Improving Human Effectiveness for Extreme-Scale Problem Solving – Final Report (Assessing the Effectiveness of Electronic Brainstorming in an Industrial Setting)

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Abstract

An experiment was conducted comparing the effectiveness of individual versus group electronic brainstorming in order to address difficult, real world challenges. While industrial reliance on electronic communications has become ubiquitous, empirical and theoretical understanding of the bounds of its effectiveness have been limited. Previous research using short-term, laboratory experiments have engaged small groups of students in answering questions irrelevant to an industrial setting. The current experiment extends current findings beyond the laboratory to larger groups of real-world employees addressing organization-relevant challenges over the course of four days. Findings are twofold. First, the data demonstrate that (for this design) individuals perform at least as well as groups in producing quantity of electronic ideas, regardless of brainstorming duration. However, when judged with respect to quality along three dimensions (originality, feasibility, and effectiveness), the individuals significantly ($p<0.05$) out performed the group working together. The theoretical and applied (e.g., cost effectiveness) implications of this finding are discussed. Second, the current experiment yielded several viable solutions to the wickedly difficult problem that was posed.

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Introduction

The LDRD project "Improving Human Effectiveness for Extreme-Scale Problem Solving" was a single year effort to investigate tools and methods for bringing very large groups of people together to solve difficult problems. In particular, we were interested in learning more about how computer mediated collaborations might attack "wickedly difficult" problems, which are problems characterized by a lack of agreement about the very nature of the problem itself. Our hypothesis was that these tools, and in particular the interactions afforded, could allow large numbers of people to come to agreement about the nature of difficult problems, and could result in a large pool of ideas that might lead to solutions to the problem.

To narrow the focus of the problem to fit the project funding level, we pursued an electronic brainstorming experiment, built around the very common face-to-face technique used at Sandia National Laboratories, where people submit ideas written on Yellow Sticky Post-It ® Notes. The brainstorming question involved several difficult management philosophy issues, which taken together were felt to pose a wickedly difficult problem. Here we report the results of the experiment and a surprising finding that even in these large groups, individuals working alone can cost effectively produce an equivalent quantity and quality of ideas compared to those sharing their ideas and interacting with each other.

The Need

Group decision-making and electronic communication are integral to contemporary work organizations, and moreover, represent a ripe research context in which to solve "wicked," or ill-defined problems, at the very core of the national security mission. Surprisingly, however, very little is empirically known or generally understood about how best to use electronic groups. Before describing our experiment and its relationship to prior literature, we will build the case that a better theoretical and empirical understanding of electronic groups is needed.

"Wicked" problems are those problems that by their very definition are so tangled that there is not agreement about their definitions, much less their solutions. Two components of wicked problem solving that are inherent to the national security environment (as well as many other business environments) include group dynamics and electronic communications. First, because there can be no 'right' answer or solution without first having agreement about the definition of the problem and the social meaning of a 'right solution,' these problems (often) fundamentally relate to the social aspects of groups (Allison, 2006). For the purposes of this paper, groups are defined as "two or more persons who share common goals, whose fates are interdependent, who have a stable relationship, and who recognize that they belong to a group" (Baron & Byrne, 1997, p. 471) [1]. Second, as computer networks have been increasingly used to conduct business

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[1] In the present paper, "group decision making" includes groups of individuals with a relationship to one another, and does not include voting (sometimes referred to as the social aggregation of individual votes). We see this distinction as important because of the existing theory and process differences between group decision making and

with decreased costs, increased information accessibility, and rapid document, database, and message exchange (Siegel, Dubrovsky, Kiesler, & McGuire, 1986, as referenced by Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002), electronic communication enables a new form of group problem solving that has yet to be well understood, especially as it relates to solving wicked problems.

The need for a better empirical and theoretical understanding of electronic groups is practically demonstrated through industry's shift from individual to team contributions, as well as increasing reliance on computer-mediated communications. From a more academic viewpoint, the need for increased understanding of electronic groups can be seen through a vast, non-unified, literature whose findings have yet to be rigorously applied to industrial settings.

According to Kozlowski & Ilgen (2006), organizations worldwide are at least 15 years into "shifting from individual jobs in functionalized structures to teams embedded in more complex workflow systems" (Devine, Clayton, Phillips, Dunford, & Melner, 1999; Lawler, Mohrman, & Ledford, 1992, 1995; Mathieu, Marks, & Zaccaro, 2001). This shift is being driven by increased competition, consolidation, and innovation which increase needs for the skill diversity, expertise, rapid response, and adaptability that groups may enable (Kozlowski, Gully, Nason, & Smith, 1999, as cited by Kozlowski & Ilgen, 2006). Add to this shift the increased computer availability and broadband communication that enable groups to be distributed across time and space (Bell & Kozlowski, 2002b, as cited by Kozlowski & Ilgen, 2006), and an interesting and complex research area emerges. Kozlowski and Ilgen (2006) have argued that the confluence of such virtual groups with potentially worldwide membership is "inevitable and the source of new research challenges" including "how to harness the emerging technological capability to *enhance* and *evolve* team processes in virtual environments that cut across different cultures" (p. 114).

Computer networks have attained omnipresence within work environments, meaning that electronic communication now offers a novel form of problem solving groups, potentially interesting to solving wicked problems. Over the last 20 years, computer networks have been increasingly used to conduct business because they convey decreased costs with increased information accessibility, and rapid document, database, and message exchange (Siegel, Dubrovsky, Kiesler, & McGuire, 1986, as referenced by Baltes et al., 2002). As compared to face-to-face groups, electronic groups allow for more flexible (e.g., non-simultaneous and geographically distributed) forms of intragroup communication; however, they can also foster stronger group identification (Lea et al, 2001, as cited by Kerr & Tindale, 2004) and adherence to group norms (Spears et al, 1990; although see Douglas & McGarty, 2001, both as cited by Kerr & Tindale, 2004). Interestingly, this networking growth has not fully addressed questions about the decision quality arising from the computer-mediated communication (CMC) groups or interaction differences between online versus face-to-face meetings. In fact, what empirical evidence is available "raises significant questions about the appropriateness of heavy reliance on computer-mediated communication for organizational group decision making" (Baltes et al., p. 175).

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voting, as well as because of the increased time and effort investment required of the former (Greitemeyer, Brodbeck, Schulz-Hardt, Frey, 2006).

There is well over half a century of research regarding small groups and related topics, however, several broad challenges remain if computer-mediated groups are to be effectively used to solve wickedly difficult problems. First, much about group effectiveness remains unknown even within this substantial knowledge base (see Dornburg, Stevens, Forsythe, & Davidson, 2007, for more detailed discussion). Second, identifying what is known within and between such vast and multi-disciplinary literatures remains challenging (Kozlowski & Ilgen, 2006). Third, current research has been largely limited to the laboratory environment of intellective tasks (e.g., tasks with a demonstrably correct answer) rather than "wicked" tasks that, because their ambiguous nature, are more difficult to empirically study. In real-world organizational contexts, groups are seldom aware of whether they have made the correct decision regardless of whether the groups are face-to-face or computer-mediated. In fact, the correct answer is usually unavailable for teams outside the laboratory, because if the correct answer were available, there would be no reason to convene a team to make the decision (Roch & Ayman, 2005).

Noting these challenges and the research infancy of computer-mediated communications, it is clear that a great deal of empirical and theoretical work remains to be accomplished. That work will be especially valuable considering the incremental costs associated with group decision making compared to individual decision making (Greitemeyer, Brodbeck, Schulz-Hardt, Frey, 2006). Thus, it is important to be able to justify this increased investment and to be able to mitigate potential pitfalls.

Experimental Extension of the Current Literature

Group problem solving performance depends on how well the group generates *quantity* and *quality* of ideas. High quality ideas are particularly prized, which are commonly believed to be more likely to arise if a large collection of diverse ideas are generated. One method to generate such a collection of ideas is verbal brainstorming, a process were a group of individuals, typically working in the same room, create and share ideas in a free flowing, non-judgmental way. Such groups have typically followed Osborn's (1957) brainstorming rules:

- the more items proposed the better,
- strive to combine and improve on others' ideas,
- the wilder the idea the better,
- do not criticize, and
- be as clear and concise as possible.

With the arrival of computer mediated communications, people are, naturally, congregating and engaging in group problem solving online. As a result, the literature covering group problem solving has grown from just studies of verbal brainstorming to include electronic brainstorming. However, even after half a century of study, the bounds of effective brainstorming are yet to be well understood even for verbal brainstorming and the electronic version is even less well understood.

Popular opinion holds that verbal brainstorming yields more (and better) ideas than the same number of individuals working alone would produce (see Furnham, 2000; Guerin, 1986; Osborn, 1957). More formally, researchers have long believed that verbal (or group) brainstorming is superior to individual

brainstorming for several reasons. For example, becoming aware of and/or feeling the presence of others has been shown to provide social facilitation (Bond & Titus, 1983; Guerin, 1986; Zajonc, 1965), and exposure to other individuals' ideas often generates intellectual synergy (Madsen & Finger, 1978). In addition, claimed advantages of brainstorming include (Furnham, 2000):

- reducing dependence on a single authority figure,
- encouraging open sharing of ideas,
- stimulating participation among group members,
- providing individual safety in a competitive group,
- maximizing output for a short period of time, and
- ensuring a non-evaluative, enjoyable and stimulating environment.

However, investigations into the actual operation of groups involved in brainstorming have uncovered a number of issues, which cast some doubt, or at least caveats, on these optimistic claims.

Issues

Despite popular opinion, verbal brainstorming has been found to result in certain undesirable consequences when compared to individual, or nominal, brainstorming where individuals brainstorm alone. As discussed below, these consequences include production blocking, evaluation apprehension and social loafing (Kerr & Tindale, 2004).

Blocking

Production blocking is an individual's inability to spontaneously interject ideas without violating group etiquette or breaking the concentration of other members (DeRosa, Smith & Hantula, 2007). That is, if one person is sharing his/her ideas, other members of the group are not able to share their ideas simultaneously. Consequently, their ideas may be "blocked". Nijstad, Stroebe & Lodewijkx (2003) manipulated the delay within which participants were able to contribute ideas. They found that delay length negatively related to performance when the participants were blocked before entering each idea and that unpredictable delays led to fewer trains of thought. In addition, those who are silent during a brainstorming session appear to self-censor, forget or get talked out of a significant number of their ideas (Diehl & Stroebe, 1991).

Evaluation Apprehension

Another negative consequence of verbal brainstorming is evaluation apprehension, which is the tendency for people to hold back their ideas for fear that others will negatively evaluate them (Dennis & Valacich, 1994; Paulus & Yang, 2000). Because verbal brainstorming involves individuals who must, necessarily, share ideas with the group, those individuals who are uncomfortable speaking in front of people, or who are afraid that others will negatively judge their ideas, may refrain from making contributions to the brainstorming session (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe, Cooper, Grise & Bastianutti, 1994; Paulus & Yang, 2000; Roy, Gauvin & Limayem, 1996).

Finally, verbal brainstorming could result in social loafing, which is the tendency for individuals to invest less effort in group projects than they do in equivalent individual work (Connolly, Routhieaux & Schneider, 1993). Social loafing has been shown in a variety of tasks, from rope pulling to hand clapping to identifying radar signals on a computer screen (Furnham, 2000; Karau & Williams, 1993; Kravitz & Martin, 1986; Latané, Williams & Harkins, 1979). Ringlemann found that participants exerted less force when asked to pull a rope when they were with a group of people than when they were alone (as cited by Kravitz & Martin, 1986). Similarly, Latané and colleagues (1979) found that average sound pressure generated by their participants' hand clapping decreased as the number of people per group increased. The researchers argued that these results are consistent with the phenomenon of social loafing (Latané, Williams and Harkins, 1979).

Can EBS mitigate problems with traditional brainstorming?

While verbal brainstorming is often a popular method for eliciting ideas from groups of individuals, the process seems to have serious limitations. To address some of these limitations, electronic brainstorming (EBS) has been proposed as an alternative. An EBS session consists of individuals interacting and exchanging ideas via a computer.

Because the members of the group exchange ideas through computer connections, several members can input ideas at the same time; thus, production blocking should not occur. Studies have shown that EBS does in fact mitigate the negative effects of production blocking (Gallupe et al., 1994; Nijstad et al., 2003; Valacich, Dennis & Connolly, 1994). Valacich and colleagues (1994) had their participants perform two different brainstorming activities. Half of the participants performed tasks in the standard EBS format. For the other half of the participants, the technology was modified so that only one person could type in a response at a time (thus introducing production blocking). The researchers found that the standard EBS groups outperformed the production blocking EBS groups and concluded that EBS was effective at eliminating production blocking (Valacich et al., 1994).

Because EBS enables submission of responses and ideas in an anonymous fashion, evaluation apprehension can also be eliminated. Cooper and colleagues (1998) had four groups of participants brainstorm ideas about topics of a controversial nature. The groups included an anonymous EBS group, a non-anonymous EBS group (in which the participants identified which ideas were their own), a verbal brainstorming group, and an individual, or nominal, group. The researchers found that the anonymous EBS groups were the most productive overall, produced a larger number of highly controversial ideas and reported less perceived production blocking than the non-anonymous EBS groups (Cooper, Gallupe, Pollard & Cadbsy, 1998).

The research looking at social loafing and EBS has found mixed results, but some researchers have suggested that allowing participants to view others' ideas results in a decrease in social loafing, possibly because the participants may be comparing their performance to the performance of their peers (Roy, Gauvin & Limayem, 1996). Karau & Williams (1993) have suggested that "monitoring individual performance or making such performance identifiable,

making tasks unique such that individuals feel more responsibility for their work, enhancing the cohesiveness of work groups, and making individuals feel that their contributions to the task are necessary and not irrelevant might reduce or eliminate social loafing" (p. 700). Furnham (2000) noted that social loafing may be less likely to occur with EBS because individuals may be assured that the ideas they contribute are logged and counted.

Finally, other advantages of EBS over verbal brainstorming include features that are advantageous to their institutions or organizations. In particular, EBS enables shorter meetings, increased participation by remote team members, better documentation via electronic recording, improved access to the meeting records and, importantly, cash savings (Furnham, 2000).

Admittedly, EBS also has some disadvantages. An EBS session could be considered less rich than a face-to-face session since the electronic medium filters out nonverbal communication. In addition, EBS can not provide rapid feedback as easily, and can reduce communication efficiency since it takes longer to type than to speak (Dennis & Valacich, 1994). However, despite these disadvantages, the literature indicates that EBS groups almost always outperform verbal brainstorming groups.

EBS compared to verbal brainstorming and individual, or nominal, brainstorming for small and large groups

While EBS has been shown superior to verbal brainstorming, the research comparing EBS to nominal brainstorming has produced rather mixed results. Some studies have found that EBS is superior to nominal brainstorming (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Paulus & Yang, 2000) while a few others have found that nominal groups were superior to EBS (Barki & Pinosonneault, 2001; Pinosonneault et al., 1999). Still others have found no differences between the two groups (Connolly et al., 1993; Cooper et al., 1998; DeRosa et al., 2007; Dugosh et al., 2000).

Most of the research has involved fairly small groups (3-4 people); researchers who have studied larger groups (12-18 people) have found that EBS was superior to nominal brainstorming (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe et al., 1991; Valacich et al., 1994). Thus, it seems that EBS is superior to nominal brainstorming with large groups of people. However, the two techniques are quite similar with smaller groups of people. The studies finding EBS performance superior to nominal group performance have attributed these findings to the stimulating effect of exposure to others' ideas (Dugosh et al, 2000; Nijstad et al, 2003; Paulus & Yang, 2000; although also see Ziegler et al, 2000 as cited by Kerr & Tindale, 2004) and the diversity and heterogeneity of those groups (Schruijer & Mostert, 1997).

Experimental Goals

To date most, if not all, of the research in this area has been performed in laboratory settings with college students, leaving its generalizability to industrial applications unclear. Previous studies have primarily looked at the quantity of ideas generated from small groups of university students (usually) brainstorming about an industrially irrelevant topic. These conditions leave

indeterminate how the results could apply to larger groups within industrial settings, where people brainstorm with one another about important issues across several days.

There are several key differences that must be addressed in order to apply the existing research to an industrial setting. First, groups in typical industrial settings grappling with "wicked" problems and may be more inclined to assess the quality of ideas, rather than the quantity of ideas as is typical in the current literature. For example, one great idea that solves the "wicked" problem will be better than several hundred lesser ideas. Second, as mentioned above, most research has studied three- to four-person student groups, rather than larger work teams that leverage diverse skill and knowledge bases. Because there seems to be a relationship between group size and effectiveness (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe et al., 1991; Valacich et al., 1994), there is reason to speculate that very large, diverse work teams might be especially effective. Third, the current literature's brainstorming topics are not as meaningful to students as a "wicked" problem might be to a vested employee. For example, an often used question in the current literature is the *Thumbs Question* (Bouchard & Hare, 1970; Gallupe et al., 1991), where students are asked to "generate ideas about the practical benefits or difficulties that would arise if everyone had an extra thumb on each hand after next year." While this question is interesting to muse about, it is farfetched from the real-world "wicked" and complex problems that top scientists struggle with every day. A professional's stance toward such a question can be expected to be very different compared his or her stance toward a question about the future of the company. Fourth, it is unclear how typical workplace scheduling demands might affect the outcome. Within the Sandia work environment, it is very difficult to schedule 30 (or more) people to brainstorm concurrently. Thus, results from short, one-time brainstorming sessions may not generalize to real-world situations where groups of individuals brainstorm over a period of time.

An experiment to investigate these questions was conducted at Sandia National Laboratories in the summer of 2007. Specifically, this experiment explored the effectiveness of EBS within the industrial setting of a modern, national research laboratory.

Method

The experimental design conformed to national statues and regulations with respect to human studies. The design and all experimental materials were approved by Sandia National Laboratories' Human Studies Review Board (HSB; Notice of Approval 6/29/2007).

Participants and Materials

Over the course of four days, 120 employees and contractors at Sandia National Laboratories voluntarily enrolled in the web-based brainstorming experiment. Of the total number that enrolled, 69 participants contributed ideas. The employment breakdown by job classification of the participants that contributed ideas is presented in Table 1. All further analyses include only those participants that contributed ideas.

Table 1. Employment Breakdown of the Brainstorming Participants.

	Group	Nominal
Employee/Contractor	30	39
Manager	2	2
DMTS	1	2
DMLS	1	1
PMTS	4	12
PMLS	1	3
SMTS	13	11
SMLS	1	1
MTS	2	3
MLS	1	0
OMA	0	1
Other Regular	3	2

The experiment was conducted using a website created and managed by the experimenters. All experimental materials were pre-approved by the institutional HSB, and are available in a separate report (Davidson, Dornburg, Stevens & Forsythe, 2007). After being shown a description of the experiment and participant rights, the registration form explained that continuing with the registration (by creating an account) constituted acknowledgement and acceptance of the conditions of the informed consent materials. When creating the account the participants were asked to generate user IDs that were anonymous so as to conceal their identities. Following this acknowledgement, demographic information was solicited to enable assignment to appropriate experimental groups.

After registration, participants had the opportunity to view the brainstorming question, respond with ideas, and view the available responses (which would only be their own submissions if they were randomly assigned to the nominal group). Participants were encouraged to read the brainstorming suggestions and rules for using the web site. They were also asked to complete an electronic satisfaction questionnaire at the end of the experiment.

Procedure

Participants were primarily recruited through an advertisement in the Sandia Daily News (an internal news source emailed daily to Sandia employees) soliciting participants for the study at both Sandia National Laboratories in Albuquerque, New Mexico and in Livermore, California. In order to further increase recruitment, the experimenters also sent personal recruitment emails to Sandia employees they knew requesting that they participate in the study. In addition, a link to information regarding the study was placed on the intranet via the Sandia Techweb Homepage. All of the recruitment messages explained that the study was investigating electronic brainstorming by having participants brainstorm (either alone or in a group) via a website over the course of four days.

The participants were randomly assigned to either group or nominal brainstorming conditions. For both conditions, participants were asked to work on a "wicked" problem proposed by Sandia National Laboratories President Tom Hunter. The question read as follows:

> "Tom Hunter is interested in the contrast between two models of how organizations relate to their people. One model views people, metaphorically, as just another natural resource, and like other natural resources, to be used (read extracted) for the good of the organization. In that model obtaining people is largely a financial question and the company will derive whatever contributions it can from their skills or experience.
>
> A second model asserts that people are an asset to be continually developed and the investment in their development will yield a dividend to the organization or even to the broader society.
>
> In contrasting these two models, Tom is greatly interested in your thoughts and ideas about:
>
> - how employees establish an identity for themselves in relation to their work environment, i.e., how do they define their *we*, and
> - how to create the appropriate balance between the role of management and the sense of empowerment of employees.
>
> He would like your comments and ideas about the above two questions, and also your insights into
>
> - what environment best supports the identification and development of leaders."

When the participants logged onto the website, the question was displayed at the top of the screen, and they were asked to input their ideas. Those in the nominal condition worked alone and did not see the ideas of other participants. Those in the group condition worked with others and were able to see and build on the ideas of the other members in the group.

Even though the ideas were tagged with the submitter's user ID, the submitter's actual identity was anonymous. The first reason for tagging ideas with the submitter's user ID (but not the participant's actual name) was that anonymity in group brainstorming sessions has been shown to reduce evaluation apprehension (e.g., Cooper, Gallupe, Pollard & Cadbsy, 1998). The second reason was that we hoped that by disclosing to the EBS participants the performance of their peers (i.e., the number of ideas submitted by each individual and the quality of those ideas) they would be less likely to engage in social loafing (Karau & Williams, 1993; Roy et al., 1996).

Participants were also asked to adhere to the rules of brainstorming per Osborn (1957), and were advised that abusive language and name calling would not be tolerated. The exact text of this notification was as follows:

> "Please think of possible solutions to the question and contribute your answers over the next four days. You are encouraged to contribute ideas at any time but we ask that you

contribute at least once a day for the duration of the experiment. You will be able to see other participants' responses and add to them.[2]

Because this is a group brainstorming activity, there are specific rules we would like you to follow:

- the more ideas the better
- strive to combine and improve on others' ideas
- the wilder the idea the better
- be as clear and concise as possible
- do not criticize
- NO NAME CALLING OR ABUSIVE LANGUAGE

We ask that you act in a professional and proper manner. There may be ideas that you do not agree with or feel uncomfortable with, but please do not engage in any sort of inappropriate behavior. Be advised that the website will be monitored constantly throughout the experiment. ANYONE ENGAGING IN NAME CALLING OR ABUSIVE LANGUAGE WILL BE LOCKED OUT FROM THE EXPERIMENT. Please respect your fellow colleagues.

Be aware that employees of all different security levels will be participating in this experiment. It is CRUCIAL that you do NOT include any classified or sensitive information.

Also, keep in mind that you are using a DOE computer, website and server. All DOE computer rules and regulations apply to this experiment."

At the end of the experiment, the participants were encouraged to complete a satisfaction questionnaire (modeled after Dennis & Valacich, 1993). The questionnaire asked several questions regarding the participants' satisfaction with the experiment, along with inquiries about their motivation and interest levels for the task. The exact text of the satisfaction questionnaire is available in a separate document (Davidson, Dornburg, Stevens & Forsythe, 2007).

Results

Differences by Employment

A wide range of employees participated in the brainstorm exercise. Of the 69 employee/contractors that participated and actively generated ideas, 39 were assigned to the

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[2] Note that these instructions erroneously failed to mention that there would be a fraction of the participants, randomly assigned to the nominal group, who would *not* be able to see other participants' ideas. This mistake led to a great deal of dissatisfaction among those in the nominal group. As a result, after the first day, participants were advised that they might be in a group working alone, in which case they would only be able to see their own responses.

nominal condition and 30 were in the group condition[3]. Figure 1 displays the number of ideas contributed by individual employees within each of the various job classifications.

Figure 1. Number of Cumulative Ideas Offered by Employees
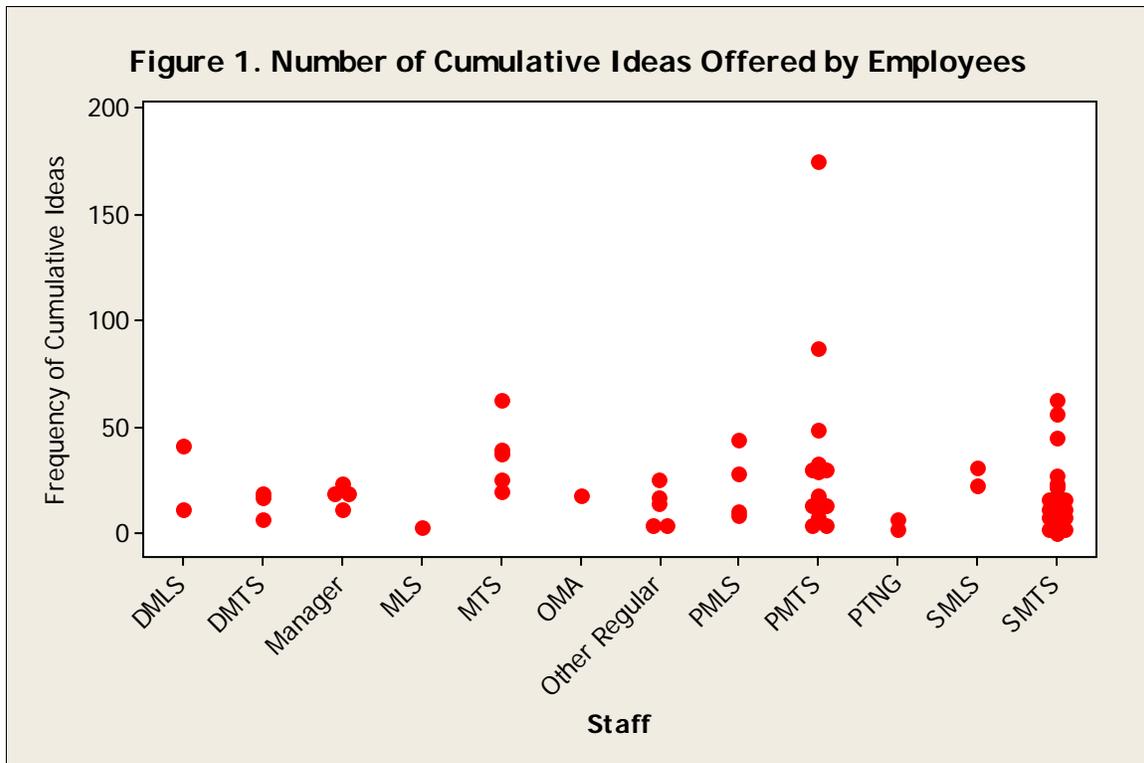
Quantity of Ideas Analysis

The number of ideas contributed by each employee/contractor was counted for each day of the experiment (Figure 2). To assess if a difference existed between the research groups (nominal or group) in the number of ideas offered, we performed a repeated measures analysis of variance (ANOVA) on the number of ideas expressed on each of the days by research group membership (nominal or group). There was a significant effect for the number of ideas expressed on each day (Wilks' Lambda, $F(3, 65) = 2.784$, $p = .048$, $\eta_p^2 = .114$) in which there was a larger number of ideas put forward on day one compared to the following three days. There was no significant interaction between the number of ideas per day and group membership. Furthermore, there was no significant difference in the number of ideas expressed by the members of the nominal ($M = 6.26$, $SD = 12.85$) or group ($M = 4.66$, $SD = 9.21$) conditions.

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[3] These numbers reflect the participants who generated ideas, not the number that were assigned to the groups.

Figure 2. Number of Ideas by Day of Study
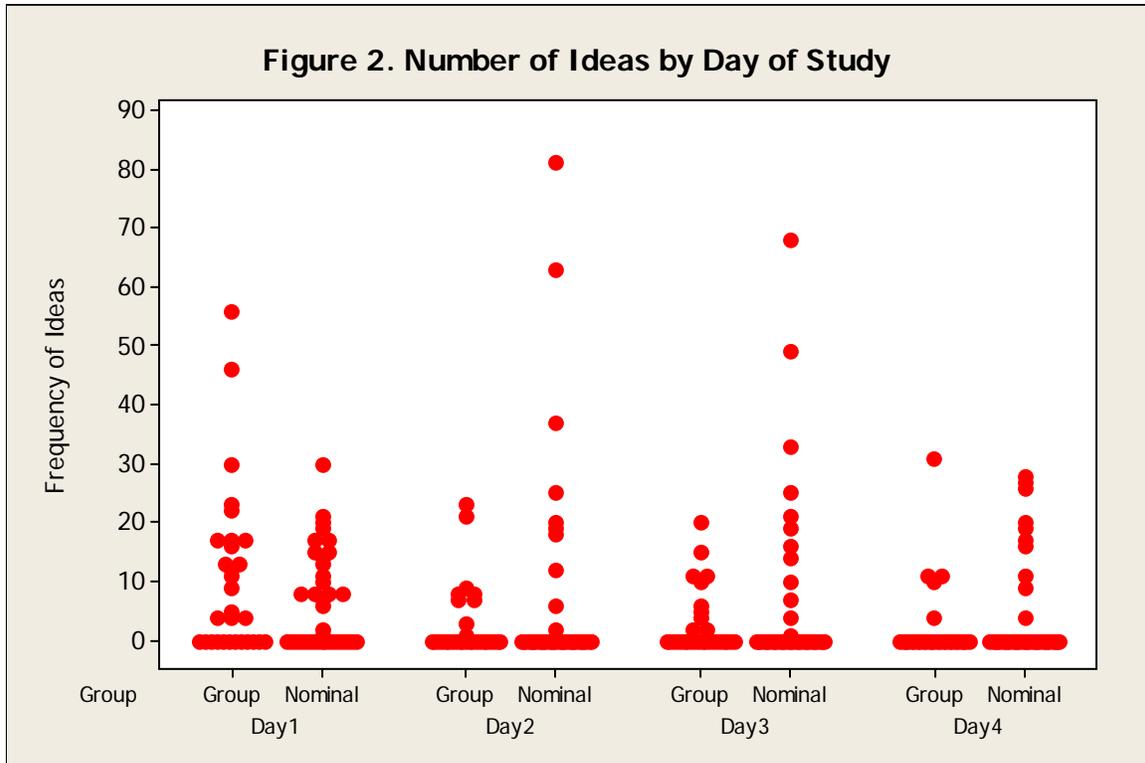
Following this analysis, we wished to further investigate if there was a difference between the research groups in the number of cumulative ideas contributed (Figure 3). The number of cumulative ideas was calculated by adding the number of ideas offered within a single day to the number of ideas offered on each of the previous days. As to be expected due to the method in which the number of cumulative ideas is calculated, there was a significant difference in the number of cumulative ideas offered on each of the days (Wilks' lambda, F (3, 65) = 7.326, $p < .001$, $\eta_p^2 = .253$). There was no significant interaction between number of cumulative ideas expressed each day and group membership. Furthermore, similar to the previous findings, there was no significant difference between the research groups. The average number of cumulative ideas expressed by the nominal group was 25.05 ($SD = 29.08$) and by the combined group was 18.63 ($SD = 18.18$).

Figure 3. Number of Cumulative Ideas by Day of Study

In addition, we assessed whether there was a difference in the number of sentences and words generated per day between the research groups. We performed a repeated measures ANOVA on the number of sentences contributed on each of the days by research group membership (nominal or group). There was a significant difference for the number of sentences per day (Wilks' lambda, F (3, 65) = 2.785, p = .048, η_p^2 = .114) in which there were more sentences produced on the first day compared to the other three days. However, there was no significant interaction between the number of sentences expressed on each day and group membership and there was no significant difference in the number of sentences expressed by the group (M = 4.27, SD = .96) and nominal (M = 4.97, SD = .84) conditions. We also performed a repeated measures ANOVA on the number of words provided each day by research group (nominal or group). There was no significant interaction in the number of words written each day by research group. Furthermore, there was no significant difference between days in the number of words submitted and no significant difference in the number of words between the group (M = 80.3, SD = 18.58) and nominal (M = 90.17, SD = 16.30) groups.

Quality of Ideas Analysis

In addition to quantity measures, responses were also examined for quality. In order to do this analysis, responses were summarized into general concepts representing each participant's answer to the Hunter question so as to minimize redundancy within each participant's individual entries. Responses unrelated to the question, like those addressing the website design, were not considered in this analysis. Following the example of Barki and Pinsonneault (2001), the quality of ideas was scored according to originality, feasibility, and effectiveness. In this scoring scheme, *originality* referred to the extent to which the idea is novel, or out of the ordinary, *feasibility* referred to the extent to which the idea is precise and the ease with which it can be

implemented, given the current context (including available financial resources, infrastructure, time required, legal issues, etc.), and *effectiveness* referred to the extent to which the idea helps to solve the given problem.

Two raters were chosen for their background and experience in operations management and industrial/organizational psychology. The raters independently scored the ideas using Barki and Pinsonneault's seven-point Likert Scale in which 1 corresponded to low evidence for the component and 7 corresponded to high evidence for the component. These ratings were then averaged for each idea[4].

A two-factor mixed analysis of variance (ANOVA) was conducted to independently evaluate originality, feasibility, and effectiveness. Because we were interested in the most meaningful ideas, we evaluated maximum ratings rather than average ratings. Thus, if a participant received ratings of 3, 4, and 5 for a particular day, the maximum 5 rating was used as that participant's dependent variable.

Originality. Originality of ideas was analyzed using a two-factor fixed ANOVA examining the between-group effect of Condition (Group and Nominal) and the effect of Response day (1, 2, 3, and 4). The analysis yielded a significant effect of Condition ($F (1, 83) = 19.04$, $MSe = 1.05$, $p < .001$), indicating that the Nominal condition conferred a significant advantage over the Group condition ($M = 4.71$ and 3.66, respectively). The analysis did not yield a significant effect of Response day ($F (3, 83) = 0.89$, $MSe = 1.11$, $p = 0.45$), nor did it yield a significant interaction between Condition and Response day ($F (3, 83) = .89$, $MSe = 1.11$, $p = 0.45$).

Feasibility. Feasibility of ideas was analyzed in the same way as Originality. Again, this analysis demonstrated a significant effect of Condition ($F (1, 83) = 4.33$, $MSe = 6.04$, $p = .04$), such that the Nominal condition outperformed the Group condition ($M = 3.81$ and 3.29, respectively). The analysis did not yield a significant effect of Response day ($F (3, 83) = 0.83$, $MSe = 1.16$, $p = .48$), nor did it yield a significant interaction between Condition and Response day ($F (3, 83) = 0.08$, $MSe = 0.11$, $p = .97$).

Effectiveness. Effectiveness of ideas was also analyzed using the two-factor ANOVA discussed above. The analysis yielded a significant effect of Condition ($F (1, 82) = 6.03$, $MSe = 8.71$, $p = .02$), such that the Nominal condition outperformed the Group condition ($M = 4.27$ and 3.59, respectively). This analysis did not yield a significant effect of Response day ($F (3, 82) = 0.93$, $MSe = 1.35$, $p = .43$), nor did it yield a significant interaction between Condition and Response day ($F (3, 82) = 0.09$, $MSe = 0.13$, $p = .97$).

Participant Satisfaction

We also assessed the participants' responses to questions on the satisfaction questionnaire. A total of 9 participants (3 in the group condition and 6 in the nominal group) filled out the

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[4] Ideally, the raters would come to consensus on any rating differences; however, given the time-frame allowed, averaging was chosen as the best alternative.

satisfaction questionnaire. Previous research has found that participants in the group condition are generally more satisfied, motivated and interested with the brainstorming task than are those in the nominal groups (Cooper, Gallupe, Pollard, & Cadsby, 1998; Dennis & Valacich, 1993; DeRosa, Smith, & Hantula, 2007; Gallupe, Bastianutti & Cooper, 1991; Valacich, Dennis, & Connolly, 1994). We compared the responses on this questionnaire between groups (i.e., group vs. nominal) using an independent samples t-test. We did not obtain a significant difference between the two groups (likely due to the small number of respondents). However, we did obtain an overall trend that has been established in the previous literature (see Cooper, Gallupe, Pollard & Cadsby, 1998; Dennis & Valacich, 1993; DeRosa, Smith & Hantula, 2007; Gallupe, Bastianutti & Cooper, 1991; Valacich, Dennis & Connolly, 1994); that is, that the participants in the group condition were generally more satisfied ($M = 3.85$, $SD = 0.75$ for group condition; $M = 3.75$, $SD = 1.99$ for nominal condition), motivated ($M = 4.00$, $SD = 1.00$ for group condition; $M = 3.33$, $SD = 2.87$ for nominal condition) and interested ($M = 3.83$, $SD = 1.17$ for group condition; $M = 3.41$, $SD = 2.68$ for nominal condition)in the brainstorming task than were those in the nominal condition.
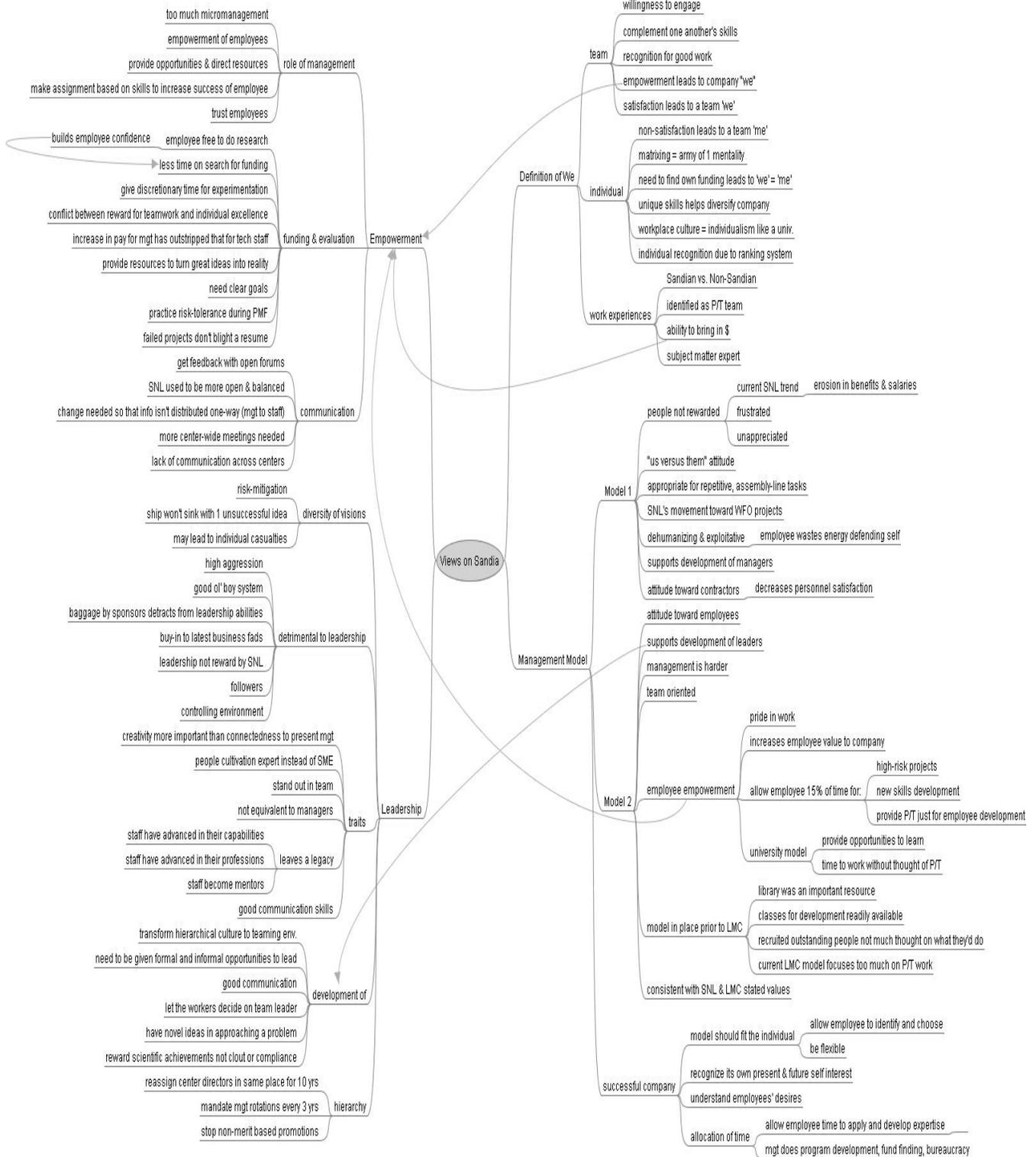
Participant Responses

Participant responses were also qualitatively captured through both a manual mind map, as well as a technical text analysis tool, STANLEY.

Mind Map

The mind map was created as a way to visualize the ideas that had been generated through the electronic brainstorming. The mind map shown in Figure 4 was generated through the use of FreeMind software, version 0.8.0 (Mueller, Polansky, Novak, Foltin, & Polivaev). All ideas that were generated by participants, regardless of group membership, were divided into categories representing the central nodes of Tom Hunter's question. These central nodes were identified as: empowerment, definition of we, leadership, and management model. The node of empowerment represented all those ideas that were directly related to how the participants viewed the empowerment of the employee within the company. The definition of we included all responses made by the participants in how the "we" of the company was defined as well as how the individual employee identified with the "we". The management model node addressed the participants' remarks and ideas to the study question regarding the two management models of viewing employees as resources to be used by the company or as assets to be developed. Finally, the leadership node included those ideas that directly related to how leaders are identified and defined within the company.

Ideas were not represented verbatim within the mind map as written by the study participants. Instead, the gist of the idea was represented as relating to the central nodes. Many ideas were repeated by several participants. These ideas were only represented once within the mind map.

Views on Sandia

Empowerment

role of management
- too much micromanagement
- empowerment of employees
- provide opportunities & direct resources
- make assignment based on skills to increase success of employee
- trust employees

builds employee confidence
- employee free to do research
- less time on search for funding

funding & evaluation
- give discretionary time for experimentation
- conflict between reward for teamwork and individual excellence
- increase in pay for mgt has outstripped that for tech staff
- provide resources to turn great ideas into reality
- need clear goals
- practice risk-tolerance during PMF
- failed projects don't blight a resume

communication
- get feedback with open forums
- SNL used to be more open & balanced
- change needed so that info isn't distributed one-way (mgt to staff)
- more center-wide meetings needed
- lack of communication across centers

Leadership

diversity of visions
- risk-mitigation
- ship won't sink with 1 unsuccessful idea
- may lead to individual casualties

detrimental to leadership
- high aggression
- good ol' boy system
- baggage by sponsors detracts from leadership abilities
- buy-in to latest business fads
- leadership not reward by SNL
- followers
- controlling environment

traits
- creativity more important than connectedness to present mgt
- people cultivation expert instead of SME
- stand out in team
- not equivalent to managers

leaves a legacy
- staff have advanced in their capabilities
- staff have advanced in their professions
- staff become mentors
- good communication skills

development of
- transform hierarchical culture to teaming env.
- need to be given formal and informal opportunities to lead
- good communication
- let the workers decide on team leader
- have novel ideas in approaching a problem
- reward scientific achievements not clout or compliance

hierarchy
- reassign center directors in same place for 10 yrs
- mandate mgt rotations every 3 yrs
- stop non-merit based promotions

Definition of We

team
- willingness to engage
- complement one another's skills
- recognition for good work
- empowerment leads to company "we"
- satisfaction leads to a team 'we'

individual
- non-satisfaction leads to a team 'me'
- matrixing = army of 1 mentality
- need to find own funding leads to 'we'= 'me'
- unique skills helps diversify company
- workplace culture = individualism like a univ.
- individual recognition due to ranking system

work experiences
- Sandian vs. Non-Sandian
- identified as P/T team
- ability to bring in $
- subject matter expert

Management Model

Model 1
- people not rewarded
  - current SNL trend — erosion in benefits & salaries
  - frustrated
  - unappreciated
- "us versus them" attitude
- appropriate for repetitive, assembly-line tasks
- SNL's movement toward WFO projects
- dehumanizing & exploitative — employee wastes energy defending self
- supports development of managers
- attitude toward contractors — decreases personnel satisfaction
- attitude toward employees
- supports development of leaders
- management is harder
- team oriented

Model 2

employee empowerment
- pride in work
- increases employee value to company
- allow employee 15% of time for:
  - high-risk projects
  - new skills development
  - provide P/T just for employee development

university model
- provide opportunities to learn
- time to work without thought of P/T

model in place prior to LMC
- library was an important resource
- classes for development readily available
- recruited outstanding people not much thought on what they'd do
- current LMC model focuses too much on P/T work

- consistent with SNL & LMC stated values

successful company
- model should fit the individual
  - allow employee to identify and choose
  - be flexible
- recognize its own present & future self interest
- understand employees' desires
- allocation of time
  - allow employee time to apply and develop expertise
  - mgt does program development, fund finding, bureaucracy

**Figure 4. Mind map of ideas generated through brainstorming.**

STANLEY Analysis

STANLEY is a text analysis tool developed at Sandia National Laboratories (Bauer, Verzi, Basilico, 2005). We used this tool to analyze the responses and compare models of the two conditions (nominal vs. group). STANLEY first performed a syntax analysis on the responses to find the frequent noun phrases (see Table 2).

Common Noun Phrases	Occurrences
appropriate balance	10
natural resource	9
identification and development	8
environment best	7
natural resources	6
technical professionals	4
social environment	4
leadership development	4
environment i e	4

Table 2 A list of the most common noun phrases found in the idea submissions.

The next step was to build a model of the nominal and group submissions using the Analyst Aide tool within STANLEY. To improve the models, we removed the 842 most common stop words (common words such as *and, the, a, etc.* that carry little semantic content in English). Thirty seven terms were also excluded from the analysis because they did not include strongly meaningful words. These models were then visualized using the Analyst Aide (see Figure 5).
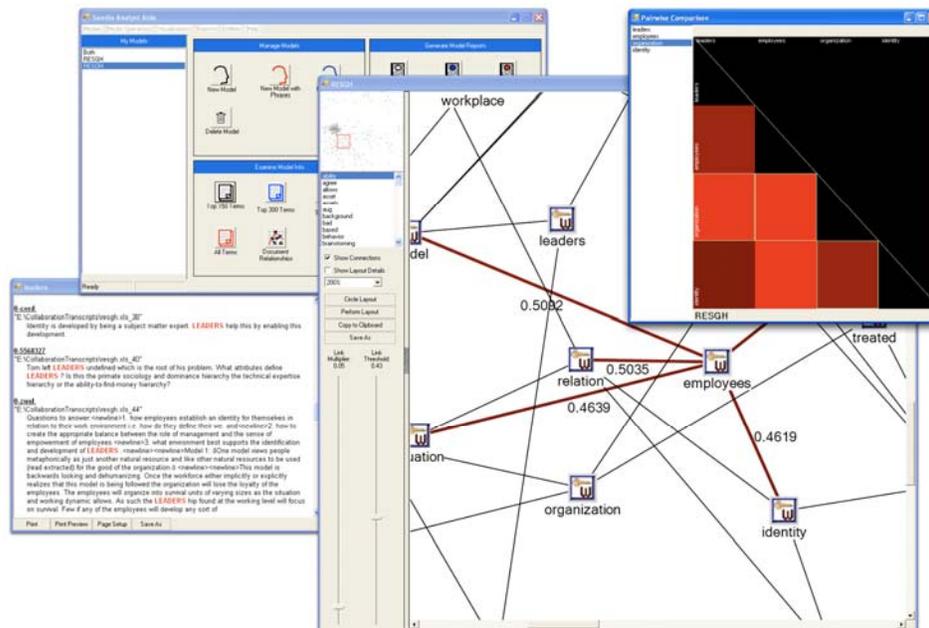
Figure 5. Visualization with Analyst Aide., Note that key terms are now highlighted in the text (lower left), and that the relationship strengths between terms are compared in the heat map (upper right) while the same annotations are provided on the links in the graphical representation (lower right).

The visualizations show graphs of relationships among key terms. A key term is one that both occurs frequently and is relatively evenly distributed among the documents in a corpus[5]. Two terms are considered to be related to each other if they co-occur in a posting[6] and the strength of relationship is a function of how frequently the term occurs and its distribution among all of the documents. The strength of relationships range from a low of 0 to a maximum of 1 and is related to the a cosine of term occurrence vectors.

In the visualizations, each node in the graph corresponds to a term. Each link represents a relationship among two terms. The visualization is then drawn to minimize the distance among strongly related terms.

Based on linkage densities (see Figure 6), the discussion in group condition appears to be more cohesive than the combined, individual inputs in the nominal condition. In both data sets, there appears to be a core of closely related terms and a set of more loosely related terms. However, in the nominal condition, there is a single link between the core cluster and the other related terms, whereas in the group condition, there are clearly more links to the core cluster. This observation is consistent with the actual discourse among those in the group; while those in nominal condition were only exposed to their own ideas
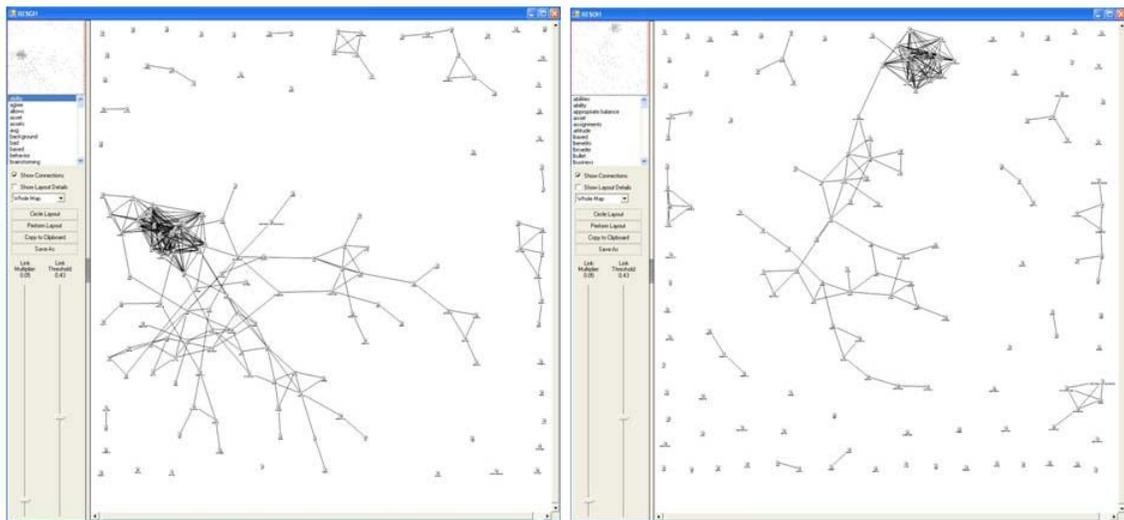
Figure 6. Visualization of the model for the group that worked together (left), and the model for the group that worked alone (right). Note that the collaborative group has a higher connection density than the group working as isolated individuals, indicating a more cohesive discourse.

It is important to note, however, that both data sets are fairly small and the group condition contains less data (since there were fewer participants in this condition). It is possible the group sizes account for the differences; we have seen similar affects among other small datasets.

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[5] i.e., has a high entropy
[6] Long postings (more than 150 words) were automatically split into smaller chunks and treated as individual postings for the purpose of this analysis.

Further work would be required before any conclusion could be confidently drawn from the automated STANLEY analysis.

Discussion

Experiment
Group decision-making and electronic communication are integral to contemporary work organizations, and offer a yet to be explored research context in which to solve the "wicked," or ill-defined problems. Industry's shift from individual to team contributions, as well as increasing reliance on computer-mediated communications, underscores the practicality of this need. From a more academic viewpoint, the relevant, vast, non-unified, group research has yet to be rigorously applied to industrial settings. Thus, the current experiment sought to experimentally extend current laboratory findings to a real-world setting, and additionally to provide viable solutions to a current, wickedly difficult problem facing Sandia management.

To date, the relevant research has primarily involved laboratory settings with college students, leaving its generalizability to industrial applications unclear. The current experiment expanded upon previous research by addressing several key differences between preceding laboratory work and an industrial setting like Sandia. These differences and experimental design considerations included the following:

- Industrial settings, grappling with "wicked" problems, may be more inclined to assess the quality of ideas, rather than the quantity of ideas typical of the current literature. The current experiment measured both quality and quantity of ideas.
- Industrial settings often have the opportunity to leverage large teams with diverse skills and knowledge. Previous research has primarily studied three- to four-person student groups, but because there seems to be a relationship between group size and effectiveness (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe et al., 1991; Valacich et al., 1994), there is reason to speculate that very large, diverse work teams might be especially effective for industrial settings. The current experiment tested a much larger group (N = 30) consisting of diverse employee job classifications.
- Industrial employees are often invested in the outcome of a problem solving activity in a way that laboratory participants may not be. Rather than generating solutions to irrelevant questions about extra thumbs, the current experiment asked participants to address a wickedly difficult problem posed by our company president.
- Industrial settings often have scheduling demands that preclude the abbreviated, concurrent brainstorming typically used by studies in the current literature. The current experiment expanded the brainstorming session to a four-day period during which individuals could contribute as their schedule allowed.

Our primary empirical finding demonstrates that (at least for this interface design) nominal brainstorming is superior to group brainstorming. While there was no significant difference in the number of ideas between participants in our nominal and group conditions, our results

suggest that the nominal condition tended to produce more ideas than those in the group condition. As might be expected, those in the nominal condition tended to produce a greater number of sentences and words than those in the group condition.

What is more interesting, though, is that the quality of the ideas in the nominal condition was significantly better across all three quality ratings, including originality, feasibility, and effectiveness. Although these results are preliminary, they are potentially interesting for two reasons that will be discussed in turn. First, they demonstrate that employees may effectively use computer-mediated nominal brainstorming as a cost effective means to work on wickedly difficult problems. Second, they are a novel empirical finding suggesting that electronic group effectiveness may be mediated by group size.

First, the finding that individuals are more successful than groups in computer-mediated brainstorming suggests a time- and cost-savings potential for companies. Generally, when electronic group brainstorming is compared to verbal brainstorming, it is touted as having the advantages of shorter meetings, increased participation by remote team members, better documentation via electronic recording, improved access to the meeting records and, importantly, cash savings (Furnham, 2000). When there is no longer the mandate that these electronic communications occur concurrently, these advantages would seem to be even greater. One might assume that participants in a nominal condition would require less time to contribute ideas as compared to those in a group condition where they would (ideally) read the other postings before giving their ideas. However, at least some of the submissions suggested that they were prepared offline and pasted into the web site forms. Thus an evaluation of the time savings in this experiment is not addressed. However, nominal brainstorming does allow for increased participation due to greater scheduling flexibility. In sum, these current findings suggest a novel way to solve wickedly difficult problems face-to-face or electronic meetings.

Second, the current findings indicate that electronic group effectiveness may be mediated by group size. While the previous literature comparing group to nominal brainstorming has produced mixed results with small groups of 3-4 participants (group superior: Dennis & Valacich, 1993; Dennis & Valacich, 1994; Paulus & Yang, 2000; nominal superior: Barki et al., 2001; Pinosonneault et al., 1999; no difference: Connolly et al., 1993; Cooper et al., 1998; DeRosa et al., 2007; Dugosh et al., 2000), larger groups of 12 - 18 people have outperformed nominal brainstormers (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe et al., 1991; Valacich et al., 1994). The studies finding EBS performance superior to nominal group performance have attributed these findings to the stimulating effect of exposure to others' ideas (Dugosh et al, 2000; Nijstad et al, 2003; Paulus & Yang, 2000; although also see Ziegler et al, 2000 as cited by Kerr & Tindale, 2004) and the diversity and heterogeneity of those groups (Schruijer & Mostert, 1997). However, our data suggest that these findings may not be scalable. Instead, there may be some limitations with very large groups. Such limitations might relate to the extra working memory load of holding large amounts of other participants' responses in mind while simultaneously responding. They may also relate to social loafing within a larger group or even a website usability issue in which group participants were unable to use the website to optimally read through the vast quantity of responses.

In fact, participants in our group condition did comment about difficulty navigating through other people's responses. Participants commented that the "interface is terribly awkward and ugly…a proper forum with…threading would lead to true brainstorming. As it is, we really can't respond to each other and are just posting in isolation…if there is no indication of which posts are new, how are we supposed (to) respond to each other?" Furthermore, nine more participants in the group condition logged-on but failed to leave a response compared to those in the nominal condition. It is possible that the group condition drop-outs might have logged on, found the interface difficult to use and then logged off without contributing an idea.

While a difficult to use interface might initially seem to explain the data, it doesn't completely account for our findings. First, the satisfaction data tended to favor the group condition over the nominal condition. Thus, it anecdotally seems that group participants were more satisfied, motivated and interested in the brainstorming task than were those in the nominal condition, which counters the idea that group participants were disproportionately impacted by the interface. Second, the interface usability issue would be expected to differentially impact the group condition only to the extent that it inhibited their ability to read other people's responses. Thus, it is unclear that the interface would fully account for the results favoring nominal group performance. Moreover, the STANLEY data suggests that participants in the group condition were more strongly clustered than those in the nominal condition. This observation seems to support the fact that participants in the group condition were in fact able to accurately read and respond to other postings.

In sum, our data demonstrate that within the current industrial setting, nominal brainstorming was at least as effective as group brainstorming. This study is the first to our knowledge to empirically examine brainstorming within an industrial setting. Additionally, the current experiment is the first to extend brainstorming groups beyond the typical 3- or 4-person groups (occasionally 12-person) to a large, 30-person group. It is also the first to examine how a longer duration of 4 days affects results.

While our results demonstrate that nominal brainstorming is more effective than group brainstorming, more research will be necessary in order to fully circumscribe the generalizability of this finding to other questions, interfaces, and industrial settings. Future research may compare different computer-mediated technologies, interfaces, and experimental manipulations. For example, a more wiki-like interface might allow users to build off of other people's ideas more easily than the interface used for the current experiment and, thus, outperform a nominal group. Another potential mitigation for large group brainstorming might also include having some kind of facilitator. As one of our participants suggested, "In a real world brainstorm it seems like there should be at least one person in charge with the ability to bring up additional points and keep the ideas flowing when they slow down as they did after the first 2 days here."

Brainstorming Response

In addition to the empirical data, we also had an opportunity to collect responses from a wide variety of the Sandia workforce regarding a real-world, wickedly difficult problem. From both a text analysis and a manual mind-mapping exercise, we found the following themes from respondents.

- Most participants balked at being managed under a resource-driven model and preferred the asset-driven model
- There was a consistent theme of expressed discontent with the constant pressure to secure funding. The participants preferred an environment in which they are allowed a percentage of time to explore other interests and develop new skills.
- There is a lack of communication across the labs resulting in a fractured team mentality.
- Empowerment of employees will come with the instatement of good leaders who approach problems with creativity and support employee development.

Because of Sandia National Laboratories' mission, "a variety of research and development programs to help secure a peaceful and free world through technology" (Sandia National Laboratories external homepage, 2007), Sandia's success is integrally intertwined with solving wickedly difficult issues, especially through computer-mediated means. The question that Tom Hunter posed seem to fit well the description of a wickedly, difficult problem as evidenced by the following participant response.

> *Nothing in this statement is a problem. The questions that are asked are completely (or nearly so) unrelated to the proposed models. As a result, there is no meaningful context for the questions themselves. A further problem is that too many of the key words in this statement are vague, undefined, and likely loaded terms in the individual readers' minds that it is likely nearly impossible to communicate meaningfully.*

Despite this participant's comments, the group and individuals working alone did explore the posed question, and did produce over 200 concepts and ideas. Consequently, companies may find a way to use EBS to clarify issues surrounding wickedly difficult problems they face.

Achieving a better understanding of effective computer-mediated decision-making could allow us to mitigate the deleterious decision-making effects and bolster potential benefits. As the following respondents stated, Sandia innovation will rely upon further research and technology invested in these types of problem solving.

- *In Japan, large companies get about 1-2 MILLION improvement ideas/year and implement 95% or more of them. Try to get a new idea through Sandia.*
- *We are trying to be like industry…we have to be better…How do you empower employees? Ask them. Talk to them. Get their ideas and if they are good ideas, implement them. Tell employees why decisions are made and be truthful about it. Don't treat them as resources to be used up and tossed away.*

Doing these things in a world class way will require the very best kind of internal communications, and the tools to support those discussions. If we need to be better than industry and if we want to think of ourselves as a "we" that works and innovates in the national interest, then we should invest in tools, and the creation of an internal culture to let us ask all of our employees to participate in creating (even engineering) the pathway to that future Sandia National Laboratories.

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