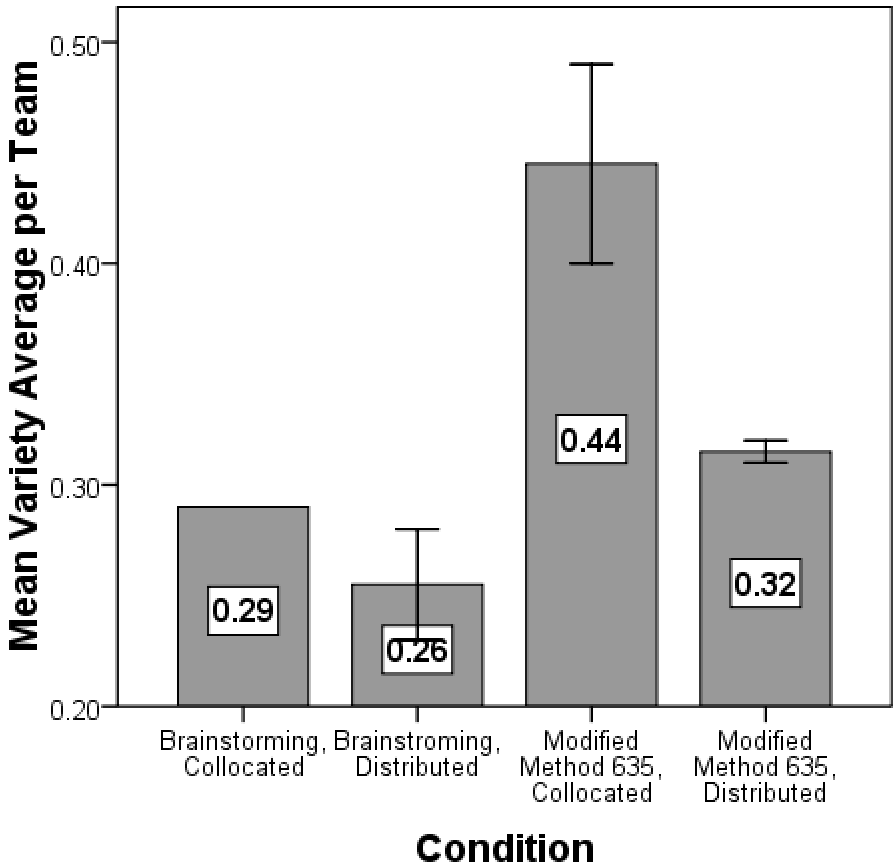

Figure 33 Final study variety 1st rater mean values per condition (+/-1 SE)

4.4.4. Final Study Conclusions and Implications for Future Work

The idea generation method has a significant effect on the number of ideas generated per team member; team members in the modified method 635 generate significantly more ideas than team members in the brainstorming conditions, independent of their location. Quality, novelty, and variety are each significantly influenced by both the idea generation method chosen and the team member's location, but in different ways by the same level of each factor. No interaction effect has been observed for either of them. Table 23 shows the summarized significant main effects for each dependent variable and the level of the factor that provided the highest value. The novelty of the team member's solution is observed to be higher when the team uses brainstorming instead of the modified method 635. Further, the observed novelty is higher for distributed teams, independent of the used idea generation method. This is true for variety, too, which showed collocated teams having more varied ideas than distributed teams. However, the idea generation method producing a higher variety is –in contrast to novelty- the modified method 635. The measured average quality of a team's ideas is highest, too, in modified method 635 teams. Independent form the idea generation method, distributed teams produced higher quality ideas, which sets quality apart from novelty and variety which both showed a positive influence of collocation.

Table 23 Final study summary of significant main effects

	Significance & higher values observed for:			
Factor	Quantity	Quality	Novelty	Variety
Idea Generation Method	Modified Method 635	Modified Method 635	Brainstorming	Modified Method 635
Location	-	distributed	collocated	collocated

The variety of solutions generated is also dependent on the idea generation method and independent of the location of the team members. But here the brainstorming teams show the more desirable state: they have wider variety in their solutions than the modified method 635 teams. This result stems partly from the fact that the quantity evaluation uses ideas, whereas the variety evaluation uses solutions. One idea often is one solution in the brainstorming teams, but one solution contains many ideas for the typical modified method 635 team.

The novelty of the generated solutions shows a significant effect of the idea generation method within collocated teams and for location (distribution and collocation) within either brainstorming or the modified method 635. These results are based on the average novelty values of the four conditions ranging from 0.88 to 0.92, differing only by $\delta=0.04$. The practical implication is that the differences in the novelty are not justifying a preference for either of the two idea generation methods or for distribution or collocation.

The quality of the generated solutions is correlated with the distribution in location of the team members, either collocated or distributed, but not the idea generation method. Distributed teams produce significantly fewer quality solutions than collocated teams. Even though the number of ideas is not influenced by the spatial distribution of the team members, the quality of the solution depends on it. This seems to contradict the usefulness of idea generation in distributed teams, but the quality evaluation favors teams with a high number of solutions, thus putting an advantage on the brainstorming conditions. Generally, multiple ideas constitute one solution for the modified method 635 and one idea equals one solution in brainstorming. The quality evaluation procedure needs to be scrutinized to adjust for the connection of number of solutions generated by a team and the average quality built by all of a team's solution.

Based on the presented results, it is recommended to apply different idea generation methods and team distributions to the same design problem to achieve the highest quantity of solutions, and the best quality and widest variety as well as greatest novelty of generated ideas. One should start with the idea generation and team distribution shown in this work to lead to the most desired outcome – either of the four dependent variables, quantity, quality, novelty or variety.

It has been shown that distributed idea generation in brainstorming and modified method 635 teams is feasible and can be an effective means of collaboration. Distributed teams have higher quality scores than collocated teams, which shows that a distributed team can have superior results compared to collocated teams.

Suggestions for future work are to expand the experiment with different idea generation methods, for example electronic brainstorming or C-Sketch. It might be that the restriction to use only words or only sketches influences the idea generation in distributed teams differently than in collocated teams, and it is assumed that a non verbal communication and thus possibly asynchronous idea generation method is easier to implement in real distributed teams. If idea generation in distributed teams is the goal of future research, then it is suggested to focus on idea generation methods suitable for asynchronous communication. They allow all team members to work on the project on their own during their regular work hours. If these methods show to be as effective as when they are employed synchronous in a collocated team, they might also be used in collocated teams to uncouple their schedules. If they show to produce a preferable outcome for one measure, they might also be employed in addition to any idea generation method used collocated.

A time delay in idea generation could be researched in a separate experiment: First, to learn about and to explore suitable methods for globally distributed engineering teams besides the time delayed modified method 635. Second, to compare the methods among each other using the metrics employed in this work. Third, it is desirable to gain insight into the complex incubation process in engineering design. The motivation to solve the given design problem, to think about it, or to have it in the back of one's head all seem to have an influence on the results of the incubation period. For an academic setting, it might be suitable to keep the participants involved with the design problem, for example by sending out emails containing a project related task during the incubation to increase both motivation for and occupation with the problem. Small rewards could be useful in engaging the participants more in the experiment over, for example a daily quiz related to the design problem with a chance to win a $5 voucher or a free meal in town. A different population for the experiment, mainly engineers recruited from the active workforce, is also desirable to evaluate the methods' practicality.

Independent form the actual experiment, the used evaluation methods, especially the quality evaluation, but also the novelty and variety methods, should be tested and modified further to even out the differences between brainstorming and the modified method 635. Brainstorming tends to lead to general methods, general terms, or one word descriptions of a component, whereas the modified method 635 tends to lead to detailed sketches with many components. This creates the problem of different levels: Brainstorming solutions are on a higher hierarchical level than the modified method 635 solutions, which can be sorted under the given hierarchy. It resembles comparing apples to fruit trees to try to decide if they are the same thing or not. Further, the higher number of ideas gives an advantage to the modified method 635 teams. To even this out, the brainstorming teams could be given extra time after the idea generation phase is up and ask them to detail their ideas in either words or sketches. The “cotton gin” could then be explained by the team, the team member who had the idea, or each team member in private on a component level. Similarly, the modified method 635 teams could be asked to find heading or categories for their sketches. This seems harder, as someone who sketched two parallel rollers might not know about a cotton gin, but participants might surprise the experimenter.

One other suggestion to even out the discrepancies is to provide the main functions to the team after the idea generation process and to ask the participants to identify the components that satisfy them. The evaluation could then be focused on the main functions and would be less influenced by “funny” ideas such as magic, monkeys, or top hats.

5. SUMMARY AND FUTURE WORK

In this thesis, two different experiments inquiring on the usability of distributed engineering teams are described. The first experiment, called VirtualCFD, explores the gains and process losses if a CFD analysis is executed in globally distributed teams. In the second experiment, termed dDesign, idea generation in the conceptual design phase is researched.

The findings of the VirtualCFD experiment are encouraging. The experiment shows that it is possible to solve a CFD problem when passing a project from one person to the next, utilizing the follow-the-sun approach. No special technical equipment is needed besides the equipment needed for the CFD analysis. Useful software is available from several sources, often without charge. One unforeseen problem overshadowed the experiment: The distributed team was not able to reach a converging solution for the design problem, as the chosen problem was too advanced for the skill level of the participants. So, even though there are no significant differences between the single worker's and the team's mesh quality in regards of the number of cells used and the number of cells exceeding the allowed skewness, the team's mesh does not allow a converging solution for the problem.

The VirtualCFD experiment shows that tradeoffs exist when a team solves a CFD problem: The sum of work hours of the team members is greater than the work hours the single worker needed to generate a solution for the same problem, increasing the hours a company has to pay for. The time to obtain a solution in days however is reduced – the solution of the distributed team would be available in the morning of the following work day as they worked during the night, whereas the single worker would reach the solution at the end of the second work day. Also, the success and progress of the team work is dependent on the information exchange in the team. The handshake procedures in this experiment and the provided technology allowed this information exchange. For bigger projects –having more participants, a more complex problem, or a longer duration- means need to be provided to record and easily access completed work and results, to avoid redundancies.

The next step in the VirtualCFD experiment is to follow up the pilot study with a second experiment, most importantly improving on the identified main weakness: matching the design problem to the skill level of the participants. To gain deeper insight into the information exchange, it is proposed to run the experiment with a four or five person distributed team. This will allow identifying when and where communication problems arise if not all participants can communicate synchronously with each other. It might further show if additional communication tools are needed for the success of a distributed CFD project comprising many team members. Further, the metrics used for should be updated to include the actual functionality of the mesh.

The second experiment, called dDesign, is composed of three consecutive experiments: A pilot study, a low control study, and the final study. Their objective is the examination of two idea generation methods in globally distributed teams in comparison to collocated teams.

The pilot study showed that the used spice composing design problem does not spark the creativity of the participants as expected. Especially in the modified method 635 it yields only a fraction of the multitude of solutions seen for other design problems. Instead of sketching how the mechanical components in a device fulfill a function, participants sketched a box with buttons. Despite this, the pilot study indicates that the general idea of generating ideas in distributed teams is not only possible but even promising. It shows a significant effect of the idea generation method used (brainstorming versus modified method 635 synchronous) on the number of ideas generated per team member. This will be further investigated in the follow-up studies.

In the low control study, the time delayed modified method 635 is applied to two capstone design projects of a globally distributed senior class. The results show that the time delayed modified method 635 works as well with pen and paper as with tablet screens. No significant difference between quantity counts per team or per team member in regards of the factor location (distributed and collocated) is observed, but with only one team in each condition, this needs to be researched further.

The final study is a continuation of the pilot study. Based on the insights gained from the literature review and the results from the pilot study, the number of tested conditions was reduced by the two ‘time delayed modified method 635’ conditions to a total of four conditions. Two teams with three team members each participated per condition. The idea generation method over location has a significant effect on the number of ideas generated per team member. Significantly more ideas are generated per team member in the modified method 635 conditions than in the brainstorming conditions. Quality, Novelty, and Variety are each significantly influenced by both factors scrutinized, idea generation method and location. No interaction effect is observed. To reach the full potential of idea generation teams in all four measures, this implies that in industry both methods and locations should be employed if possible.

Future work in the dDesign experiment series should compromise more idea generation methods, focusing on those that do not rely on synchronous communication. This decouples the schedules of the team members and allows each distributed team member to work during their own work hours. If the tested idea generation methods show to be competitive compared to idea generation methods using synchronous communication, the benefits of having less meetings and decoupling schedules can be carried over to collocated teams. Three examples for idea generation methods using asynchronous communication are electronic brainstorming, c-sketch and the modified method 635 as presented in this thesis. The incubation period in engineering design also offers ample opportunity for future research. The duration of the incubation period, the number of incubation periods per design problem, the influence of different activities during the incubation period, and the motivation and engagement of a participant solving a design problem are just some factors that need to be scrutinized. Then, if methods with different outcomes such as key words (e.g. brainstorming) and detailed sketches (e.g. modified method 635) are compared, the evaluation methods should be optimized to accompany different levels of solutions or the experiments should be modified to lead to results on one level.

The effective serial team work in the VirtualCFD experiment and the successful idea generation sessions of the distributed teams in the dDesign experiment allow the conclusion that globally distributed teams can work efficiently together, using only information technology widely available today. This indicates a promising future for globally distributed teams, making them a possible success factor in the global marketplace for worldwide operating companies.

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APPENDIX A

Appendix A contains the summarized interview results of the Virtual CFD experiment.

1.	**What do you think about the experiment?** Interesting, challenging & adequate. Learned a lot Pretty effective to simulate real world; Problems with StarCD/ VNC crashing 30 min handshake worked well Got easier with each session (to take over others work) Should have gotten problem statement 1 day in advance to prepare (without discussion, just to read it & understand) Pretty Good, liked it. 2 hours work time are a little short, it took me more than 30 min to get into the problem and follow what my colleagues did Error finding by other person was really good Fairly well – good workflow Combined minds – one person lacking, one person knows more
2.	**Do you feel the overall process was efficient?** Yes Learned about the software Some kind of initial meeting to lay down basic rules, or appoint one person who lays down rules for all Yes & No Open ended problem – hard to say compared to example a defined math problem For the most part Only a few cases were something was done double
*3.	**How would you evaluate your team's performance?** Surpassed my expectations as to get a solution Really good Thursday: (we) solved first case Friday: (we solved) all other cases Very efficient, very good progress No project to compare it to Not sure how to rate it
4.	**How do you feel about your participation in the experiment?** Crucial Crappy 1st day 2nd day good biggest input, guided the team I liked it. I set up the first case file Pointed out some errors, some errors got pointed out by others Good sharing of knowledge Enjoyed it I may have been lacking in knowledge, but I was still able to influence the overall process

*5.	**Did you feel like you had the ability to make decision regarding the project?** Yes, when I was working. Yes A yes, definitely. Others used my case file. Yeah We all had the ability and opportunities at various times Few decisions were changed later by someone else (mainly because they turned out to be wrong, not at random)
*5.a	**Did you feel included in the decision making process?** Yes Yes, definitely. Others used my case file. Yes, took input here and then
6.	**How did you feel about working without the guidance of a team leader?** Good. I like to work independently. Probably more mistakes because there was none. I was insecure during the first session, it was the hardest session. I would be happier to have someone to ask besides my team mates. May have helped It was manageable For a harder project probably beneficial
7.	**Did you miss the interactions of working in a collocated team?** Not so much. No. A little I cannot ask a question right here and then, have to wait for an opinion
*8.	**Based on you experience, do you think CFD projects are suitable for distributed teams?** Yes, probably. Streamlined process Hard for something (topic, problem) that is very new Professional would/ could do it easily, because they have lots of experience, so it would be effective. They are more sure of how things can be done in the software. I think so.
*9.	**Do you think the handshake was efficient?** Yes Pretty efficient Shared screen – very good to point out things Audio Video conference did not seem necessary
9a	**What did you find annoying?** StarCD in combination with VNC – crashed a few times. Mouse-pointer is invisible on second screen – sometimes not able to see what the other person is showing (pointing to a specific part of the structure on the screen) Nothing. Overall, pretty good. Easier telephone conference with less clicks (participants needed to lock into email, start conference from link within emails, program would start, enter email dress …)

9.b	**What worked really well for you?** The problem See the work of predecessor (screen sharing) very good. Direct talking Shared screen was important communication
10.	**What would you suggest as handshake procedure for future experiments?** It worked well. Visible mouse pointer Writing notes was good – helps even the person taking the notes to trace his own steps back – often neglected when working alone Perhaps increase time limit of work time Pretty Good. Time frame was good.
11.	**Were you comfortable using the different software programs?** No problem Yes. I missed my mouse. (thought the one in the room did not work too well, but did not say anything, so it was probably no big thing) Yes.
11.a	**Was there one you liked a lot or one you did not like to use?** No. Crashes of StarCD – take time away All ok.
12.	**Were you comfortable following the procedures during the experiment?** Yes. Yes, absolutely.
12.a	**Were the procedures explained well before the experiment?** Yes, no ambiguities Liked to have had the problem statement in advance. Everything was taken care of, well organized. Straight forward, good documentation, well worked out, well laid out
13	**Was the training session before the start of the experiment beneficial to you?** Clearly yes. Yes. Definitely yes.
13.a	**Why?** % The VNC Introduction – had not used before. Seeing it (the programs/ software) in advance was really good
13.b	**What was good about, what should be improved?** Everything was ok. Was sufficient All ok

14.	**Did you have the urge to undo your predecessor's work at any point? Please explain.** Not too much – disagreement on physical input – would probably do myself, try something to change it (-> change settings until things fit, not because someone else did them) Only because of errors. No.
15.	**Is there anything you would like to add regarding the experiment? Any suggestions, critique or ideas?** No. Increase work time, because it takes time to look at the others' work Not sure how efficient virtual teams are for open ended problems, as there are many approaches to solve them. No. Sometimes (the work time was) not long enough to see results of runs.

APPENDIX B

Appendix B contains the following materials of the pilot study:

- Participant Instructions Condition A (Brainstorming Distributed)
- Experimenter Script Condition A (Brainstorming Distributed)
- Participant Instructions Condition B (Modified Method 635 Distributed Synchronous)
- Experimenter Script Condition B (Modified Method 635 Distributed Synchronous)
- Participant Instructions Condition C (Modified Method 635 Distributed Time-Delayed)
- Experimenter Script Condition C (Modified Method 635 Distributed Time-Delayed)
- Participant Instructions Condition D (Brainstorming Collocated)
- Experimenter Script Condition D (Brainstorming Collocated)
- Participant Instructions Condition E (Modified Method 635 Collocated Synchronous)
- Experimenter Script Condition E (Modified Method 635 Collocated Synchronous)
- Participant Instructions Condition F (Modified Method 635 Collocated Time-Delayed)
- Experimenter Script Condition F Modified Method 635 Collocated Time-Delayed)

Pilot Study: Participant Instructions Condition A (Brainstorming Distributed)

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Method: Brainstorming

You and your teammates will brainstorm ideas for a given design problem in a distributed team. One member of your team will be the note taker. That person will capture in key words the essence of the ideas verbally developed by the team. Your team will have 45 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to recap the given design problem or to have the note taker repeat some of the ideas already developed.

- One note taker
- 45 minutes

As you are simulating a distributed team, you will not be in the same physical environment as your teammates. You will communicate using Saba Centra, a PC application that enables voice and picture submission as well as to share a desktop.

Appendix Figure 1 Pilot study participant instructions condition A page 1 of 2

Participant Instructions dDesign A

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task

- Generate as many solutions as possible in the allotted time using brainstorming for the given design problem.
- Tell your teammates about your ideas, even if they do not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.
- Try to be as clear as possible with your verbal description.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

- 2 –

Appendix Figure 2 Pilot study participant instructions condition A page 2 of 2

Pilot Study: Experimenter Script, Condition A (Brainstorming Distributed)

1. Preparation for the experiment

☐ Computers are set up (www) & running
- □ 2 in the experiment room with a divider in between
- □ 2 in the lab under the pipe, small divider in between
- □ IDREEM1 to monitor and give instructions

☐ Screens are set up, working & calibrated

☐ Saba Centra is up, all computers are in a session, all microphones are locked to talk

☐ Headsets (5) are distributed and have been tested to work

☐ Tablet pens are on right upper side of screen:
A B C D

☐ Camtasia is running on machine:
A B C D

☐ OneNote is running on machine:
A B C D

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
A B C D

☐ Participant instructions (minimum 4 copies) under drawing template

☐ Stop watch

☐ First one to come through door will be participant 1:
1st -> P1 ____
2nd ->P2 ____
3rd -> P4 ____
4th -> P3____

☐ Randomly assign participants to screens:
P1 ->Screen C; P2 -> Screen A; P3 -> Screen D; P4 -> Screen B

☐ Who will be the note taker?
P1

☐ Stop watch at hand

2. Consent

a) Read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.

You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be voice recorded and screen recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours.

Please go ahead and read the consent form. Let me know if you have any questions about the experiment.

If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off your cell phones."**

"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.

This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, I will guide you to your workstations. "

Go to one workstation in room and have respective participant sit down. Explain Saba Centra.

4. Saba Centra exploration

"Today you will simulate a geographically distributed team. Therefore, your method of communication for your team meeting will be a telephone conference. The software you will be using is called Saba Centra. It is already ready on your computers. Please pick up the headsets and adjust them so they fit comfortably. Then go ahead and adjust the volume of the headphones and the microphone by clicking on "Audio Wizard", a headset symbol, in the top toolbar and following the directions. You can adjust the general volume of your headset by using the wheel next to the left ear cushion. You can further adjust the volume by using the sliders on the upper left of the screen next to microphone and headset symbols.
I will guide you to your respective workplaces and now. Please put on the headset and adjust it. I will join in the conference, too, so that you will receive further instructions over the telephone conference system."

5. Screen exploration

Make all following announcements through Saba Centra, so that each participant can hear you.

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.
You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space. To change the angle of the screen, press the two black levers in the back and adjust its angle.
To become familiar with the pen display please start to sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this.

I'll let you know when the time is up.
If you have any questions, please ask. I will be going around to make sure there are no technical difficulties with the system.
After the 7 minutes are up:
"The time is up. Please use the end of your pen to erase everything you sketched."

6. Experiment description

a. Read the following statement:
"Please look at the instructions, underneath the picture of the Coca Cola Bottle. Does everybody have a copy of the instructions?
This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using Brainstorming in a distributed team. The time allotted for this will be 45 minutes."

b. Method (brainstorming) description; Read the following statement:
"The idea generation method you will be using is brainstorming in a distributed team. You and your teammates will brainstorm ideas for a given design problem. One member of your team has randomly been chosen to be the note taker. That person will capture in keywords the essence of the ideas developed by your team.
Your will have 45 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to discuss the given design problem or to have the note taker repeat some of the ideas already developed. The note taker will be using the interactive pen display to capture the essence of the team's ideas. The note taker's desktop will be shared with you, so that each team member will be able to see the notes on the screen.

c. **P1, you have randomly been assigned to be the team note taker. You may also participate in the idea generation. The notes you take will be on your screen and on your team mates' screens, so everybody can see them. Please confirm the**

dialogue that opened on your screen to share your screen. Do you have any questions regarding your task?”

Answer questions if asked.

d. General instructions. Continue reading:

“Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainstorming for the given design problems.**
- **Tell your teammates about your ideas, even if they do not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wilde, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **Try to be as clear as possible with your verbal description.**

You will have 45 minutes to generate solutions to the design problem using brainstorming. You do not need to keep track of time; I will do that and give you a 5 minute warning before the time is up.

Your design problem is to develop a flavor composing device.

If you have any questions at any time during this experiment, please ask. I will be listening and go back and forth between the rooms a few times.

I will now read the design problem to you, please follow along. After I am done reading, I will start the time and you can go ahead and begin to generate ideas:

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new

dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.
Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.
The Customer Needs are:

- **Provide room for ten to twenty spices**
- **Easy to clean**
- **fit on a kitchen counter**
- **Needs to measure the amount of spice released.**

Go ahead, I'll start the time now."

e. Start stop watch

f. Give a warning after 40 minutes:
"You have 5 minutes left to finish you idea generation."

g. After 45 minutes are up please read: **"Thank you for your participation. Please do not discuss this experiment with your classmates until after December 31, 2009 since discussing the experiment will bias the data."**

h. Collect participants' instruction sheets, the participants should not take them with them. Save note taker's notes and recordings from session.

Pilot Study: Participant Instructions Condition B (Modified Method 635 Distributed and Synchronous)

Participant Instructions dDesign B

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Technique: Distributed Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem in a distributed setting. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, your sketches will be forwarded to one of your teammates. You will have 8 minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, your sketches will be forwarded to the next teammate. This will be repeated until everybody had a chance to work on everybody's' solutions. For four team members, that means three exchanges.

- 15 minutes to sketch initial design problem solutions
- Forward sketches
- 8 minutes to modify and add to your predecessor's solutions
- Forward sketches
- 8 minutes to modify …
- …repeat until each team member had a chance to work on everybody's initial ideas.

As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. Thus, after each time period it is necessary to save your sketch to a shared folder so that the next person can retrieve it from the location. Please wait for instructions.

- 1 -

Appendix Figure 3 Pilot study participant instructions condition B page 1 of 2

Participant Instructions dDesign B

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

- 2 -

Appendix Figure 4 Pilot study participant instructions condition B page 2 of 2

Pilot Study: Experimenter Script Condition B (Modified Method 635 Distributed and Synchronous)

1. Preparation for the experiment

☐ Computers are set up (www) & running - in the experiment room with 3 dividers in between

☐ Screens are set up, working & calibrated

☐ Tablet pens are on right upper side of screen: 1 2 3 4

☐ Camtasia is running on machine: 1 2 3 4

☐ OneNote is running on machine, team workbook is open, full page view:
1 2 3 4

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
A B C D

☐ Participant instructions (minimum 4 copies) positioned

☐ Stop watch

☐ First one to come through door will be participant 1:
1st -> PC ____
2nd ->PC ____
3rd -> PC ____
4th -> PC ____

☐ Stop watch at hand

2. Consent

a) Read the following statement:

“You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.
You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the

session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours. Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

b) Sign and collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Hello and thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, I will guide you to your workstations. "

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.

You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.

To change the angle of the screen, press the two black levers in the back and adjust its angle.

To become familiar with the pen display, please sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.

If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system."

After the 7 minutes are up:

"The time is up. Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

"Are there any questions before we begin?"

5. Experiment description

a. Make sure each participant has the participant instructions.

b. Read the following statement:

"This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. The time allotted for this about 45 minutes total, but other activities will fill the remaining time."

c. Method (brainwriting) description; Read the following statement:

“The idea generation method you will be using is brainwriting in a distributed team. You and your teammates will generate ideas using brainwriting for a given design idea while simulating to be in different physical environments. You and your team members will have a pen display each. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have 8 minutes to modify your predecessor’s solutions and to add anything you come up with. After the time is up, you will exchange sketches again. This will be repeated until everybody had a chance to work on everybody’s solution. For four team members, that means three exchanges.

- **15 minutes to sketch initial design problem solutions**
- **Forward sketches**
- **8 minutes to modify and add to your predecessor’s solutions**
- **Forward sketches**
- **8 minutes to modify …**
- **…repeat until each team member had a chance to work on everybody’s initial ideas.**

As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. No talking among you is allowed. I will guide you through the sketch exchange.
You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before each time period is up as well as the final call for each time period.
Do you have any questions regarding your task?”
Answer questions if asked.

d. General instructions. Continue reading:
“Please turn over the sheet.
While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problems.**

- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**

Your design problem is to develop a flavor composing device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it. In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes. Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

You can go ahead; I'll start the time now."

e. Initial time period:

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

"You have one minute left to finish the initial idea generation"

After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of**

the screen to go into tabbed view. Please open the tab one number smaller than your PC; PC 1 please open PC 4."

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

f. Second time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

*After 8*minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab two numbers smaller than your PC; PC 1 please open PC 3."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

g. Third time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab three numbers smaller than your PC; PC 1 please open PC 2."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

h. Fourth and Final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch. Please put the pan down. We will have a 5 minute break now. ”

Pilot Study: Participant Instructions Condition C (Modified Method 635 Distributed and Time Delayed)

Participant Instructions dDesign C

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Method: Distributed & Time Delayed Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem in a distributed and time-delayed setting. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, your sketches will be forwarded to one of your teammates. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.

In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session will complete the cycle, so that everybody had a chance to work on everybody's' solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (team mates, classmates, friends, family) as this may bias the results.

Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions.

As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. Thus, after each time period it is necessary to save your sketch to a shared folder so that the next person can retrieve it from the location. For your convenience the experiment attendant will perform this task.

1. Session:
   - 15 minutes to sketch initial design problem solutions
   - Forward Sketches
   - 8 minutes to modify and add to your predecessor's solutions
   - Think about the problem until the next session, but please do not discuss it with anybody!
2. Session:
   - 8 minutes to modify and add to your predecessor's solutions
   - Forward Sketches
   - 8 minutes to modify and add to your predecessor's solutions

- 1 -

Appendix Figure 5 Pilot study participant instructions condition C page 1 of 2

Participant Instructions dDesign C

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

- 2 -

Appendix Figure 6 Pilot study participant instructions condition C page 2 of 2

Pilot Study: Experimenter Script Condition C (Modified Method 635 Distributed and Time Delayed)

1. Preparation for the experiment (1st & 2nd session)

☐ Computers are set up (www) & running
  ▫ 4 in the experiment room with 3 dividers in between

☐ Screens are set up, working & calibrated

☐ Tablet pens are on right upper side of screen: 1 2 3 4

☐ Camtasia is running on machine: 1 2 3 4

☐ OneNote is running on machine, team workbook is open, full page view:
  1 2 3 4

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
  A B C D

☐ Participant instructions (minimum 4 copies) positioned

☐ First one to come through door will be participant 1:
1st -> PC ____
2nd ->PC ____
3rd -> PC ____
4th -> PC ____

☐ Stop watch at hand

2. Consent

a) Read the following statement:

“You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.

You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes

taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours total, one today and two at your next appointment. Please go ahead and read the consent form. Let me know if you have any questions about the experiment.
If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, I will guide you to your workstations. "

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.

You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.
To change the angle of the screen, press the two black levers in the back and adjust its angle.
To become familiar with the pen display, please sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.
If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system.
After the 7 minutes are up:
"The time is up.
Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."
Check all participants are opening the correct tab.
"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."
Check all participants are back to full page view.

5. Experiment description

a) Make sure each participant has the participant instructions.

b) Read the following statement:

"This study is seeking to evaluate different idea generation methods in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. The time allotted for this will be 45 minutes, but other activities will fill the remaining time."
Method (brainwriting) description; Read the following statement:

“The idea generation method you will be using is time delayed brainwriting . You and your teammates will generate ideas using brainwriting for a given design idea.

You and your teammates each have a pen display in front of you. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have 8 additional minutes to modify your predecessor’s solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.

In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session will complete the cycle, so that everybody had a chance to work on everybody’s’ solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (classmates, friends, family) in between sessions and until December 31, 2009 as this may bias the results.

Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions. As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. I will guide you through the sketch exchange.

You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before the time is up as well as the final call for each time period.

Do you have any questions regarding your task?”

Answer questions if asked.

Experimenter Script dDesign C

c) General instructions. Continue reading:

“Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problems.**

- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**

Your design problem is to develop a flavor composing device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

You can go ahead; I'll start the time now."

6. First Session

a) Initial time period:

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

"You have one minute left to finish the initial idea generation"

After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab one number smaller than your PC; PC 1 please open PC 4."**

Check if all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check if all participants are back to full page view.

b) Second time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch. We will continue in the next session."

Please read: **"Thank you for your participation. You are encouraged to think about the design problem in between sessions. But please do not discuss this experiment with your classmates or anybody else in between session and until after December 31, 2009 since discussing the experiment will bias the data. Your next session will take place on Weekday, Month, Day at Hour: Minutes"**

Print all tabs as .pdf. , Stop Camtasia, save all movies.

7. Second Session

a) Instruct participants to sit at the same table as last time. Make sure each participant has the participant instructions.

Third time period: Open the files in OneNote, two numbers smaller than PC number.

b) Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the initial idea generation"

After 8 minutes: **“Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab three numbers smaller than your PC; PC 1 please open PC 2.”**

Check if all participants are opening the correct tab.

“Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help.”

Check if all participants are back to full page view.

c) Fourth and Final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch.”

We will have a 5minute break now.

Print all tabs as .pdf.

Pilot Study: Participant Instructions Condition D (Brainstorming Collocated)

Participant Instructions dDesign D

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Method: Brainstorming

You and your teammates will brainstorm ideas for a given design problem. One member of your team will be the note taker. That person will capture in key words the essence of the ideas verbally developed by the team. Your team will have 45 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to recap the given design problem or to have the note taker repeat some of the ideas already developed.

- One note taker
- 45 minutes

- 1 –

Appendix Figure 7 Pilot study participant instructions condition D page 1 of 2

Participant Instructions dDesign D

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task:

- Generate as many solutions as possible in the allotted time using brainstorming for the given design problem.
- Tell your teammates about your ideas, even if they do not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.
- Try to be as clear as possible with your verbal description.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

- 2 –

Appendix Figure 8 Pilot study participant instructions condition D page 2 of 2

Pilot Study: Experimenter Script Condition D (Brainstorming Collocated)

1. Preparation for the experiment

☐ Computers are set up & running

☐ Screens are set up, working & calibrated

☐ Microphone installed, tested & working on round table machine

☐ Projector is set up and ready

☐ Tablet pens are on right upper side of screen: A B C D

☐ Camtasia is running on machine: A B C D

☐ OneNote is running on machine: A B C D

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
A B C D

☐ Participant instructions (minimum 4 copies) to hand out after drawing exercise

☐ Stop watch

☐ First one to come through door will be participant 1:
1st -> PC ____
2nd ->PC ____
3rd -> PC ____
4th -> PC ____

☐ Who will be the note taker?
Student #

☐ Stop watch at hand

2. Consent

a) Read the following statement:

"You are being asked to participate in a research study on engineering design.

Please read the consent form located in front of you on the table. You are not required to participate in this study and you may end your participation at any time.
You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be voice recorded and screen-recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours.
Please go ahead and read the consent form. Let me know if you have any questions about the experiment.
If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off your cell phones."**
"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, please go to the workstations numbered according to your participant number."

4. Screen exploration

“For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.
You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.
To change the angle of the screen, press the two black levers in the back and adjust its angle.
To become familiar with the pen display please start to sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this.
Are there any questions?”
After the 7 minutes are up:
“The time is up. Please use the end of your pen to erase everything you sketched. Please come back to the round table and have a seat. XYZ, please change seats with LMN. ”

5. Experiment description

a. Hand out the ***participant instructions (2 sheets – method on top, instructions below)*** to each participant. Make sure each participant has the required material.

b. Read the following statement:
“This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using brainstorming. The time allotted for this will be 45 minutes.

c. Method (brainstorming) description; Read the following statement:
“The idea generation method you will be using is brainstorming. You and your teammates will brainstorm ideas for the given design idea. One member of your team has randomly been chosen to be the note taker. That person will capture in

keywords the essence of the ideas developed by the team. Your team will have 45 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to discuss the given design problem or to have the note taker repeat some of the ideas already developed. The note taker will be using the interactive pen display to capture the essence of the team's ideas.

d. **P3, you have randomly been assigned to be the team note taker. You may also participate in the idea generation. The notes you take will be on your screen and projected to the back wall, so you all can see them. Do you have any questions regarding your task?"**
Answer questions if asked.

e. General instructions. Continue reading:
"Please turn over the sheet.
While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainstorming for the given design problems.**
- **Tell your teammates about your ideas, even if they do not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wilde, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**
- **Try to be as clear as possible with your verbal description.**

You will have 45 minutes to generate solutions to the design problem using brainstorming. You do not need to keep track of time; I will do that and give you a 5 minute warning before the time is up.
Your design problem is to develop a flavor composing device.
If you have any questions at any time during this experiment, please ask.
I will now read the design problem to you, please follow along. After I am done reading, I will start the time and you can go ahead and begin to generate ideas:

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

The Customer Needs are:

- **Provide room for ten to twenty spices**
- **Easy to clean**
- **fit on a kitchen counter**
- **Needs to measure the amount of spice released.**

Go ahead; I'll start the time now."

f. Start stop watch.

g. Give a warning after 40 minutes:

"You have 5 minutes left to finish you idea generation."

h. After 45 minutes are up read: **"The time is up. Please put your pens down. Thank you for your participation. Please do not discuss this experiment with your classmates until after December 31, 2009 since discussing the experiment will bias the data."**

i. Collect participant instruction sheets, the participants should not take them with them.

j. Save not takers notes, download Saba Centra file.

Pilot Study: Participant Instructions Condition E (Modified Method 635 Collocated and Synchronous)

Participant Instructions dDesign E

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Method: Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, each team member will get up and move one screen in clockwise direction. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, you will move to the next screen in clockwise direction again. This will be repeated until everybody had a chance to work on everybody's' solutions. For four team members, that means three exchanges. Brainwriting is a non-verbal idea generation process – no talking is allowed.

- 15 minutes to sketch initial design problem solutions
- Move clockwise
- 8 minutes to modify and add to your predecessor's solutions
- Move clockwise
- 8 minutes to modify …
- …repeat until each team member had a chance to work on everybody's initial ideas.
- No talking.

- 1 -

Appendix Figure 9 Pilot study participant instructions condition E page 1 of 2

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task:

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes.

Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

Appendix Figure 10 Pilot study participant instructions condition E page 2 of 2

Pilot Study: Experimenter Script Condition E (Modified Method 635 Collocated and Synchronous)

1. Preparation for the experiment

☐ Computers are set up (www) & running

☐ Screens are set up, working & calibrated

☐ Tablet pens are on right upper side of screen: 1 2 3 4

☐ Camtasia is running on machine: 1 2 3 4

☐ OneNote is running on machine, team workbook is open, full page view:
1 2 3 4

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
A B C D

☐ Participant instructions (minimum 4 copies) positioned

☐ Stop watch

☐ First one to come through door will be participant 1:

1st -> PC ____
2nd ->PC ____
3rd -> PC ____
4th -> PC ____

☐ Stop watch at hand

2. Consent

a) Read the following statement:

“You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.

You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the

session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours. Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

b) Sign and collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Hello and thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, I will guide you to your workstations. "

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.
You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.

To change the angle of the screen, press the two black levers in the back and adjust its angle.

To become familiar with the pen display please sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.

If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system."

After the 7 minutes are up:

"The time is up.

Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

5. Experiment description

a. Make sure each participant has the participant instructions.

b. Read the following statement:

"This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. The time allotted for this is about 45 minutes total, but other activities will fill the remaining time."

c. Method (brainwriting) description; Read the following statement:

"The idea generation method you will be using is brainwriting. You and your teammates will generate ideas using brainwriting for a given design idea while simulating to be in different physical environments.

You and your team members will have a pen display each. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have

8 minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, you will exchange sketches again. This will be repeated until everybody had a chance to work on everybody's solution. For four team members, that means three exchanges.

You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before each time period is up as well as the final call for each time period.

Do you have any questions regarding your task?"

Answer questions if asked.

d. General instructions. Continue reading:

"Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problems.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing. Your design problem is to develop a flavor composing device.**

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.
In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes. Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

You can go ahead; I'll start the time now."

e. Initial time period:
Start stop watch, *set to 15* minutes.
Give a *warning after 14* minutes:
"You have one minute left to finish the initial idea generation"
After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab one number smaller than your PC; PC 1 please open PC 4."**
Check all participants are opening the correct tab.
"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."
Check all participants are back to full page view.

f. Second time period:
Start stop watch, *set to 8* minutes.
Give a *warning after 7* minutes:
"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab two numbers smaller than your PC; PC 1 please open PC 3."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

g. Third time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab three numbers smaller than your PC; PC 1 please open PC 2."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

h. Fourth and Final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch. Please put the pan down. We will have a 5 minute break now. "

Pilot Study: Participant Instructions Condition F (Modified Method 635 Collocated and Time Delayed)

Participant Instructions dDesign F

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Idea Generation Method: Time Delayed Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem in a time-delayed setting. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, each team member will get up and move one screen in clockwise direction. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.

In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session will complete the cycle, so that everybody had a chance to work on everybody's' solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (team mates, classmates, friends, family) as this may bias the results.

Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions.

1. Session:
   - 15 minutes to sketch initial design problem solutions
   - Move clockwise
   - 8 minutes to modify and add to your predecessor's solutions
   - Think about the problem until the next session, but please do not discuss it with anybody!
2. Session:
   - 8 minutes to modify and add to your predecessor's solutions
   - Move clockwise
   - 8 minutes to modify and add to your predecessor's solutions

1

Appendix Figure 11 Pilot study participant instructions condition F page 1 of 2

Participant Instructions dDesign F

Please do not discuss this problem with your classmates or anybody else until after December 31, 2009.

Task

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

- 2 -

Appendix Figure 12 Pilot study participant instructions condition F page 2 of 2

Pilot Study: Experimenter Script Condition F (Modified Method 635 Collocated and Time Delayed)

1. Preparation for the experiment (1st & 2nd session)

☐ Computers are set up (www) & running (4 in the experiment room in diamond shape)

☐ Screens are set up, working & calibrated

☐ Tablet pens are on right upper side of screen: 1 2 3 4

☐ Camtasia is running on machine: 1 2 3 4

☐ OneNote is running on machine, team workbook is open, full page view:
1 2 3 4

☐ Consent forms (minimum 4 copies) on round table

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Drawing template (minimum 4 copies) positioned on left lower side of screen
A B C D

☐ Participant instructions (minimum 4 copies) positioned

☐ Random assignment done

☐ First one to come through door will be participant 1:
1st -> PC ____
2nd ->PC ____
3rd -> PC ____
4th -> PC ____

☐ Stop watch at hand

2. Consent

a) Read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.
You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the

session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours total, one today and two at your next appointment. Please go ahead and read the consent form.
Let me know if you have any questions about the experiment.
If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
"Your effort will be compensated either with extra credit in your design class or a gift card or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2009 since this will bias the results. Your participation is voluntary. Are there any questions before we begin? Then, I will guide you to your workstations. "

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.

You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.
To change the angle of the screen, press the two black levers in the back and adjust its angle.
To become familiar with the pen display please sketch a Coca Cola bottle. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up. If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system.
After the 7 minutes are up:
"The time is up.
Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."
Check if all participants are opening the correct tab.
"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."
Check if all participants are back to full page view.

5. Experiment description

a. Make sure each participant has the participant instructions.

b. Read the following statement:
"This study is seeking to evaluate different idea generation methods in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. You will have time to read the instructions and then the time allotted for this first session will be approximately 25 minutes."
c. Method (brainwriting) description; Read the following statement:

“The idea generation method you will be using is time delayed brainwriting. You and your teammates will generate ideas using brainwriting for a given design idea.
You and your teammates each have a pen display in front of you. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have 8 additional minutes to modify your predecessor’s solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.
In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session will complete the cycle, so that everybody had a chance to work on everybody’s’ solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (team mates, friends, family) in between sessions and until December 31, 2009 as this may bias the results.
Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions.
You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before the time is up as well as the final call for each time period.
Do you have any questions regarding your task?”
Answer questions if asked.

d. General instructions. Continue reading:
“Please turn over the sheet.
While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problems.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**

- **Wilde, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**

Your design problem is to develop a flavor composing device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

Many young people have not learned to cook while growing up and feel overwhelmed by the many steps that go into preparing a dish from scratch. One specific pitfall is the flavoring of a dish. The wrong amount or combination of spices can ruin it.

In addition, more experienced cooks would like to venture out and start cooking a more diverse set of dishes. They are looking for assistance in flavoring these new dishes – for example, for an American cook, these could be Indian, Chinese, Italian or Mexican dishes. Therefore your task is to develop the mechanical aspect of a flavor composing device - a device that automatically measures, combines and dispenses spices.

Customer Needs:

- Room for ten to twenty spices
- Easy to clean
- Has to fit on a kitchen counter
- Needs to measure the amount of spice released

You can go ahead; I'll start the time now."

6. First Session

e. Initial time period:

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

"You have one minute left to finish the initial idea generation"

After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab one number smaller than your PC; PC 1 please open PC 4."**

Check if all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check if all participants are back to full page view.

f. Second time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch. We will continue in the next session.”

Please read: **“Thank you for your participation. You are encouraged to think about the design problem in between sessions. But please do not discuss this experiment with your classmates or anybody else in between session and until after December 31, 2009 since discussing the experiment will bias the data. Your next session will take place on Weekday, Month, Day at Hour: Minutes”**

Print all tabs as .pdf. Stop Camtasia, save all movies

7. Second Session

a. Instruct participants to sit at the same table as last time. Make sure each participant has the participant instructions.

Third time period: Open the files in OneNote, two numbers smaller than PC number.

b. Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the initial idea generation”

After 8 minutes: **“Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab three numbers smaller than your PC; PC 1 please open PC 2.”**

Check all participants are opening the correct tab.

“Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help.”

Check all participants are back to full page view.

c. Fourth and Final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch.”

We will have a 5minute break now.

Print all tabs as .pdf.

APPENDIX C

Appendix C contains documents relevant to the low control study, namely:

- Participant Instructions (identical in College Station and Qatar)
- Experimenter Script (Qatar version)
- Experimenter Script (College Station version)

Low Control Study: Participant Instructions (identical in College Station and Qatar)

Participant Instructions dDesign C

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Idea Generation Method: Distributed & Time Delayed Brainwriting

You and your teammates will perform a brainwriting to develop ideas for your team's design problem in a distributed and time-delayed setting. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, your sketches will be forwarded to one of your teammates. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.

In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange, and depending on your team size a third exchange, during your second session will complete the cycle, so that everybody had a chance to work on everybody's' solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (team mates, classmates, friends, family) as this may bias the results.

Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions.

As you are working in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. Thus, after each time period the experiment attendant will exchange the sketches.

1. Session:
    - 15 minutes to sketch initial design problem solutions
    - Forward Sketches
    - 8 minutes to modify and add to your predecessor's solutions
    - Think about the problem until the next session, but please do not discuss it with anybody!
2. Session:
    - 8 minutes to modify and add to your predecessor's solutions
    - Forward Sketches
    - 8 minutes to modify and add to your predecessor's solutions
    - Forward Sketches
    - 8 minutes to modify and add to your predecessor's solutions

- 1 -

Appendix Figure 13 Low control study participant instructions page 1 of 2

Participant Instructions dDesign C

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Task

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

- 2 -

Appendix Figure 14 Low control study participant instructions page 2 of 2

Low Control Study: Experimenter Script (Qatar version)

1. Preparation for the experiment (1st & 2nd session)

☐ Consent forms, one copy for each student

☐ Information Sheets, one copy for each student

☐ Pens, one of each color for each participant
- Black
- Blue
- Red (2nd session, Car Team)
- Green, (2nd session, Car Team)

☐ Participant instructions (minimum 4 copies) positioned

☐ Labeled sketch paper

2. Consent

a) Read the following statement:
"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time. You will be asked to complete a series of tasks. You will be asked to generate ideas for your design problem. Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms. Information sheets to remain with students.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your

teammates, friends, family- until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?

4. Experiment description

a) Make sure each participant has the participant instructions. (2 pages)

b) Read the following statement:

Method (brainwriting) description; Read the following statement:

"Your task today is to generate as many ideas as possible for your design problem using time delayed brainwriting. You and your teammates will generate ideas using brainwriting for a given design idea.

You and your teammates each have a piece of paper and pens in front of you. You will have 15 minutes to sketch possible solutions to the design problem. Aim for 3 initial ideas. After that time period, sketches and pens will be exchanged. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled. In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session will complete the cycle, so that everybody had a chance to work on everybody's solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (classmates, friends, family) in between sessions and until December 31, 2010 as this may bias the results. Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions. As you are working in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. I will guide you through the sketch exchange.

You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before the time is up as well as the final call for each time period.

Do you have any questions regarding your task?"

Answer questions if asked.

c) Instructions. Continue reading:

“Please turn over the sheet. And look at the second page.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing. Your design problem is your team’s design problem.**

Do you have any questions?

You can go ahead; I’ll start the time now.”

5. First Session

a) Initial time period: BLACK PENS

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

“You have one minute left to finish the initial idea generation”

After 15 minutes: **“Please stop working on your sketch. Dr C., please exchange the sketches and pens.**

b) Second time period: BLUE PENS

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch. We will continue in the next session.”

Please read: **“Thank you for your participation. You are encouraged to think about the design problem in between sessions. But please do not discuss this**

experiment with your classmates or anybody else in between session and until after December 31, 2010 since discussing the experiment will bias the data. Your next session will take place on Weekday, Month, Day at Hour: Minutes"

6. Second Session

a) Instruct participants to sit at the same table as last time. Make sure each participant has

the participants' instructions.

Dr C. distributes Pens and sheets before the start of the experiment and advises students were to sit.

"Welcome back. You can go ahead and start the idea generation. I'll start the time now."

b) Start stop watch, *set to 8* minutes. BLACK PENS; CAR TEAM: GREEN PENS

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. Dr C., please exchange the sketches.**

c) Fourth time period: BLUE PENS: CAR TEAM: RED

Please go ahead; I'll start the time now

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch."

Thank you very much for your participation. I will email you, or Dr C. will email you, the final solutions created by your team.

Low Control Study: Experimenter Script (College Station)

1. Preparation for the experiment (1st & 2nd session)

☐ Consent forms (minimum 4 copies) on round table, already signed by me

☐ Information Sheets (minimum 4 copies) on round table under consent sheet

☐ Pens (minimum 5) one on each consent sheet

☐ Participants instructions (minimum 4 copies) positioned,

☐ Stop watch at hand

2. Consent

a) Read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.

You will be asked to complete a series of tasks. You will be asked to generate ideas for your design problem. Please go ahead and read the consent form. Let me know if you have any questions about the experiment.

If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**

This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?"

4. Experiment description

a) Make sure each participant has the participant instructions.

b) Read the following statement:

"Your task today is to generate as many ideas as possible for your design problem using a specified design method.

Method (brainwriting) description 1st page; Read the following statement:

"The idea generation method you will be using is time delayed brainwriting. You and your teammates will generate ideas using brainwriting for a given design idea. You and your teammates each have a piece of paper and pens in front of you. You will have 15 minutes to sketch possible solutions to the design problem. Aim for 3 initial ideas. After that time period, sketches and pens will be exchanged. After a short break, you will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After this second time period you will have a break, its length depending on when your next session is scheduled.

In the second session, you will pick up where you left, working on the next set of design ideas. A second exchange during your second session, will complete the cycle, so that everybody had a chance to work on everybody's' solutions. You are encouraged to think about the problem in between the two sessions but please do not discuss this problem with anybody (classmates, friends, family) in between sessions and until December 31, 2010 as this may bias the results.

Brainwriting is a non-verbal idea generation process – No talking is allowed during sessions. As you are working in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. I will guide you through the sketch exchange.

You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before the time is up as well as the final call for each time period.

Do you have any questions regarding your task?"

Answer questions if asked.

c) General instructions, 2nd page. Continue reading:

“Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**

Your design problem is your teams design problem.

5. First Session

Distribute papers and purple pens.

“Please go ahead now and start the idea generation, I will start the time now.”

a) Initial time period: PURPLE PENS

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

“You have one minute left to finish the initial idea generation”

After 15 minutes: **“Please stop working on your sketch. You will have a short break, as I need to scan in and print one solution. Please Do not talk, but think in silence about the design problem.”**

“Please go ahead and start now, you will have 8 minutes.”

b) Second time period: PINK PENS

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch. We will continue in the next session.”

Please read: **"Thank you for your participation. You are encouraged to think about the design problem in between sessions. But please do not discuss this experiment with your classmates or anybody else in between session and until after December 31, 2010 since discussing the experiment will bias the data. Your next session will take place on Weekday, Month, Day at Hour: Minutes"**

6. Second Session

a) Instruct participants to sit at the same table as last time. Make sure each participant has the participants' instructions.

You can go ahead; I'll start the time now."

b) Start stop watch, *set to 8* minutes. BLACK PENS;

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. Dr C., please exchange the sketches.**

c) Fourth time period: BLUE PENS;

Please go ahead, I'll start the time now

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch."

d) Fifth time period*: 5 person TEAM only*: GREEN PENS

Please go ahead, I'll start the time now

Start stop watch, *set to 8* minutes.

Give a *warning after 7*minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch."

Thank you very much for your participation. I will email you, or Dr C. will email you, the final solutions created by your team.

APPENDIX D

Appendix D contains the following materials relevant to the final study:

- Participant Instructions Condition A (Brainstorming Distributed)
- Experimenter Script Condition A (Brainstorming Distributed)
- Participant Instructions Condition B (Modified Method 635 Distributed Synchronous)
- Experimenter Script Condition B (Modified Method 635 Distributed Synchronous)
- Participant Instructions Condition D (Brainstorming Collocated)
- Experimenter Script Condition D (Brainstorming Collocated)
- Participant Instructions Condition E (Modified Method 635 Collocated Synchronous)
- Experimenter Script Condition E (Modified Method 635 Collocated Synchronous)

Final Study: Participant Instructions Condition A (Brainstorming Distributed)

Participant Instructions dDesign A

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Idea Generation Method: Brainstorming

You and your teammates will brainstorm ideas for a given design problem in a distributed team. One member of your team will be the note taker. That person will capture in key words the essence of the ideas verbally developed by the team. Your team will have 35 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to recap the given design problem or to have the note taker repeat some of the ideas already developed.

- One note taker
- 35 minutes

As you are simulating a distributed team, you will not be in the same physical environment as your teammates. You will communicate using Saba Centra, a PC application that enables voice and picture submission as well as to share a desktop.

- 1 –

Appendix Figure 15 Final study participant instructions condition A page 1 of 2

Participant Instructions dDesign A

<u>Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.</u>

Task

- Generate as many solutions as possible in the allotted time using brainstorming for the given design problem.
- Tell your teammates about your ideas, even if they do not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.
- Try to be as clear as possible with your verbal description.

Design Problem

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

- 2 –

Appendix Figure 16 Final study participant instructions condition A page 2 of 2

Final Study: Experimenter Script Condition A (Brainstorming Distributed)

1. Preparation for the experiment

☐ Computers are set up (www) & running
- ◻ 1 in the experiment room with a divider in between
- ◻ 1 in the lab under the pipe
- ◻ 1 in the second lab
- ◻ IDREEM1 for experimenter

☐ Screens are set up, working & calibrated

☐ Saba Centra is up, all computers are in a session

☐ Headsets are distributed

☐ Tablet pens are on right upper side of screen

☐ Camtasia is running on machine

☐ OneNote is running on machine

☐ Consent forms (3) on table

☐ Information Sheets (3) on table under consent sheet

☐ Pens (3) one on each consent sheet

☐ Drawing template (3) positioned on left lower side of screen

☐ Participants instructions (3) positioned

☐ First one to come through door will be participant 1st:
1st -> PC 2nd ->PC 3rd -> PC

☐ Who will be the note taker? PC

☐ Stop watch at hand

2. Consent

a) Ask student to sit around table in experiment room and start reading consent forms.

b) Read the following statement:

“You are being asked to participate in a research study on engineering design.

Please read the consent form. You are not required to participate in this study and may end your participation at any time. You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be voice recorded and screen recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours.
Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

c) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off your cell phones."**
"Your effort will be compensated either with extra credit in your design class or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit.
This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?"

4. Saba Centra exploration

At Workstation in Experiment room, show Saba Centra to all:
"Today you will simulate a geographically distributed team. Therefore, your method of communication for your team meeting will be a telephone conference.

The software you will be using is called Saba Centra. It is already ready on your computers. Please pick up the headsets and adjust them so they fit comfortably. Then go ahead and adjust the volume of the headphones and the microphone by clicking on "Audio Wizard", a headset symbol, in the top toolbar and following the directions. You can adjust the general volume of your headset by using the wheel next to the left ear cushion. You can further adjust the volume by using the sliders on the upper left of the screen next to microphone and headset symbols. I will guide you to your respective workplaces and now. Please put on the headset and adjust it. I will join in the conference, too, so that you will receive further instructions over the telephone conference system."

Allow time for each participant to adjust headset.

5. Screen exploration

Make all following announcements through Saba Centra:

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.

You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.

To change the angle of the screen, press the two black levers in the back and adjust its angle.

To become familiar with the pen display, please sketch a Coca Cola bottle. There is an inspiring picture of one at your left. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.

If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system."

After the 7 minutes are up:

"The time is up. Are there any questions before we begin?"

Go around to each PC, and start the screen recording including voice recording now. Start the application sharing. Notetaker needs to share OneNote. Ask if all can see.

6. Experiment description

a) "Please take the instructions from the top left corner of your desk and look at page 1. Does everybody have a copy of the instructions? Ok.
This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using Brainstorming in a distributed team. The time allotted for this will be 35 minutes."

b) Method (brainstorming) description; Read the following statement:

"The idea generation method you will be using is brainstorming in a distributed team. You and your teammates will brainstorm ideas for a given design problem. One member of your team has randomly been chosen to be the note taker. That person will capture in keywords the essence of the ideas developed by your team.
Your will have 35 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to discuss the given design problem or to have the note taker repeat some of the ideas already developed. The note taker will be using the interactive pen display to capture the essence of the team's ideas. The note taker's desktop will be shared with you, so that each team member will be able to see the notes on the screen.

c) Px, you have randomly been assigned to be the team note taker. You may also participate in the idea generation. You are actually encouraged to do so. The notes you take will be on your screen and on your team mates' screens, so everybody can see them. Do you have any questions regarding your task?"
Answer questions if asked.

d) General instructions. Continue reading:

"Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainstorming for the given design problem.**
- **Tell your teammates about your ideas, even if they do not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **Try to be as clear as possible with your verbal description.**

You will have 35 minutes to generate solutions to the design problem using brainstorming. You do not need to keep track of time; I will do that and give you a 5 minute warning before the time is up.

Your design problem is to develop a peanut shelling device.

If you have any questions at any time during this experiment, please ask. I will be listening and go back and forth between the rooms a few times.

I will now read the design problem to you, please follow along. After I am done reading, I will start the time and you can go ahead and begin to generate ideas:

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Go ahead; I'll start the time now."

e) Start stop watch

f) Give a warning after 30 minutes:

“You have 5 minutes left to finish you idea generation.”

g) Collect participants’ instruction sheets, the participants should not take them with them. Save note taker’s notes and recordings from session.

Final Study: Participant Instructions Condition B (Modified Method 635 Distributed)

Participant Instructions dDesign B

<u>Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.</u>

Idea Generation Technique: Distributed Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem in a distributed setting. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, your sketches will be forwarded to one of your teammates. You will have 8 minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, your sketches will be forwarded to the next teammate. This will be repeated until everybody had a chance to work on everybody's' solutions. For three team members, that means two exchanges.

- 15 minutes to sketch initial design problem solutions
- Forward sketches
- 8 minutes to modify and add to your predecessor's solutions
- Forward sketches
- 8 minutes to modify

As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches, no talking is allowed. After each time period it is necessary to save your sketch to a shared folder so that the next person can retrieve it from the location. Please wait for instructions.

Appendix Figure 17 Final study participant instructions condition B page 1 of 2

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Task

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Appendix Figure 18 Final study participant instructions condition B page 2 of 2

Final Study: Experimenter Script Condition B (Modified Method 635 Distributed)

1. Preparation for the experiment

- ☐ Computers are set up (www) & running
  - ◻ 4 in the experiment room with 3 dividers in between
- ☐ Screens are set up, working & calibrated
- ☐ Mouse, Keyboard stowed.
- ☐ Tablet pens are on right side of screen
- ☐ Camtasia is running on PCs
- ☐ OneNote is running on PCs, team workbook is open, full page view, Y on pages
- ☐ Consent Forms (3 copies)
- ☐ Information Sheets (3 copies)
- ☐ Pens (4)
- ☐ Participants instructions (4 copies) positioned
- ☐ PC Assignment: First one to come through door will be participant 1st:
  1st -> PC 2nd ->PC 3rd -> PC
- ☐ Stop watch at hand

2. Consent

a) Guide students to workstations as they come in, ask them to start reading consent form.

b) After all participants have arrived, read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.

You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes

taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours. Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

c) Sign and collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Hello and thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**
"Your effort will be compensated either with extra credit in your design class or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit. This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family– until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?"

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.
You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.
To change the angle of the screen, press the two black levers in the back and adjust its angle.

To become familiar with the pen display, please sketch a Coca Cola bottle. There is an inspiring picture of one at your left. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.
If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system."
After the 7 minutes are up:
"The time is up.
Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."
Check all participants are opening the correct tab.
"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help. I will start the screen recording now."
Go around to each PC, and start the screen recording now.
Check all participants are back to full page view
"Are there any questions before we begin?"

5. Experiment description

a) **"Please take the instructions from the top left corner of your desk and look at page 1."** Make sure each participant has the participant instructions.

b) Read the following statement:

"This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. The time allotted for this about 35 minutes total, but other activities will fill the remaining time."

c) Method (brainwriting) description; Read the following statement:

“The idea generation method you will be using is brainwriting in a distributed team. You and your teammates will generate ideas using brainwriting for a given design problem while simulating to be in different physical environments.
You and your team members will have a pen display each. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have 8 minutes to modify your predecessor’s solutions and to add anything you come up with. After the time is up, you will exchange sketches again. This will be repeated until everybody had a chance to work on everybody’s solution. For three team members, that means two exchanges.

- **15 minutes to sketch initial design problem solutions**
- **Forward sketches**
- **8 minutes to modify and add to your predecessor’s solutions**
- **Forward sketches**
- **8 minutes to modify**

As we are simulating work in a distributed team, you and your teammates will only be able to interact through the exchanged sketches. No talking among you is allowed. I will guide you through the sketch exchange.
You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before each time period is up as well as the final call for each time period.
Do you have any questions regarding your task?”
Answer questions if asked.

d) General instructions. Continue reading:

“Please turn over the sheet.
While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**

- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**

Your design problem is to develop a peanut shelling device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

1. Must remove the shell with minimal damage to the peanuts.
2. Electrical outlets are not available as a power source.
3. A large quantity of peanuts must be quickly shelled.
4. Low cost.
5. Easy to manufacture.

You can go ahead; I'll start the time now."

e) Initial time period:

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

"You have one minute left to finish the initial idea generation"

After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab one number bigger than your PC."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

f) Second time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab two numbers smaller than *your PC."***

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

g) Third and final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

Stop second idea generation process

"Please stop working on your sketch. Please put the pen down. You will have a 5 minute break."

Stop & Save screen recordings.

Final Study: Participant Instructions Condition D (Brainstorming Collocated)

Participant Instructions dDesign D

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Idea Generation Method: Brainstorming

You and your teammates will brainstorm ideas for a given design problem. One member of your team will be the note taker. That person will capture in key words the essence of the ideas verbally developed by the team. Your team will have 35 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to recap the given design problem or to have the note taker repeat some of the ideas already developed.

- One note taker
- 35 minutes

- 1 –

Appendix Figure 19 Final study participant instructions condition D page 1 of 2

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Task:

- Generate as many solutions as possible in the allotted time using brainstorming for the given design problem.
- Tell your teammates about your ideas, even if they do not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.
- Try to be as clear as possible with your verbal description.

Design Problem

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Appendix Figure 20 Final study participant instructions condition D page 2 of 2

Final Study: Experimenter Script Condition D (Brainstorming Collocated)

1. Preparation for the experiment

☐ Computers are set up & running

☐ Screens are set up, working & calibrated

☐ Microphone installed, tested & working on round table machine

☐ Projector is set up and ready

☐ Tablet pens are on right upper side of screen

☐ Camtasia is running on machine

☐ OneNote is running on machine

☐ Consent forms (3) on table

☐ Information Sheets (3) on table under consent sheet

☐ Pens (3) one on each consent sheet

☐ Drawing template (3) positioned on left lower side of screen

☐ Participants instructions (3) positioned

☐ First one to come through door will be participant 1:
1st -> PC 2nd ->PC 3rd -> PC

☐ Who will be the note taker? PCxx

☐ Stop watch at hand

2. Consent

a) Read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form located in front of you on the table. You are not required to participate in this study and you may end your participation at any time. You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be voice recorded and screen-recorded to enable us to replay the session at later time to retrieve more

information and to compare it to the notes taken during the session. This will help us to analyze the experiment in greater depth. The study will require approximately 3 hours.

Please go ahead and read the consent form. Let me know if you have any questions about the experiment. If you agree to participate please sign the form and keep the information sheet for your records."

b) Collect consent forms.

3. Introduction & Compensation

Read the following statement: **"Thank you for taking time to participate in this research study today. Please turn off your cell phones."**

"Your effort will be compensated either with extra credit in your design class or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit. This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?"

Guide participants to workstation.

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser. You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.

To change the angle of the screen, press the two black levers in the back and adjust its angle. To become familiar with the pen display, please sketch a Coca Cola bottle. There is an inspiring picture of one at your left. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.

Are there any questions?"

After the 7 minutes are up:

"The time is up. Please come back to the table and have a seat. XYZ, you have been randomly assigned to be the note taker, please sit at PCxx . "

5. Experiment description

a) Have participants pick up ***participant instructions (2 sheets – method on top, instructions below)***. Make sure each participant has the required material.

b) START CAMTASIA

c) Read the following statement:

"This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using brainstorming. The time allotted for this will be 35 minutes.

d) Method (brainstorming) description; Read the following statement:

"The idea generation method you will be using is brainstorming. You and your teammates will brainstorm ideas for the given design idea. One member of your team has randomly been chosen to be the note taker. That person will capture in keywords the essence of the ideas developed by the team. Your team will have 35 minutes to develop ideas. If you get stuck, two helpful methods to get going again are to discuss the given design problem or to have the note taker repeat some of the ideas already developed. The note taker will be using the interactive pen display to capture the essence of the team's ideas.

e) **You have randomly been assigned to be the team note taker. You may also participate in the idea generation. The notes you take will be on your screen and projected to the back wall, so you team members can see them. Do you have any questions regarding your task?"**

Answer questions if asked.

f) General instructions. Continue reading:

"Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainstorming for the given design problems.**
- **Tell your teammates about your ideas, even if they do not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**
- **Try to be as clear as possible with your verbal description.**

You will have 35 minutes to generate solutions to the design problem using brainstorming. You do not need to keep track of time; I will do that and give you a 5 minute warning before the time is up.

Your design problem is to develop a peanut shelling device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you, please follow along. After I am done reading, I will start the time and you can go ahead and begin to generate ideas:

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

6. Must remove the shell with minimal damage to the peanuts.
7. Electrical outlets are not available as a power source.
8. A large quantity of peanuts must be quickly shelled.
9. Low cost.
10. Easy to manufacture.

Go ahead; I'll start the time now."

g) Start stop watch.

h) Give a warning after 30 minutes:

"You have 5 minutes left to finish you idea generation."

i) After 35 minutes are up read: "The time is up. Please put your pens down. Thank you for your participation

j) Collect participants' instruction sheets, the participants should not take them with them. Save not takers notes.

Final Study: Participant Instructions Condition E (Modified Method 635 Collocated)

Participant Instructions dDesign E

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Idea Generation Method: Brainwriting

You and your teammates will perform a brainwriting to develop ideas for a given design problem. Each of you has a pen display in front of you. You will have 15 minutes to sketch 3 possible solutions to the design problem. After that time period, your sketches will be forwarded to one of your teammates. You will then have 8 additional minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, your sketches will be forwarded to the next teammate. This will be repeated until everybody had a chance to work on everybody's' solutions. For three team members, that means two exchanges. Brainwriting is a non-verbal idea generation process – no talking is allowed.

- 15 minutes to sketch initial design problem solutions
- Move clockwise
- 8 minutes to modify and add to your predecessor's solutions
- Move clockwise
- 8 minutes to modify

- 1 -

Appendix Figure 21 Final study participant instructions condition E page 1 of 2

Participant Instructions dDesign E

Please do not discuss this problem with your classmates or anybody else until after December 31, 2010.

Task:

- Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.
- Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.
- The goal is to generate as many solutions with as high of quality and with as great of variety as possible.
- Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.
- No negative comments, please. Aim for being positive and nurturing.

Design Problem

Problem Description:
In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Goals:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Appendix Figure 22 Final study participant instructions condition E page 2 of 2

Final Study: Experimenter Scrip, Condition E (Modified Method 635 Collocated)

1. Preparation for the experiment

- ☐ Computers are set up (www) & running
  - ☐ 4 in the experiment room with 3 dividers in between
- ☐ Screens are set up, working & calibrated
- ☐ Mouse, Keyboard stowed.
- ☐ Tablet pens are on right side of screen
- ☐ Camtasia is running on PCs
- ☐ OneNote is running on PCs, team workbook is open, full page view, Y on pages
- ☐ Consent Forms (3 copies)
- ☐ Information Sheets (3 copies)
- ☐ Pens (4)
- ☐ Participants instructions (4 copies) positioned
- ☐ PC Assignment: First one to come through door will be participant 1st:
  1st -> PC 2nd ->PC 3rd -> PC
- ☐ Stop watch at hand

2. Consent

a) Guide students to workstations as they come in, ask them to start reading consent form

b) Read the following statement:

"You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time. You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem. You will be screen recorded to enable us to replay the session at later time to retrieve more information and to compare it to the notes taken during the session. This

will help us to analyze the experiment in greater depth. The study will require approximately 3 hours. Please go ahead and read the consent form. Let me know if you have any questions about the experiment.

If you agree to participate please sign the form and keep the information sheet for your records."

c) Sign and collect consent forms.

d)

3. Introduction & Compensation

Read the following statement: **"Hello and thank you for taking time to participate in this research study today. Please turn off or silence your cell phones."**

"Your effort will be compensated either with extra credit in your design class or cash. Disbursement will occur at the end of the three hours. If you choose to end your participation before the end of the experiment you will be compensated with partial credit or a partial payment. Failure to follow directions or engage in prescribed activities may result in termination of the experiment and partial payment or credit. This experiment has multiple activities and participation in all is required. You must agree to not discuss any aspects of the study with anybody –your teammates, friends, family- until after December 31, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?"

4. Screen exploration

"For this experiment you will be using the interactive pen display in front of you on the table. You will use the pen located to the right of the screen instead of a mouse. Pressing the pen against the screen or tapping it equals a left mouse click. The end of the pen works as an eraser.

You will be using software called Microsoft OneNote to draw and take notes. The program is already running in full page view. Once you have filled this page, scroll bars will appear - just move them to get more space.

To change the angle of the screen, press the two black levers in the back and adjust its angle. To become familiar with the pen display, please sketch a Coca

Cola bottle. There is an inspiring picture of one at your left. Then go ahead and take some random notes and sketch some more, so you get comfortable using the screen to sketch and write. You will have approximately 7 minutes to do this. I'll let you know when the time is up.

If you have any questions, please ask. I will be going around making sure there are no technical difficulties with the system."

After the 7 minutes are up:

"The time is up. Please click on the rectangular symbol in the toolbar at the far left of the screen to go into tabbed view. Please click on the section labeled experiment. Please open the tab according to your PC number."

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help. I will start the screen recording now."

Go around to each PC, and start the screen recording now.

Check all participants are back to full page view

"Are there any questions before we begin?"

5. Experiment description

a) Make sure each participant has the participant instructions.

"Please take the participant instructions at the top left corner of your desk"

b) Read the following statement:

"This study is seeking to evaluate idea generation in the design process. Your task today is to generate as many ideas as possible for a design problem using a specified design method. The time allotted for this is about 35 minutes total, but other activities will fill the remaining time."

c) Method (brainwriting) description; Read the following statement:

"The idea generation method you will be using is brainwriting. You and your teammates will generate ideas using brainwriting for a given design problem in a collocated team.

You and your team members will have a pen display each. You will have 15 minutes to sketch possible solutions to the design problem. Aim for at least 3 initial ideas. After that time period, sketches will be exchanged. You will then have 8 minutes to modify your predecessor's solutions and to add anything you come up with. After the time is up, you will exchange sketches again. This will be repeated until everybody had a chance to work on everybody's solution. For three team members, that means two exchanges.

- **15 minutes to sketch initial design problem solutions**
- **Forward sketches**
- **8 minutes to modify and add to your predecessor's solutions**
- **Forward sketches**
- **8 minutes to modify**

You do not need to keep track of the time, I will use a stop watch to do that and give you a one minute warning before each time period is up as well as the final call for each time period.

Do you have any questions regarding your task?"

Answer questions if asked.

d) General instructions. Continue reading:

"Please turn over the sheet.

While generating ideas be sure to do the following:

- **Generate as many solutions as possible in the allotted time using brainwriting for the given design problem.**
- **Sketch and include short phrases to capture everything you can think of even if it does not meet the constraints of the problem.**
- **The goal is to generate as many solutions with as high of quality and with as great of variety as possible.**
- **Wild, technically infeasible and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **No negative comments, please. Aim for being positive and nurturing.**

Your design problem is to develop a peanut shelling device.

If you have any questions at any time during this experiment, please ask.

I will now read the design problem to you and afterwards start the time.

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Goals:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

You can go ahead; I'll start the time now."

e) Initial time period:

Start stop watch, *set to 15* minutes.

Give a *warning after 14* minutes:

"You have one minute left to finish the initial idea generation"

After 15 minutes: **"Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab one number bigger than your PC."**

Check all participants are opening the correct tab.

"Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help."

Check all participants are back to full page view.

f) Second time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

"You have one minute left to finish the idea generation"

After 8 minutes: **“Please stop working on your sketch. To exchange sketches, please go back to tabbed view by clicking the rectangular symbol at the far left of the screen to go into tabbed view. Please open the tab two numbers smaller than your PC.”**

Check all participants are opening the correct tab.

“Now, please go back to full-page view by clicking the rectangular button again, it is in the very top toolbar next to help.”

Check all participants are back to full page view.

g) Final time period:

Start stop watch, *set to 8* minutes.

Give a *warning after 7* minutes:

“You have one minute left to finish the idea generation”

Stop second idea generation process

“Please stop working on your sketch. Please put the pan down. We will have a 5 minute break now. ”

Stop & Save screen recordings.

APPENDIX E

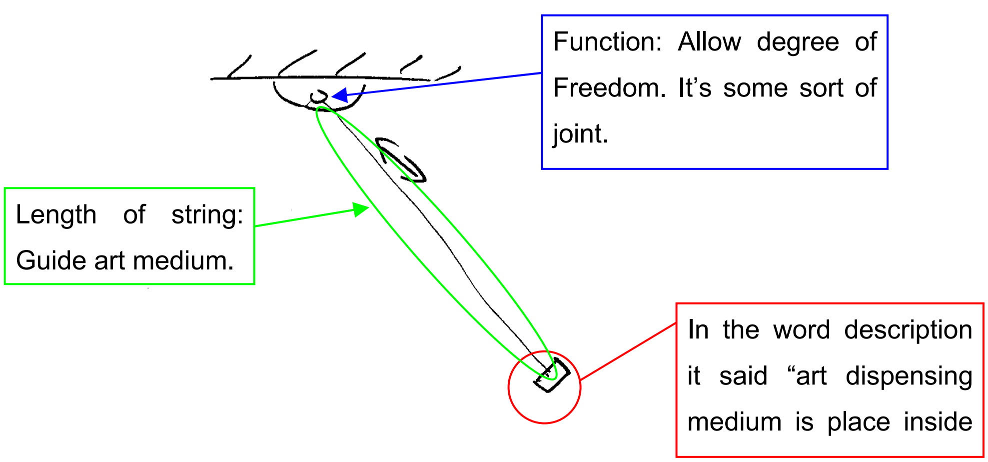
Appendix E contains one item: the updated idea counting rules used in the final study (version 2010-03-13)

Updated Idea Counting Rules 2010-03-13

1. Each idea must meet one of the functions in the functional basis.
2. An idea can meet either a primary or secondary function.
3. Each idea or component counts as only one idea even if it solves more than one function.
4. New combinations of previous concepts do not count as ideas
5. Categories only count as ideas when no subordinates are given. For examples saying use a "gear" and then listing "spur gear, worm gear" counts as 2 ideas not 3. If instead only "gear" was listed then this would count as 1 idea.
6. A component being used in multiple places counts as one idea.
7. In brainstorming, if the note teller sketches ideas, count the components in them as you would count other sketches.
8. Count all ideas that have been generated. This includes erased (brainsketching) or verbally communicated but not written down (brainstorming) ideas.

- **If ideas or components are mentioned in the problem statement then they do not count.**

- Identifiable components/ ideas
  - Count identifiable components as an idea when it meets a function
  - Count components/ideas even if they are not needed or cause the system not to function.
  - **Components usually occur when lines cross or when one line ends at a continuous line.**



- **Be sure the break-down of an idea is shown and not just implied. The breakdown of idea or component must be explicitly described verbally or drawn. Each piece of a sketch or description must have an identifiable function.**

- Function sharing
  - Count each idea only once even when it meets more than one function. **A component that serves more than one function counts as only one idea**.

- Categories
  - If only the category is given, count it as one idea. **(For example electric machines or gears are categories)**
  - If a category and items in the category are given count only the items as ideas. **(For example if use a gear is given and use a spur gear or a helical gear is also given, this counts as only 2 ideas not 3)**
  - Mark the categories

- Primary and secondary functions
  - Count all ideas that meet either a primary function or a secondary support function. *The functional basis we are using is only for the primary functions of a product and does not include the secondary and support functions.*

- When the same idea/component is used in more than one place:
  - Count it only as one idea

- **For ideas that reframe the problem such as producing a slightly different product or ways to reduce waste product, count these in a separate category call *"Problem Reframing."* These will usually be ideas that do not specifically address the design problem**
  - **These will usually not meet a function.**
  - **They must add something to the system.**
  - **Count them if they are related to the situation such as**
    - **Environmental concerns relate to the situation**
    - **Reduction in waste products resulting from solutions to the problem**
    - **Produce a slightly different product.**

    - **General principles, for example high impact or solar energy, if no more specific instance is given and if it is not clear what function they are supposed to fulfill.**
    - **Crazy ideas as trained monkey, spaceships, magic…**

Rules that are not used in the quantity evaluation of the final study:

Because it is part of the reframed description already:

- Ideas that do not specifically address the described problem
    - Count them if they are related to the situation such as:
        - Environmental concerns relate to the situation
        - Reduction in waste products resulting from solutions to the problem
        - Another method to address the situation.

Because these cases were not identified in the final study data:

- Combinations of previous ideas
    - **When the only change between ideas is a new combination of previous ideas mark it as "New combination only".** Count new combinations as a separate measure. **one sheet to the next

- **For the data where there are words only, if a new color is used and there is not identifiable idea, add one to the new color category.**

APPENDIX F

Appendix F contains evaluation results from the final study, specifically the following items:

- Values for Quantity, Quality, Novelty and Variety for each team based on the first rater's evaluation
- Quantity per person and team evaluation results
- Number of Ideas generated by all Team Members, including Doubles
- Number of ideas per team with a 2, 1, or 0 point quality rating
- Results of the novelty and variety evaluation by both raters

Appendix Table 1 Final study values for quantity, quality, novelty and variety for each team based on the first rater's evaluation

Team #	Condition	Quantity	Quality	Novelty	Variety
1	Modified Method 635, Distributed	34	1.88	0.966	0.32
5		32	1.72	0.966	0.31
2	Modified Method 635, Collocated	39	1.66	0.969	0.40
6		40	1.47	0.972	0.49
7	Brainstorming, Collocated	27	0.86	0.982	0.29
3		26	1.18	0.979	0.29
8	Brainstorming, Distributed	20	1.29	0.974	0.23
4		40	1.29	0.972	0.28

Appendix Table 2 Final study overview on quantity per person and team evaluation results

Team #	Condition	Team Value		1st Team member	2nd Team member	3rd Team member		Average # of Ideas Per Team Member & Condition
1	Modified Method 635, Distributed	34		16.7	12.7	9.7		
5		32		13.5	11.5	9.0		12.2
2	Modified Method 635, Collocated	39		14.5	13.0	11.5		
6		40		12.0	12.5	17.5		13.5
7	Brainstorming, Collocated	27		11.0	10.0	8.0		
3		26		13.5	8.5	6.0		9.5
8	Brainstorming, Distributed	20		20.5	11.0	8.5		
4		40		9.5	6.5	4.0		10.0

Appendix Table 3 Final study number of Ideas generated by all team members, including doubles

Team #	Condition	Number of Ideas generated by all Team Members, including Doubles
1	Modified Method 635, Distributed	78
5		46
2	Modified Method 635, Collocated	64
6		73
7	Brainstorming, Collocated	28
3		28
8	Brainstorming, Distributed	35
4		21

Appendix Table 4 Final study number of ideas per team with a 2, 1, or 0 point quality rating

Team #	Condition	Quality Average per Team		2 points	1 point	0 points
1	Modified Method 635, Distributed	1.88		69	9	0
5		1.72		35	9	2
2	Modified Method 635, Collocated	1.66		45	16	3
6		1.47		43	21	9
7	Brainstorming, Collocated	0.86		11	11	6
3		1.18		5	14	9
8	Brainstorming, Distributed	1.29		13	19	3
4		1.29		9	9	3

Appendix Table 5 Final study results of the novelty and variety evaluation by both raters

Team #	Condition	Novelty 1st Rater (Author)	Novelty 2nd Rater		Variety 1st Rater (Author)	Variety 2nd Rater
1	Modified Method 635, Distributed	0.966	0.964		0.32	0.28
5		0.966	0.968		0.31	0.36
2	Modified Method 635, Collocated	0.969	0.963		0.40	0.33
6		0.972	0.970		0.49	0.41
7	Brainstorming, Collocated	0.982	0.979		0.29	0.26
3		0.979	0.974		0.29	0.27
8	Brainstorming, Distributed	0.974	0.972		0.23	0.22
4		0.972	0.971		0.28	0.26

VITA

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