

On The Relationship Between Idea-Quantity and Idea-Quality During Ideation

Bruce A. Reinig · Robert O. Briggs

Published online: 18 April 2008
© Springer Science+Business Media B.V. 2008

Abstract A great deal of research has been conducted to develop methods and techniques to improve group ideation. Most of this research focuses on techniques for increasing the quantity of ideas generated during ideation; less attention has been given to the quality of the ideas produced. This focus stems from the widely held quantity–quality conjecture, that, all else being equal, more ideas give rise to more good ideas. In this paper, we argue that cognitive inertia and scarcity of solution space may affect the relationship between idea-quantity and idea-quality as ideation proceeds, resulting in a condition of diminishing returns for additional ideas. Results of a laboratory study using fourteen groups supported the diminishing returns hypothesis. Recommendations for future ideation research are suggested.

Keywords Ideation · Brainstorming · Idea quality · Idea quantity · Ideation function · Cognitive inertia

Managerial decision making is often modeled as a multi-step process (e.g., Dewey 1910; Pokras 1989; Simon 1977) and various methods and techniques have been developed to improve the performance of each step. Most multi-step decision making models include an ideation step, whereby decision makers generate multiple alternatives for addressing the task at hand. Ideation researchers have developed and tested methods such as brainstorming and the nominal group technique to improve ideation.

In practice, the goal for an ideation process is usually to generate high quality ideas. High-quality ideas are those likely to yield successful outcomes for decision makers. Low-quality ideas are those unlikely to result in successful outcomes. However, most often, the

B. A. Reinig (✉)
Department of Information & Decision Systems, San Diego State University, San Diego, USA
e-mail: breinig@mail.sdsu.edu

R. O. Briggs
Institute for Collaboration Science, University of Nebraska at Omaha, Omaha, USA

R. O. Briggs
Department of Systems Engineering, Faculty of Technology, Policy, and Management,
Delft University of Technology, Delft, The Netherlands
e-mail: rbriggs@mail.unomaha.edu

primary dependent variable in ideation research is the number of ideas produced, rather than their quality (see Diehl and Stroebe 1987; Fjermestad and Hiltz 1999, for reviews). A large quantity of ideas would only be useful insofar as it produces a subset of high-quality ideas, in which case, the critical dependent variable remains quality, not quantity. The substitution of quality for quantity is based on the long-held and widely-cited conjecture that, all else being equal, an ideation technique that gives rise to more ideas will give rise to more good ideas (e.g., Osborn 1963; Diehl and Stroebe 1987, 1991; Valacich et al. 1994).

This paper examines the quantity–quality conjecture and attempts to shed light on the relationship between idea-quantity (i.e., the number of ideas generated during ideation) and idea-quality (i.e., the number of good ideas generated during an ideation session). We begin by examining the origins and scope of the quantity–quality conjecture. We then present arguments that may challenge the validity of the quantity–quality conjecture under certain circumstances. We report the results of a laboratory study to test those arguments, and discuss the implications of the findings for previous and future ideation research.

1 Review of Ideation Literature

We define *ideation* as the process of generating or conceiving of ideas that may be useful toward the attainment of some desired state or outcome. Since the 1950s much of the work on ideation has focused on increasing the number of ideas a group can produce. This focus can be traced to seminal work by Osborn (1963) who conceived an ideation protocol called, *brainstorming*, with four ground rules: (a) that participants refrain from criticism; (b) that they hold themselves open to wild or unusual ideas; (c) that they focus on generating a large quantity of ideas; and (d) that they to build and expand on the ideas of others (Osborn 1963). Osborn held that “*It is almost axiomatic that quantity breeds quality in ideation. Logic and mathematics are on the side of the truth that the more ideas we produce, the more likely we are to think up some that are good* (Osborn 1963, p. 131).”

This quantity–quality conjecture became a guiding principle of ideation research. More than twenty studies followed that compared the number of ideas produced with the brainstorming protocol to the number produced using the nominal group protocol, wherein each participant makes a private list of ideas, after which the private lists are collected and aggregated (Diehl and Stroebe 1987). Many of those studies, however, appear to assume that the goal of their research should be to increase idea quantity. When researchers were not able to demonstrate that brainstorming produced more ideas than nominal group technique, they began to seek theoretical explanations for the number of ideas a group could produce. Diehl and Stroebe (1987, 1991) eventually demonstrated that brainstorming groups suffer from production blocking, evaluation apprehension, and free riding, all of which limit idea production. A number of subsequent ideation studies demonstrated that production blocking and evaluation apprehension could be overcome by using group support systems (GSS) that allowed participants to contribute their ideas simultaneously and anonymously over a computer network (e.g., Dennis and Valacich 1993; Gallupe et al. 1991, 1992; Valacich et al. 1994). Shepherd et al. (1996) further demonstrated that free-riding could be reduced through performance feedback combined with deliberate invocations of social comparison.

This line of research, however, still embraced the quantity–quality conjecture either implicitly or explicitly. A number of ideation studies did not address idea-quality (e.g., Cohen et al. 1960; Dennis and Valacich 1993; Harari and Graham 1975; Jessup et al. 1990; Madsen and Finger 1978; Maginn and Harris 1980; Pinsonneault et al. 1999; Rotter and Portugal 1969; Street 1974). Others argue that there was sufficient evidence for the quantity–quality

conjecture in the literature (typically by citing a study that reported a correlation between the number of ideas a group produced and some measure of idea quality), and argued that it was therefore not necessary to measure idea quality (e.g., Gallupe et al. 1991; Shepherd et al. 1996).

A number of researchers did measure both idea-quantity and idea-quality, but the results of these studies are also equivocal (Barki and Pinsonneault 2001). Some reported that certain ideation protocols improved both idea-quantity and idea-quality (e.g., Diehl and Stroebe 1987, 1991), while others found no relationship between idea-quantity and idea-quality (e.g., Aiken et al. 1996; Connolly et al. 1990; Gyskiewicz 1988).

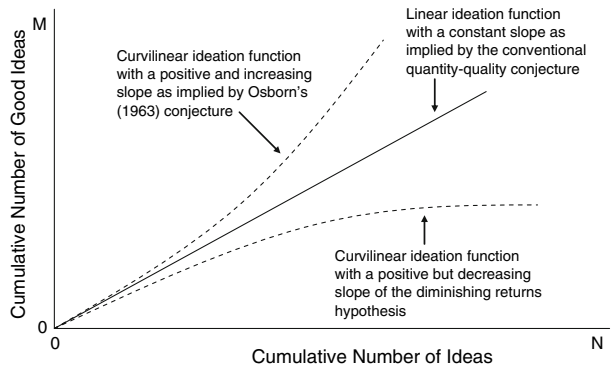
Many studies that did report both idea-quantity and idea-quality data either did not propose a theoretical relationship between the two constructs (e.g., Gallupe et al. 1992; Gurman 1968; Petrovic and Krickl 1994) or cited Osborn's quantity–quality conjecture as the basis for the relationship (e.g., Dennis et al. 1997, 1999). However, the conflicting results led others to begin exploring whether a theoretical foundation could be developed to explain and test the predictions of the quantity–quality conjecture. Briggs et al. (1997) reasoned that both idea quantity and idea quality require the expending of scarce attention resources, and so both should covary with reductions of attention demands for communication, deliberation, information access, and distractions, and that ideation quantity and quality should both be increased by goal congruence. They argued that an increase in the quantity of brainstorming ideas, even bad ones, might directly stimulate the production of more good ideas by (a) broadening awareness of the potential solution space; (b) invoking counter-arguments that increased understanding of the problem space; and (c) allowing for the development and refinement of ideas proposed by others.

However, an empirical test of their position revealed a far stronger correlation between idea-quantity and the number of bad ideas than between idea-quantity and the number of good ideas. They found that idea quality did not account for much of the variance in idea quality and concluded that, “. . . the model “Quality follows Quantity” is clearly incomplete, and as such is inadequate for predicting and explaining idea quality” (Briggs et al. 1997).

2 Relationship Between Quantity and Quality in Ideation

Ideation is used in the decision making process to generate good ideas, often in the form of solutions, courses of action, and opportunities. We define an *idea* in the context of problem-solving and decision-making as a verb–object phrase that is proposed as a solution for the problem or task at hand. A good idea would be one that is feasible to implement, and that eliminates unacceptable conditions, without creating other unacceptable conditions. An idea would not be considered good if it is infeasible to implement, or does not eliminate unacceptable conditions, or creates new unacceptable conditions. The principle objective of ideation is often to isolate a small set of good ideas with the intention of implementing one of them (Barki and Pinsonneault 2001). Thus, we will proceed by examining the theoretical relationship between idea-quantity (all ideas, both good and not-good) and idea-quality (good ideas only) during ideation, which we refer to as the *ideation function*. First we examine the theoretical implications of the quantity–quality conjecture for the ideation function and then we examine factors that may cause the ideation function to differ from what the quantity–quality conjecture suggests.

Fig. 1 Three possible shapes for the ideation function



2.1 Ideation Functions Implied by the Quantity–Quality Conjecture

Osborn (1963) argued that the rate of good ideas would become greater as ideation proceeded. Osborn (1963) states that “early ideas are unlikely to be the best ideas (p. 132)” and suggested that the second half of the ideas generated during an ideation session would produce more good ideas than the first half. This view implies an increasing ratio of good ideas to total ideas, which would give rise to a curvilinear ideation function with a positive and increasing slope (Fig. 1). That is, the ratio of good ideas to total ideas would increase as more ideas are generated, resulting in increasing returns for additional ideas.

Most other papers, however, do not argue the quantity–quality conjecture in terms of increasing returns; rather, they simply state that more ideas result in more good ideas (e.g., Dennis et al. 1997; Shepherd et al. 1996), which implies a linear ideation function (Fig. 1). With a linear ideation function, the ratio of good ideas to total ideas remains the same as more ideas are generated. If the ideation function were shown to be linear, then it would only be necessary to develop techniques that improve idea-quantity, knowing that improvements in idea-quality would necessarily follow, assuming that there were additional good ideas that could be generated. If the ideation function were linear, then ideation researchers would be justified in using quantity as a surrogate for quality in their ideation studies.

2.2 An Ideation Function with Diminishing Returns

There are certain factors that may cause the ratio of good ideas to total ideas to decrease as ideation proceeds, resulting in a condition of decreasing returns for additional ideas. Two such factors identified here are cognitive inertia and a scarcity of solution space.

Cognitive inertia is caused by the limitations of spreading activation and working memory. Knowledge is represented in the human mind as a network of concepts or categories (Smith 1995) and newly perceived objects are assigned to various categories in long-term memory depending on factors such as the typicality of their attributes (Malt and Smith 1982). External stimuli, such as a problem statement or the ideas proposed during ideation, automatically and subconsciously activate certain related concepts, moving them from long-term memory to working memory (Collins and Loftus 1975). This, in turn, gives rise to spreading activation, as concepts closely related to those already in working memory are themselves activated. However, working memory is limited (Baddeley 1990; Miller 1956), so only a small subset of concepts from long-term memory can be accessed at a given moment. As people address their task, they can only work with concepts made available to them through initial activation and

spreading activation. Eventually, spreading activation may result in the activation of concepts that are less and less relevant to the task at hand, exhausting possibilities for a particular line of thinking. However, lacking other external stimuli, people experience difficulty shifting to different, more useful lines of thought. This condition is called *cognitive inertia*. When cognitive inertia occurs, a person is stuck with a subset of concepts and has difficulty activating additional concepts in long-term memory. Cognitive inertia can cause ideation groups to focus on a few narrow topics or themes (Dennis et al. 1997). When cognitive inertia occurs, additional ideas may become more-and-more similar to previous ideas rather than offering new insight. To the degree that cognitive inertia becomes manifest, it would decrease the ratio of good ideas to total ideas, resulting in an ideation function with a positive but decreasing slope (Fig. 1).

Depending on the nature of the task, scarcity of solution space may also cause diminishing returns as ideation proceeds. The quantity–quality conjecture implies that there are always additional good ideas to be found, provided adequate conditions exist for the production of more ideas. For some tasks, such as naming a bridge, or conceiving of new products (Osborn 1963) there may exist an unlimited set of good possibilities. However, other tasks, such as identifying potential vendors and shipment alternatives, may have a finite solution space. As ideation proceeded for tasks with a finite solution space, once all of the good ideas had been generated the ideation function would flatten (i.e., a slope of zero), representing zero returns on additional ideas. Due to the effects of cognitive inertia and scarcity of solution space, as ideation proceeds additional ideas may begin to produce diminishing returns whereby the ratio of good ideas to total ideas decreases as more ideas are generated (Fig. 1).

Ideation with diminishing returns would give rise to an ideation function that is a curve with a positive but decreasing slope whereas the quantity–quality conjecture implies an ideation function that is a line with a constant slope. Therefore, on the basis of cognitive inertia and limitations of solution space, we hypothesize:

Hypothesis As ideation proceeds within a given session, a curve with a positive but decreasing slope will account for more of the variance in number of good ideas as a function of total ideas than will a line with a constant slope.

The following section reports on an experiment to test this hypothesis.

3 Method

We chose to test the diminishing returns hypothesis with a laboratory study. It is possible to study ideation with groups in the workplace, who take on a variety of rich and complex tasks. However, not all of these tasks involve ideation, and it is generally not feasible to assign groups in the workplace to all complete the same ideation task under controlled conditions. If each group conducted its own ideation task, it would be difficult to compare quality of the ideas generated across groups. A laboratory setting allowed us to collect observations of multiple groups working on the same task. This also meant that the same set of experts could rate the quality of the ideas generated by all groups. Had we used multiple field tasks, each set of ideas would have had to be evaluated by a different set of experts.

3.1 Task

We sought a task that would lend itself to ideation research and would be appropriate for, and of interest to, student participants. We used a variation of Wheeler and Mennecke's school

of business task (1992). [Mennecke and Wheeler \(1993\)](#) designed this task to achieve the following six objectives:

- (1) The task should be interesting and engaging to student subjects and should create a perceived stake among group members in the outcomes of the task;
- (2) It should require behaviors and knowledge that are within students' knowledge domain;
- (3) It should distribute unique domain knowledge and perspectives about the task issues among group members;
- (4) It should evoke students' assumptions and biases;
- (5) It should contain sufficient task complexity to simulate "wicked" problems ([Dennis et al. 1989](#)) found in natural tasks;
- (6) It should yield a meaningful index of solution quality (p. 78).

The school of business task is a hidden profile task ([Stasser 1992](#)) in which each participant starts with different information. The task requires five participants to each assume one of the following roles: Associate Dean, President of the Student Council, President of the Alumni Association, Chairperson of the Faculty Council, and Vice President of Undergraduate Instruction. Each student was given a packet with information unique to their role. The task included a number of interrelated symptoms such as overcrowded classrooms, too few sections of required classes, diminishing quality of instruction, and declining job placements among graduates. The task is structured such that solutions that address any one symptom are likely to exacerbate other symptoms.

After consulting the task authors about their experiences with the task, we modified¹ the task to reduce some of the ambiguity in the roles (e.g., we added a computation of admissions rate even though the raw data was there for the participant to compute it himself or herself) and to adapt the language to the university at which the data collection took place. We eliminated the humorous names (e.g., Dr. Polly Wannacracker and Dr. R.U. Crazy) to enhance the realism of the task and added details to the task to add complexity and broaden the possible solution space (e.g., elaborating the goals and challenges facing different levels of faculty, adding awareness of financial constraints, and adding pressure from interest groups to the Associate Dean's role).

Many participants commented after the sessions that they had personally experienced frustration from the problems described in the task. Their typed comments often referenced real places, people, and circumstances at the university in which the study took place, rather than hypothetical or imagined circumstances. Thus, evidence suggested that the students found the task to be engaging, and that they valued the opportunity to think through the possible ways these problems might be resolved.

3.2 Participants

Seventy undergraduate students from the college of business in a large university were randomly assigned to 14 five-person groups working on an ideation task. The participants received extra credit in an introductory course in management information systems for their participation because it gave them hands-on experience with collaboration technology. However, their instructor was not involved in the study.

¹ [Salisbury et al. \(2002\)](#) also modified the school of business task ([Wheeler and Mennecke 1992](#)); their objective was to make the task fit the setting of a western Canadian university.

3.3 Procedure

We began each experimental session with a sense-making activity to ensure that all groups began the task with the same set of information about the problem (this does not however, imply that they surfaced all relevant information about the solutions). We did this for two reasons. First, this approach is consistent with our experience facilitating hundreds of problem-solving teams in the workplace, where working professionals typically begin with a discussion about the problem before starting to generate solutions. Some organizational teams require little time for sense-making because they are already familiar with the problem when they arrive. Second, it ensures some consistency across all sessions in that each group had the opportunity to address the problem. We did not want to have a situation where no good ideas could occur because the participants did not understand the purpose of their ideation.

Participants received a small packet containing information about the case and were given ten minutes to familiarize themselves with its contents. A researcher then conducted a structured interview which included a set of questions designed to surface all of the relevant information. For example, questions included, “How are the student computer labs?” to elicit the fact that there were not enough computers on campus and “Can you get the classes you need?” to elicit the fact that not enough sections were available. At the end of the interviews, the researcher printed and distributed a standard list of symptoms, so all participants started generating solutions with an identical problem statement.

Participants began ideation immediately after the sense-making exercise. Consistent with previous ideation research (e.g., [Dennis and Valacich 1993](#); [Diehl and Stroebe 1991](#); [Gallupe et al. 1992](#)), we instructed participants to generate ideas as follows:

Your goal is to identify as many different solutions as possible in a short amount of time. So we urge you to concentrate on generating new solutions. Try not to repeat yourself. State your case and move on; don't get bogged down arguing the same point over and over again. . . . Right now your goal is to generate as many different solutions as possible.

Pilot tests revealed that students were willing to ideate for between 40 and 60 min on the school of business task. We therefore gave participants 40 min to generate ideas using GSS technology. The technology had been used in previous ideation research (e.g., [Barki and Pinsonneault 2001](#); [Dennis et al. 1990](#); [Valacich et al. 1994](#)) and included a computer for each participant connected over a network. The question, “What can be done to resolve the problems of the school of business?” appeared at the top of each participant's computer screen, which included a window for them to type their ideas. When participants submitted an idea, the system would remove the page containing their comment, and automatically replace it with a new page containing other people's comments. The comments were made anonymously and the GSS generated time-stamped transcripts of the ideation sessions.

3.4 Evaluating Idea Quality

Two treatment-blind analysts evaluated the session transcripts to extract the unique ideas from the comments each group contributed. A unique idea is defined as a unique verb-object pair suggesting a possible solution to the problems. Contributions that contained multiple ideas were disaggregated into single unique ideas. For instance, a comment suggesting to “Hire more faculty and build more computer labs,” would be disaggregated into two unique ideas: “Hire more faculty,” and “build more computer labs.” The raters also recorded the

order and time-stamp for each unique idea. The raters achieved 97% agreement in their lists of unique ideas. Raters then met to resolve their disagreements.

Two treatment-blind experts, each with more than 15 years experience in the task domain, conducted a structured solution-quality evaluation of the unique ideas extracted from each session. Each rater judged the quality of each idea using the following rubric:

- A solution receives a score of 4 if it is easily implemented and if it solves the problems (eliminates unacceptable symptoms) completely without creating new unacceptable symptoms.
- A solution receives a score of 3 if it is easily implemented, and would ease most symptoms considerably, but would not completely eliminate them or if it would be difficult to implement, but would completely solve the problems.
- A solution receives a score of 2 if it would be very difficult to implement and would solve some of the problems considerably but would not completely eliminate them, or if it is easily implemented, but would only have minor, marginal improvement in terms of solving the problems.
- A solution receives a score of 1 if it would be impossible to implement or if it does not solve any of the problems to any degree.

Coders were instructed to consider economic, technical, and political feasibility as a part of their evaluations. The raters gave scores that differed by no more than one point to over 99% of the ideas. The raters then met to reconcile the discrepancies.

3.5 Choosing a Quality Threshold

An ideation function characterizes the number of good ideas as a function of the total number of ideas. It is therefore necessary to decide what constitutes a good idea. Table 1 presents the distribution of ideas by quality rating for each session. Participants contributed many more ideas that received lower ratings than they did ideas that received higher ratings. For some kinds of problems, a team seeks only ideas that fully solve the problem, so only the best ideas (e.g., those that rated a four in our study) would be counted as good ideas. For other kinds of problems, any idea that could contribute even a little toward the goal might be regarded as a good idea (e.g., ideas that rated a two in our study). Because there is nothing in our theoretical arguments that would suggest that different quality thresholds would yield fundamentally different ideation functions, we tested whether the diminishing returns hypothesis held with quality thresholds set at four points, three points, and two points.

3.6 Hypothesis Testing

3.6.1 Polynomial Regression Analysis

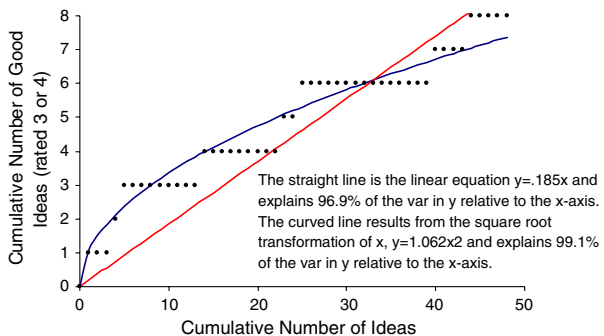
For each ideation session, we used the idea quantity and idea quality findings to plot an ogive representing the observed ideation function. The original order of the ideas was maintained using the time-stamps provided by the GSS. This yielded a monotonically increasing distribution of the cumulative number of ideas on the X -axis and the cumulative number of good ideas on the Y -axis (see example plotted in Fig. 2).

Logically, an ideation function must start at the origin (0, 0), because no good ideas can exist when no ideas have yet been contributed. Therefore, all regressions were calculated with the y -intercept set equal to zero.

Table 1 Distribution of idea quality ratings over each session

Session	Ideas rated 4	Ideas rated 3	Ideas rated 2	Ideas rated 1	Total
1	2	3	6	11	22
2	2	2	5	16	25
3	2	2	5	23	32
4	2	2	9	18	31
5	1	2	3	33	39
6	3	3	19	31	56
7	2	1	3	22	28
8	3	0	7	13	23
9	2	1	16	22	41
10	4	3	16	46	69
11	3	5	9	31	48
12	5	1	7	5	18
13	2	1	14	45	62
14	2	0	9	22	33
Mean	2.50	1.86	9.14	24.14	37.64
Std. dev	1.02	1.35	5.14	11.99	15.76

Fig. 2 An observed ideation function for one of the experimental sessions



First, we tested the hypothesis for each individual session by examining the quadratic term resulting from polynomial regression. This test determines if the quadratic component provides a significant gain in prediction above and beyond a simple linear relationship (Cohen et al. 2003). A significant negative quadratic term would indicate that the slope is decreasing as x -values become larger which is consistent with our hypothesis.

We conducted 42 polynomial regressions, covering 14 sessions at each of the three quality thresholds. All 42 regressions were significant ($p < 0.001$) and all b_1 parameters were positive and significant ($p < 0.001$) indicating that all models had a positive linear component. To test the diminishing returns hypothesis, we examined the quadratic term of the polynomial regression resulting from each of the three quality thresholds. Support for the hypothesis would be indicated by a negative value of b_2 ($H_0 : b_2 \geq 0, H_A : b_2 < 0$). The quadratic term was significant at the $p < 0.05$ level or lower for each of the 14 sessions using a quality rating of four points as the threshold (Table 2a). All but one of the 14 sessions had a quadratic term that was significant at the $p < 0.05$ level or lower with a quality

Table 2 Results of polynomial regressions of the number of good ideas [(a) rated a four (b) rated a four or three (c) rated a two, three or four] on number of ideas

Session	Equation	Overall sig.	Curvilinear effect
(a) Rated a four			
1	$y = 0.351x - 0.013x^2$	$F(2,21) = 143.76^{***}$	$t = -6.60^{***}$
2	$y = 0.266x - 0.008x^2$	$F(2,24) = 497.27^{***}$	$t = -10.25^{***}$
3	$y = 0.218x - 0.005x^2$	$F(2,31) = 644.06^{***}$	$t = -12.29^{***}$
4	$y = 0.093x - 0.001x^2$	$F(2,30) = 102.27^{***}$	$t = -1.85^*$
5	$y = 0.101x - 0.002x^2$	$F(2,38) = 170.81^{***}$	$t = -7.30^{***}$
6	$y = 0.115x - 0.001x^2$	$F(2,55) = 1440.09^{***}$	$t = -9.34^{***}$
7	$y = 0.201x - 0.005x^2$	$F(2,27) = 481.05^{***}$	$t = -8.13^{***}$
8	$y = 0.170x - 0.002x^2$	$F(2,22) = 250.34^{***}$	$t = -1.76^*$
9	$y = 0.069x - 0.001x^2$	$F(2,40) = 147.95^{***}$	$t = -1.87^*$
10	$y = 0.189x - 0.002x^2$	$F(2,68) = 1853.58^{***}$	$t = -19.16^{***}$
11	$y = 0.216x - 0.003x^2$	$F(2,47) = 954.13^{***}$	$t = -14.75^{***}$
12	$y = 0.516x - 0.014x^2$	$F(2,17) = 187.68^{***}$	$t = -3.11^{**}$
13	$y = 0.094x - 0.001x^2$	$F(2,61) = 1825.93^{***}$	$t = -16.31^{***}$
14	$y = 0.227x - 0.006x^2$	$F(2,32) = 347.86^{***}$	$t = -9.86^{***}$
(b) Rated a four or three			
1	$y = 0.238x - 0.002x^2$	$F(2,21) = 162.038^{***}$	$t = -0.633$
2	$y = 0.377x - 0.009x^2$	$F(2,24) = 343.77^{***}$	$t = -6.004^{***}$
3	$y = 0.380x - 0.008x^2$	$F(2,31) = 1428.60^{***}$	$t = -15.56^{***}$
4	$y = 0.202x - 0.003x^2$	$F(2,30) = 732.97^{***}$	$t = -4.17^{***}$
5	$y = 0.108x - 0.001x^2$	$F(2,38) = 366.19^{***}$	$t = -3.56^{***}$
6	$y = 0.283x - 0.003x^2$	$F(2,55) = 3901.56^{***}$	$t = -21.31^{***}$
7	$y = 0.196x - 0.003x^2$	$F(2,27) = 572.208^{***}$	$t = -4.06^{***}$
8	$y = 0.170x - 0.002x^2$	$F(2,22) = 250.34^{***}$	$t = -1.76^*$
9	$y = 0.141x - 0.002x^2$	$F(2,40) = 449.619^{***}$	$t = -5.34^{***}$
10	$y = 0.296x - 0.003x^2$	$F(2,68) = 5413.51^{***}$	$t = -28.35^{***}$
11	$y = 0.280x - 0.003x^2$	$F(2,47) = 1681.20^{***}$	$t = -7.62^{***}$
12	$y = 0.563x - 0.013x^2$	$F(2,17) = 400.32^{***}$	$t = -3.47^{**}$
13	$y = 0.121x - 0.001x^2$	$F(2,61) = 1321.28^{***}$	$t = -10.88^{***}$
14	$y = 0.227x - 0.006x^2$	$F(2,32) = 347.86^{***}$	$t = -9.86^{***}$
(c) Rated a two, three or four			
1	$y = 0.178x - 0.015x^2$	$F(2,21) = 812.89^{***}$	$t = -6.05^{***}$
2	$y = 0.732x - 0.015x^2$	$F(2,24) = 1428.20^{***}$	$t = -9.12^{***}$
3	$y = 0.649x - 0.013x^2$	$F(2,31) = 3103.66^{***}$	$t = -17.62^{***}$
4	$y = 0.589x - 0.007x^2$	$F(2,30) = 1095.92^{***}$	$t = -4.30^{***}$
5	$y = 0.277x - 0.004x^2$	$F(2,38) = 1596.39^{***}$	$t = -8.84^{***}$
6	$y = 0.744x - 0.005x^2$	$F(2,55) = 14239.02^{***}$	$t = -17.91^{***}$
7	$y = 0.328x - 0.004x^2$	$F(2,27) = 785.33^{***}$	$t = -3.93^{***}$
8	$y = 0.619x - 0.008x^2$	$F(2,22) = 1688.62^{***}$	$t = -4.67^{***}$

Table 2 continued

Session	Equation	Overall sig.	Curvilinear effect
9	$y = 0.495x - 0.001x^2$	$F_{(2,40)} = 2513.32^{***}$	$t = -1.72^*$
10	$y = 0.681x - 0.005x^2$	$F_{(2,68)} = 4926.94^{***}$	$t = -16.81^{***}$
11	$y = 0.705x - 0.008x^2$	$F_{(2,47)} = 9146.57^{***}$	$t = -21.93^{***}$
12	$y = 10.038x - 0.015x^2$	$F_{(2,17)} = 2586.91^{***}$	$t = -4.46^{***}$
13	$y = 0.452x - 0.003x^2$	$F_{(2,61)} = 10385.72^{***}$	$t = -16.81^{***}$
14	$y = 0.823x - 0.017x^2$	$F_{(2,32)} = 1132.76^{***}$	$t = -12.34^{***}$

Note: Hypothesized curvilinear effect is tested with $H_A : b_2 < 0$. Sig. levels for F tests and one-tailed t tests are indicated with * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$

threshold of three points (Table 2b). The quadratic term was significant at the $p < 0.05$ level or lower for each of the 14 sessions using a quality rating of two points as the threshold for a good idea (Table 2c). Thus, the polynomial regression analysis supports the hypothesis that the ideation function is a curve with a positive but decreasing slope.

3.7 Transformation Analysis

Although the polynomial regression analysis yielded results consistent with the theory, it may characterize an ideation function as a curve that transitions from a positive to a negative slope as x becomes large, which would not be possible for the cumulative distribution of the ideation function. We therefore conducted a secondary analysis, where we compared a simple linear regression of the ideation function to a regression using the square root transformation of the number of ideas (i.e., the independent variable). The square root transformation of the independent variable is recommended by Neter et al. (1990) and Levine et al. (2002) for linearizing nonlinear regression relationships. There are a number of advantages using this approach with the present study. First, the square root transformation produces a curve that has a positive but decreasing slope, as if it is approaching an asymptote, which is the form predicted by our theory. Second, the square root transformation allows the y -intercept term to be set to zero so that the regression line passes through the origin, which is consistent with the reality of an ideation session. This would not have been possible using a logarithmic transformation or other alternatives that are undefined at the origin. Third, the degrees of freedom are the same between the non-transformed and transformed model and thus allows for a comparison between the non-transformed (linear) model and the transformed (nonlinear model) to determine which approach explains more variance in the dependent variable across all sessions.

We compared the results of a simple least squared linear regression of number of good ideas on the number of ideas to the results of a least squared regression using the square root transformation of the number of ideas. We then compared the R^2 statistic² of the linear and square root models to determine which model explained more variance in the number of good ideas. Summary data for the R^2 statistic is presented in Table 3 for each of the three quality thresholds and the transformed and non-transformed models are presented in Table 4a-c.

² Because the regression models are through the origin, the R^2 statistic represents the proportion of variance in the dependent variable that is explained about the origin.

Table 3 Summary statistics of variance explained (R^2) and matched sample t test results for linear and square root transformation models for the 14 ideation sessions

Transformation of number of ideas	M	SD	Min	Max	95% CI	t test
Variance explained for good ideas (rated a four)						
Linear model: no transformation	0.874	0.056	0.759	0.952	0.841–0.906	$t = -7.62, p < 0.001$
Square root transformation	0.952	0.027	0.898	0.985	0.936–0.967	
Variance explained for good ideas (rated a four or three)						
Linear model: no transformation	0.932	0.038	0.822	0.969	0.910–0.953	$t = -4.77, p < 0.001$
Square root transformation	0.974	0.016	0.943	0.991	0.964–0.982	
Variance explained for good ideas (rated a four, three, or two)						
Linear model: no transformation	0.971	0.020	0.920	0.993	0.959–0.981	$t = -0.87, p = .199$
Square root transformation	0.979	0.027	0.890	0.998	0.963–0.993	

Table 4 Regression of cumulative number of good ideas [(a) rated a four (b) rated a three or four (c) rated a two, three or four] on cumulative number of ideas

Session	Df	Linear model			Square root transformation		
		Equation	F	R ²	Equation	F	R ²
(a) Rated a four							
1	23	$y = 0.133x$	83.06***	0.791	$y = 0.557(x)^{1/2}$	263.28***	0.923
2	26	$y = 0.114x$	172.29***	0.873	$y = 0.494(x)^{1/2}$	706.84***	0.966
3	33	$y = 0.090x$	199.89***	0.862	$y = 0.442(x)^{1/2}$	679.98***	0.955
4	32	$y = 0.062x$	186.61***	0.858	$y = 0.291(x)^{1/2}$	338.16***	0.916
5	40	$y = 0.038x$	123.16***	0.759	$y = 0.212(x)^{1/2}$	343.85***	0.898
6	57	$y = 0.068x$	1100.38***	0.952	$y = 0.426(x)^{1/2}$	3803.636***	0.985
7	29	$y = 0.098x$	269.68***	0.906	$y = 0.443(x)^{1/2}$	1005.62***	0.973
8	24	$y = 0.130x$	456.24***	0.952	$y = 0.518(x)^{1/2}$	601.31***	0.963
9	42	$y = 0.049x$	275.71***	0.871	$y = 0.264(x)^{1/2}$	475.51***	0.921
10	70	$y = 0.083x$	529.82***	0.885	$y = 0.591(x)^{1/2}$	2831.79***	0.976
11	49	$y = 0.090x$	306.95***	0.865	$y = 0.542(x)^{1/2}$	1385.22***	0.967
12	19	$y = 0.317x$	247.00***	0.932	$y = 1.140(x)^{1/2}$	828.88***	0.979
13	63	$y = 0.045x$	641.83***	0.912	$y = 0.300(x)^{1/2}$	1747.32***	0.966
14	34	$y = 0.089x$	152.87***	0.822	$y = 0.449(x)^{1/2}$	545.94***	0.943
(b) Rated a three or four							
1	23	$y = 0.210x$	332.73***	0.938	$y = 0.818(x)^{1/2}$	418.12***	0.950
2	26	$y = 0.197x$	271.28***	0.916	$y = 0.842(x)^{1/2}$	1505.09***	0.984
3	33	$y = 0.175x$	306.48***	0.905	$y = 0.847(x)^{1/2}$	1906.64***	0.983
4	32	$y = 0.142x$	947.47***	0.968	$y = 0.654(x)^{1/2}$	1823.17***	0.983
5	40	$y = 0.071x$	553.89***	0.934	$y = 0.372(x)^{1/2}$	1036.13***	0.964
6	57	$y = 0.144x$	808.55***	0.935	$y = 0.911(x)^{1/2}$	6188.11***	0.991
7	29	$y = 0.133x$	726.34***	0.963	$y = 0.583(x)^{1/2}$	972.28***	0.972
8	24	$y = 0.130x$	456.24***	0.952	$y = 0.518(x)^{1/2}$	601.31***	0.963
9	42	$y = 0.083x$	520.65***	0.927	$y = 0.448(x)^{1/2}$	1678.63***	0.976
10	70	$y = 0.141x$	793.27***	0.920	$y = 0.996(x)^{1/2}$	5677.80***	0.988
11	49	$y = 0.185x$	1509.80***	0.969	$y = 1.062(x)^{1/2}$	5210.87***	0.991
12	19	$y = 0.381x$	488.82***	0.964	$y = 1.353(x)^{1/2}$	1505.21***	0.988
13	63	$y = 0.066x$	872.92***	0.934	$y = 0.430(x)^{1/2}$	1374.57***	0.957
14	34	$y = 0.089x$	152.87***	0.822	$y = 0.449(x)^{1/2}$	545.94***	0.943
(c) Rated a two, three or four							
1	23	$y = 0.433x$	606.90***	0.965	$y = 1.611(x)^{1/2}$	177.92***	0.980
2	26	$y = 0.438x$	647.47***	0.963	$y = 1.836(x)^{1/2}$	6287.80***	0.996
3	33	$y = 0.344x$	552.50***	0.945	$y = 1.638(x)^{1/2}$	3626.14***	0.991
4	32	$y = 0.434x$	1388.84***	0.978	$y = 1.996(x)^{1/2}$	2009.77***	0.985
5	40	$y = 0.172x$	1045.90***	0.964	$y = 0.890(x)^{1/2}$	2100.59***	0.982
6	57	$y = 0.526x$	4197.52***	0.987	$y = 3.221(x)^{1/2}$	3084.60***	0.982

Table 4 continued

Session	Df	Linear model			Square root transformation		
		Equation	<i>F</i>	<i>R</i> ²	Equation	<i>F</i>	<i>R</i> ²
7	29	$y = 0.237x$	1026.53***	0.973	$y = 1.037(x)^{1/2}$	1410.87***	0.981
8	24	$y = 0.472x$	1762.74***	0.987	$y = 1.866(x)^{1/2}$	1548.74***	0.985
9	42	$y = 0.452x$	4793.91***	0.992	$y = 2.356(x)^{1/2}$	1499.35***	0.973
10	70	$y = 0.409x$	1883.89***	0.965	$y = 2.833(x)^{1/2}$	32878.62***	0.998
11	49	$y = 0.431x$	1620.15***	0.971	$y = 2.475(x)^{1/2}$	4741.03***	0.990
12	19	$y = 0.836x$	2514.16***	0.993	$y = 2.906(x)^{1/2}$	616.85***	0.972
13	63	$y = 0.311x$	3698.28***	0.984	$y = 2.008(x)^{1/2}$	4390.70***	0.986
14	34	$y = 0.404x$	378.68***	0.920	$y = 1.977(x)^{1/2}$	2789.20***	0.988

Note: y is the number of good ideas and x is the total number of ideas. *** $p < 0.001$

SPSS 14.0 software notes that “For regression through the origin (the no-intercept model), R^2 measures the proportion of the variability in the dependent variable about the origin explained by regression.” Thus, the R^2 statistic should not be interpreted relative to regression with an intercept coefficient, which measures the proportion of the variability in the dependent variable about its mean

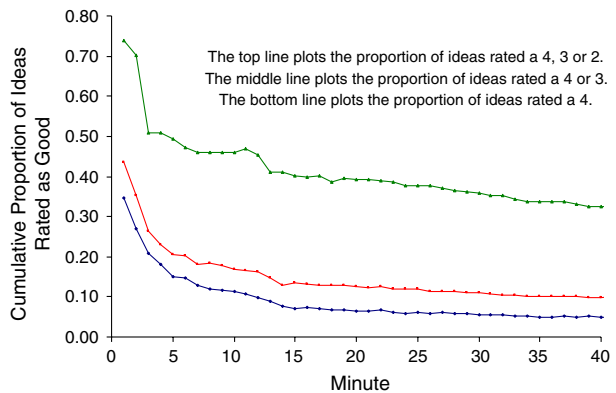
We conducted a matched sample t test comparing the variance explained by a linear regression to the variance explained by the square root transformation of the number of good ideas (Table 3). The square root transformation explained significantly more variance across the 14 sessions in the cumulative number of good ideas than did the linear model for the quality thresholds of four ($t = -7.62$, $p < 0.001$) and three ($t = -4.77$, $p < 0.001$). However, the difference was not significant for a quality threshold of two ($t = -0.87$, $p = 0.199$). Thus, the hypothesis was supported for the two highest quality thresholds, but was not significant at the lowest threshold.

4 Discussion

The results of this study support the hypothesis that a curve with a positive but decreasing slope is a better characterization of the observed ideation functions than is a line. These findings are consistent with the theoretical arguments offered above that cognitive inertia and solution space limits and may cause a diminishing returns effect in the ideation function. In all of the 14 experimental sessions, ideation efforts produced diminishing returns as additional ideas were generated. Thus, the quantity–quality conjecture did not hold for this study.

The results of this study provide a potential explanation for why some authors find support for the quantity–quality conjecture and others do not. The constructs that cause diminishing returns may not manifest early in an ideation session. Thus, the linear function suggested by the quantity–quality conjecture would not deviate substantially from the curvilinear function suggested by the diminishing returns hypothesis in sessions of short duration. Many of the ideation sessions in the literature were of time periods ranging from 5 min (e.g., Gurman 1968), to 10 min (e.g., Street 1974), to 12 min (e.g., Cohen et al. 1960), and 15 min (e.g., Barki and Pinsonneault 2001; Cooper et al. 1998; Dennis and Valacich 1993; Diehl and Stroebe 1987; Gallupe et al. 1991, 1992; Pinsonneault et al. 1999). However, in studies like the one reported here that use longer-duration ideation sessions, the constructs that cause diminishing

Fig. 3 The cumulative proportion of good ideas to total ideas aggregated across the fourteen experimental sessions and plotted over meeting time



returns may be more likely to manifest. Thus, the quantity–quality conjecture may be less useful in longer-duration ideation sessions than in shorter-duration ideation sessions.

To examine the relationship between the number of good ideas and the number of ideas over time, we aggregated the data from the 14 sessions and used the time stamps to plot the *cumulative proportion* of ideas rated as good ideas by minute (Fig. 3). It is important to note that the theory does not suggest a relationship between good ideas and time but rather good ideas and the number of ideas. In this analysis, a diminishing returns effect would manifest as a nonlinear curve with a negative but increasing slope. The plot of the data from the current study does show a steep decline in the proportion of ideas rated as good early in the session, with the slope leveling off over time (i.e., negative but approaching zero).

The sense-making activity that occurred prior to ideation was an important element in the design of this study. Although it is unusual among reports of ideation studies, it more closely maps the process used in organizational settings. Organizational groups routinely engage in information sharing and sense making prior to ideation. For example, the team leader might summarize known information, articulate the meeting objectives, solicit comments about problem symptoms. This approach matches the steps outlined by Simon (1977) for solving a problem; that is, defining the problem precedes generating solutions to a problem. Some researchers may skip this first step because their problem is so basic that it does not require much sense-making (e.g., What can we do with extra long-play records?). Had we proceeded directly to ideation without first employing the sense-making activity, we may have observed an ideation function of a slightly different shape. Ideating under incomplete information or even a misunderstanding would be more likely produce bad ideas at first while sensemaking and ideation were combined, followed by a diminishing returns effect after participants gained understanding of their problem. We would therefore expect that the slope of the ideation function would increase early in the session, and then decline as the session proceeded as the diminishing return effect manifested. This scenario helps articulate the boundary of our current theory. It explains the ideation function under conditions in which the problem has been identified and relevant information existing within the group has been shared.

5 Limitations and Future Directions

There are a several limitations with this study. First, participants in this study were students working on a hypothetical task, rather than teams in the workplace executing their assigned duties. It will therefore be important to conduct additional tests of these concepts in the

field to ascertain whether the theorized effects manifest in the workplace as they did in the lab.

Second, we studied the effect using only one task. Yet the theory argues that the diminishing returns effect should be more pronounced for problems with limited solution spaces than for problems with unlimited solution spaces. It is also possible that other attributes of a task could have bearing on the shape of the ideation curve. It would therefore be useful to test the hypothesis across tasks with both limited and unlimited solutions spaces and across a variety of domains and contexts.

Third, the theory posits two constructs that should give rise to a diminishing returns effect in the ideation function: cognitive inertia and solution space limitations. However, the design of the current study only demonstrates the overall diminishing returns effect. More research will be required to distinguish the separate contributions of each of these effects.

Fourth, all the groups in this study had exactly five members. Although the logic of the theory suggests that the hypothesized diminishing returns effect should prevail across groups of any size, it would be useful, nonetheless, to test the effect across both larger and smaller groups.

Finally, the logic of the theoretical arguments offered here seem to apply regardless of the technology and techniques used to gather ideas, our test used only one methodology and one technology. Although the GSS facilitated data collection (e.g., time stamps allowed us to determine the exact order of each idea), it would be useful to conduct a similar analysis with groups using other techniques (e.g., nominal group technique) and other technologies (e.g., flip charts). Thus, there are opportunities to conduct further research to explore and improve the theory presented in this paper.

5.1 Implications for Future Research

The new theoretical framing and the empirical results offered in this paper suggest that the quantity–quality conjecture does not always provide a valid characterization of the ideation function. It may therefore be important for ideation researchers to measure idea-quality directly, rather than use idea-quantity as a surrogate for idea-quality. Because idea-quantity is not always a reasonable surrogate for idea-quality, it may be useful for ideation researchers to develop theories and methods that directly address quality rather than quantity. Also, the results suggest that number-of-ideas-generated is not a sufficient basis for concluding that one ideation intervention is superior to another; researchers should determine if an ideation intervention yields more good-quality ideas.

The theoretical arguments offered in this paper suggest some causal constructs which may be a basis for interventions that could potentially lead to more ideas of better quality. For example, researchers might be able to devise interventions that help groups break free of cognitive inertia, for example, by decomposing a larger task into subtasks (e.g., [Dennis et al. 1999](#)) or seeding electronic brainstorming folders with questions intended to elicit different approaches to solving a problem (e.g., [Santanen et al. 2004](#)), or to spread ideation across two or more sessions. In an organizational setting this could be as simple as ideating before and after lunch or a coffee break. The break may make it easier for a new line of thinking to emerge after participants have cleared their minds of previously activated concepts. These types of studies could focus on idea-quality as the phenomenon of interest, rather than seeking ways to extract a larger quantity of ideas.

6 Conclusion

The quantity–quality conjecture that has played a central role in guiding ideation research for many years may not be the most useful characterization of the ideation function. This paper contributes a theoretical argument and empirical support suggesting that cognitive inertia and scarcity of solution space could cause diminishing returns, yielding an ideation function with a positive but decreasing slope. Because of this, idea-quantity may not be a useful surrogate for idea-quality in certain circumstances. It may therefore be useful for ideation researchers to derive new theories and methods that relate directly to improving the quality of ideas produced in ideation sessions.

Acknowledgements The authors extend their gratitude to two anonymous reviewers whose detailed comments contributed substantially to the theory and analysis presented in this article.

References

- Aiken M, Vanjani M, Paolillo J (1996) A comparison of two electronic idea generation techniques. *Inf Manage* 30:91–99
- Baddeley AD (1990) *Human memory: theory and practice*. Allyn & Bacon, Needham Heights
- Barki H, Pinsonneault A (2001) Small group brainstorming and idea quality: is electronic brainstorming the most affective approach? *Small Group Res* 32(2):158–205
- Briggs RO, Reinig BA, Shepherd MM, Yen J, Nunamaker JF Jr (1997) Quality as a function of quantity in electronic brainstorming. In: *Proceedings of the thirtieth annual Hawaiian conference on system sciences*. Los Alamitos, IEEE, pp 94–103
- Cohen D, Whitmyre JW, Funk WH (1960) Effect of group cohesiveness and training upon creative thinking. *J Appl Psychol*, 44(5):319–322
- Cohen J, Cohen P, West SG, Aiken LS (2003) *Applied multiple/correlation analysis for the behavioral sciences*, 3rd edn. Lawrence Erlbaum, NJ
- Collins AM, Loftus EF (1975) A spreading activation theory of semantic processing. *Psychol Rev* 82:407–428
- Connolly T, Jessup LM, Valacich JS (1990) Effects of anonymity and evaluative tone on idea generation in computer-mediated groups. *Manage Sci* 36(6):97–120
- Cooper WH, Gallupe RB, Pollard S, Cadsby J (1998) Some liberating effects of anonymous electronic brainstorming. *Small Group Res* 29(2):147–178
- Dennis AR, Valacich JS (1993) Computer brainstorms: more heads are better than one. *J Appl Psychol* 78(4):531–537
- Dennis AR, Valacich JS, Nunamaker JF Jr (1990) An experimental investigation of the effects of group size in an electronic meeting environment. *IEEE Trans Syst Man Cybern* 20:1049–1057
- Dennis AR, Valacich JS, Carte TA, Garfield MJ, Haley BJ, Aronson JE (1997) Research report: The effectiveness of multiple dialogues in electronic brainstorming. *Inf Syst Res* 8(2):203–211
- Dennis AR, Aronson JE, Heninger WG, Walker ED (1999) Structuring time and task in electronic brainstorming. *MIS Q* 23(1):95–108
- Dewey J (1910) *How we think*. D.C. Heath, Lexington
- Diehl M, Stroebe W (1987) Productivity loss in brainstorming groups: Toward the solution of a riddle. *J Pers Social Psychol* 53:497–509
- Diehl M, Stroebe W (1991) Productivity loss in idea-generating groups: tracking down the blocking effect. *J Pers Soc Psychol* 61:392–403
- Fjermestad J, Hiltz SR (1999) An assessment of group support systems experimental research: methodology and results. *J Manage Inf Syst* 15(3):7–149
- Gallupe RB, Bastianutti LM, Cooper WH (1991) Unblocking brainstorms. *J Appl Psychol* 76(1):137–142
- Gallupe RB, Dennis AR, Cooper WH, Valacich JS, Bastianutti LM, Nunamaker JF (1992) Electronic brainstorming and group size. *Acad Manage J* 35:350–369
- Gryskiewicz SS (1988) Trial by fire in an industrial setting: a practical evaluation of three creative problem-solving techniques. In: Grohhaug K, Kaufmann G (eds) *Innovation: A Cross-disciplinary Perspective*. Norwegian University Press, Oslo
- Gurman EB (1968) Creativity as a function of orientation and group participation. *Psychol Rep* 22:471–478

- Harari O, Graham WK (1975) Tasks and task consequences as factors in individual and group brainstorming. *J Social Psychol* 95:61–65
- Jessup LM, Connolly T, Galegher J (1990) The effects of anonymity on GDSS group process with an idea-generating task. *MIS Q* 14(3):313–321
- Levine DM, Stephan D, Krehbiel T, Berenson ML (2002) *Statistics for Managers using microsoft Excel*, 3rd edn. Prentice Hall, Upper Saddle River
- Madsen DB, Finger JR Jr (1978) Comparison of a written feedback procedure, group brainstorming, and individual brainstorming. *J Appl Psychol* 63:120–123
- Maginn BK, Harris RJ (1980) Effects of anticipated evaluation on individual brainstorming performance. *J Appl Psychol* 65(2):219–225
- Malt BC, Smith EE (1982) The role of familiarity in determining typicality. *Mem Cogn* 10:69–75
- Mennecke BE, Wheeler BC (1993) Tasks matter: Modeling group task processes in experimental CSCW research. In: *Proceedings of the twenty-sixth annual hawaiian conference on system sciences*. IEEE, Los Alamitos, 71–80
- Miller GA (1956) The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychol Rev* 63:81–97
- Neter J, Wasserman W, Kutner MH (1990) *Applied linear models*, 3rd edn. Irwin, Homewood
- Osborn AF (1963) *Applied imagination*, 3rd edn. Scribner, New York
- Petrovic O, Krickl O (1994) Traditionally-moderated versus computer supported brainstorming: a comparative study. *Inform Manage* 27:233–243
- Pinsonneault A, Barki H, Gallupe RB, Hoppen N (1999) The illusion of electronic brainstorming productivity: theoretical and empirical issues. *Inf Syst Res* 10(4):378–380
- Pokras S (1989) *Systematic problem-solving and decision-making: rational methods for problem-solving and decision-making*. Crisp Publications, Los Altos
- Rotter GS, Portugal SM (1969) Group and individual effects in problem solving. *J Appl Psychol* 53(4):338–341
- Salisbury WD, Chin WW, Gopal A, Newsted PR (2002) Better theory through measurement: developing a scale to capture consensus on appropriation. *Inform Syst Res* 13(1):91–103
- Santanen EL, Briggs RO, Vreede GJ (2004) Causal relationships in creative problem solving: comparing facilitation interventions for ideation. *J Manage Inf Syst* 20(4):167–197
- Shepherd MM, Briggs RO, Reinig BA, Yen J, Nunamaker JF (1996) Social comparison to improve electronic brainstorming: beyond anonymity. *J Manage Inf Syst* 12(3):155–170
- Simon HA (1977) *The new science of management decision*. Prentice-Hall, NJ
- Smith EE (1995) Concepts and Categorization. In: Smith EE, Osherson DN (eds) *Thinking*. MIT Press, Cambridge
- Stasser G (1992) Pooling of unshared information during group discussions. In: Worchel S, Wood W, Simpson JA (eds) *Group process and productivity*, Sage Publications, Newbury Park, CA
- Street WR (1974) Brainstorming by individuals, coacting and interacting groups. *J Appl Psychol* 59(4):433–436
- Valacich JS, Dennis AR, Connolly T (1994) Idea generation in computer-based groups: A new ending to an old story. *Organ Behav Hum Decis Process* 57:448–467
- Wheeler BC, Mennecke BE (1992) Modeling group task processes using a hidden profile task: the School of Business Policy Task. Indiana University working paper 513