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In a wide variety of organizational settings, teams generate a number of possible solutions to a problem and then select a few for further investigation. We examine the effectiveness of two *idea generation processes* for such tasks— one, where the team works together as a team, and the other where individuals first work alone and then work as a team. We define effectiveness as the quality of the *best* ideas identified by the teams. Under mild distributional assumptions, we show that the quality of the best ideas depends on (1) the average quality of solutions generated, (2) the variance in the quality of generated solutions, (3) the number of solutions generated, and (4) the ability of the team to discern the quality of these solutions. Prior research has examined the effect of alternate schemes only on average quality and on the number of ideas generated, ignoring any differences in variance, higher moments, and the ability to discern the best ideas. We develop theory to explain the role of these factors and test it with an experiment. We find that working solely with a team structure increases the variance in idea quality, but reduces the number of ideas generated, the average idea quality, and the ability to discern the best ideas. However, in a holistic analysis of these factors, we find that the effect of the higher variance of team processes leads to an improvement in the quality of the best ideas generated by a team. However, the inferior ability of teams to discern the best ideas they have generated largely mitigates this advantage. On the basis of these results, we recommend that the idea generation and evaluation stages of the idea generation process employ different organizational processes. While teams are a valuable approach to idea generation, the evaluation process should integrate the independent judgements of individuals.

Key words: Creativity, Brainstorming, Teams, Teams, Individuals, Extreme Value Theory, Quantile Regression
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1 Introduction

Virtually all innovation processes in industry include the identification of opportunities and the selection of one or more of the most promising directions. When a movie studio creates a new feature film, it typically considers several hundred plot summaries, a few of which are selected for further development. When a company decides upon the branding and identity for a new product, it creates dozens or hundreds of alternatives, and picks the best of these for testing and refinement. When a consumer goods firm develops a new product, it typically considers many alternative concepts before selecting the few it will develop further. Generating the raw ideas that feed subsequent development processes thus plays a critical role in innovation.

The success of idea generation in innovation depends on the quality of the *best* opportunity identified. In most settings, an organization would prefer 20 bad ideas and 1 outstanding idea to 21 good ideas. In the world of innovation, the extremes are what matter, not the average or the norm (Dahan and Mendelson (2001), Terwiesch and Ulrich (2007)). This objective is very different from those in, for example, manufacturing, where most firms would prefer to have 21 production runs with good quality over having 1 production run with exceptional quality followed by 20 production runs of scrap.

When generating ideas, a firm makes choices by intention or default about its creative problem solving process. In this paper, we investigate two commonly suggested organizational forms for idea generation. The first involves creation and evaluation of ideas by individuals working together as a *team* in the same time and space. The team approach is widely used in organizations (Sutton and Hargadon (1996)). Despite its wide usage, hundreds of experimental studies have criticized team processes as relatively ineffective (cf. Diehl and Stroebe (1987), Diehl and Stroebe (1991)). In the second approach, a team of individuals work independently for some fraction of the allotted time, and then work together as a team. Such a *hybrid* process, also sometimes called the *nominal group* technique, has been suggested and studied in literature as a way of effectively combining the merits of individual and team approaches. (cf. Robbins and Judge (2006), Paulus, et al. (1996), Stroebe and Diehl (1994)). These studies find that the hybrid approach leads to better ideas and to higher satisfaction with the process.

Notwithstanding its conflicting prescriptions, the existing literature exhibits three gaps with respect to idea generation in innovation management. First, most papers focus on the number of ideas generated, as opposed to their quality, with the tacit assumption that more ideas will lead to more *better* ideas. Second, the few papers that look at the quality of ideas look at the *average* quality of ideas as opposed to looking at the quality of the *best* ideas. Third, the focus of the existing literature is entirely on the *creation* process, and ignores the *selection* processes that teams apply to pick the most promising ideas for further exploration.

Given our focus on the use of idea generation in innovation, our metric for the effectiveness of the process is the quality of the ideas that are selected as the best. Note that this metric can differ substantially from the average quality of the ideas generated. We build theory to identify the statistical properties of the idea generation process that influence the quality of the best ideas selected. We find that four properties of the process influence this quality: (1) the average quality of ideas, (2) the number of ideas generated, (3) the variance in the quality of ideas, and (4) the ability to discern the best ideas. Each of these properties of the process affects the quality of the best ideas produced by a team. However, their net effect depends on their interactions and on the specifics of the statistical distribution of the quality of the ideas generated.

After laying out the theory, we report on a laboratory experiment that compares the two idea generation processes with respect to each of these four properties. An accurate measurement of magnitudes of the differences in these statistical properties is central to the application of our theory. Thus we employ a novel within-subjects experimental design that uses a large sample of quality ratings to estimate the quality of each idea. We find that the hybrid process generates more ideas, with better average quality, and is superior in identifying the best ideas. The team process, on the other hand, exhibits higher variance in quality.

These results suggest that competing countervailing effects determine the quality of the best ideas. The net result depends on the magnitudes of these effects and on the interactions among the effects.

In our analysis, we first estimate the expected effect on the quality of the best ideas by applying to our theoretical model the measured values from our experiments for the four statistical properties of the idea generation process. We then test these predictions directly with our data using *quantile regression* and *extreme value statistics*.

Our analysis advises that in situations where a substantial amount of time is available, the difference in the quality of the best ideas produced by the two team processes is small. However, if there is a limited, equal amount of time available, the team process significantly outperforms the hybrid process. This finding is in stark contrast to the prescriptions of the existing experimental literature, which argues unequivocally for the superiority of individual idea generation processes in terms of effectiveness and for hybrid processes in terms of participant satisfaction. This literature has focused on the differences in *average* quality and productivity, and by ignoring the differences in the *variance* of the quality of ideas generated has overlooked a significant advantage of the team process. Our study is also the first to examine how these competing effects come together and leads to the finding that the ignored effect, variance in quality, is highly influential in determining the effectiveness of idea generation processes.

Finally, we examine situations where the ability to evaluate ideas plays a role, and we find that while teams produce better overall quality of the best ideas, they are not accurate in *discerning* their best ideas. This significantly reduces their advantage and the difference in the quality of the *best identified ideas* between the team and the hybrid process is relatively small.

These findings shed light on the longstanding conflict between the experimental research that has strongly argued for a move away from team idea generation and the empirical evidence that even the most successful creative firms still mostly employ team processes.

The remainder of this paper is organized as follows. We review the relevant literature in Section 2. In Section 3, we develop statistical theory relating average quality, productivity, variance, and self evaluation ability to the quality of the best ideas. In Section 4, we develop hypotheses about the differences between the team and hybrid processes with respect to these four properties. Section 5 describes the experiment. Section 6 reports the results with respect to the statistical properties of the processes. In Section 7, we examine how these statistical properties come together and interact. Section 8 is concluding remarks.

2 Literature

The role of organizational processes in idea generation has been examined in the social psychology literature and the technology and innovation management literatures. The social psychology literature has examined the idea generation process in detail, and is often called the *brainstorming* literature. The innovation management literature has focused on innovation outcomes and organizational forms.

The social psychology literature mostly originates with Osborne's 1957 book, *Applied Imagination* (Osborne (1957)), which introduces the term *brainstorming*. Osborne argued that working in teams leads to multiple creative stimuli and interaction leading to a highly effective process. His argument spawned many studies that tried to verify experimentally this hypothesis. Diehl and Stroebe (1987) and Mullen, et al. (1991) provide a detailed overview of this literature. A summary of this literature from Diehl and Stroebe (1987) is reproduced in Table 1 of the E-Companion. These studies experimentally examined groups generating ideas as teams or as individuals. In terms of performance metrics, the literature focuses on the average quality of the ideas generated, the number of ideas generated, and measures that combined the two such as the total quality. Quality ratings for ideas generated are typically provided through evaluations by research assistants.[1] The research has unequivocally found that the number of ideas generated (productivity) is significantly higher when individuals work by themselves and the average quality of ideas is no different between individual and team processes. Thus, team processes are identified as significantly inferior to individual processes. This main conclusion is in stark contrast with Osborne's hypothesis and anecdotal evidence documenting the wide use of team idea generation processing (i.e., brainstorming) in organizations.

In line with the social psychology literature we also conduct experiments. However, in contrast to this literature, we examine idea generation in the specific context of innovation. Thus, we are concerned with the quality of the best ideas resulting from the idea generation process. Furthermore, we depart from this literature by employing a novel method of evaluation using a panel of 17 raters.

To resolve the paradox between the social psychology literature and the anecdotal evidence, Sutton and Hargadon (1996) conducted a field-based observational study of the product design consulting firm IDEO. They found that contextual differences between the lab and the real world such as the nature of problems may explain the contrast between practice and the laboratory findings. More recently, Kavadias and Sommer (2007) take an innovative approach to this paradox. They show analytically that the specific

[1] In Deihl and Stroebe (1987), the ideas were rated by one research assistant and a second assistant was used to verify the reliability.

nature of the problem and group diversity matters to the difference in the performance of individuals and teams. In particular, they conjecture that the experimental evidence may be an artifact of employing simple idea generation problems which are not representative of real situations.

The role of organizational structure in the idea generation process has also been examined empirically, most notably, by Fleming (2007). Fleming (2007) uses patent data to study differences in productivity, quality, and quality variance between inventors who work by themselves and those who collaborate. Quality is measured as the number of citations received by the patent. Taylor and Greve (2006) examine average quality and variance of creative output in the comic book industry. The quality is measured using the collector-market value of a comic. While Fleming (2007) finds that quality variance is higher for inventors working individually, Taylor and Greve (2006) find the opposite. In the experimental studies mentioned before, the differential resource investment between individuals and teams can be controlled by aggregating individual innovators into synthetic teams (also called *nominal groups*); this is impossible to do in empirical studies. Thus, it is hard to draw conclusions about productivity from these studies, though the results on average quality and variance directly inspire our work.

Lastly, the statistical view of innovation, which is at the core of our analyses and hypotheses was first developed by Dahan and Mendelson (2001). In their analysis, they model creation as a series of random draws from a distribution followed by a selection from the generated ideas. We employ this model to identify the statistical properties that influence the quality of the best idea. We summarize the relevant literature and the key differences between the literature and our study in Table 1.

3 Theoretical Background

3.1 A Model of Creative Problem Solving

Creative problem solving can be thought of as including at least three steps. The first step is idea generation, the second is evaluation of the ideas, and the third is selection of the best ideas. Idea generation produces ideas of varying quality. This process can be modeled as a series of random draws from a well defined distribution of idea quality.[2] While each idea generated can be thought of as having some true inherent quality, this quality is not immediately observable. The next step of the process involves evaluation of the ideas. This step can be modeled as obtaining a noisy, unbiased signal of the quality of the idea. Based on these noisy signals, ideas are ranked and ordinal preferences are constructed. Finally, on the basis of these ordinal preferences a subset of ideas is selected for further investment. For an organization employing such an idea generation process, the payoff from the process depends in part on the quality of this selected subset. Thus, to evaluate and compare different idea generation processes we must use the quality of the selected subset as the key performance measure. The statistical analyses in the next section develop the relationship between the idea generation process and the properties of this subset of *best ideas*.

3.2 The Statistics of the Best Idea

Properties of the Best Idea: Let $X_i \sim F$ denote the quality of any generated idea. This is a random draw from the quality distribution with cumulative density F which has positive support. Following Dahan and Mendelson (2001) and Kavadias and Sommer (2007), we assume that the $X_i s$ are independent and identically distributed. The properties of the quality of the best idea, $M_n = Max\{X_1, X_2, \dots, X_n\}$, where the ideation exercise generates n ideas, is the focus of this section. Assume $n > 1$. It follows that $\mathbf{E}[M_n] \leq \mathbf{E}[M_{n+1}]$. In other words, all else being equal, an ideation process with a higher number of ideas generated will lead to a better quality of the best solution. (A formal statement and proof is provided in the E-companion.)

Next, we investigate the effect of the mean and the variance of the idea quality distribution on the quality of the best idea. In line with Dahan and Mendelson (2001) and Kavadias and Sommer (2007), we assume that the idea quality distribution belongs to the Generalized Extreme Value (GEV) family of distributions.[3] This is a fairly flexible family of distributions that can capture a wide variety of censored data. Since idea

[2] Quality may have multiple dimensions to it; however for the purposes of this study we conceptualize quality as a single dimension. This can be thought of as an aggregate measure of the expected utility or profits derived from the idea by the organization.
[3] Kavadias and Sommer (2007) assume idea quality to follow the Gumbel distribution, which is a member of the GEV family.

generation often involves some internal censoring by the generator, this family is an ideal candidate for capturing idea quality. Further, from data collected under a variety of idea generation settings in real organizations, we find this family to be a reasonable fit.

Now, consider two idea generation processes with GEV quality distributions with different means. All other central moments of the distributions are identical. The processes generate the same number of ideas. It follows that the expected quality of the best idea from the idea generation process with the higher mean is higher. In other words, all else being equal, the quality of the best idea from a process with a higher average quality is higher. (A formal statement and proof is provided in the E-companion.)

Again consider two ideation processes with GEV quality distributions, but this time, with different variance. All other central moments of the distributions are identical. The processes generate the same number of ideas. The expected quality of the best idea from the ideation process with the higher variance is better iff $\Gamma(1-\xi) > 0$, where Γ is the gamma function and ξ is the shape parameter for the GEV distribution. (A formal statement and proof is provided in the E-companion.)

This condition holds for all $\xi < 1$. In practice, distributions with $\xi > 1$ have a very short bounded lower tail and are almost never observed in practice. Similarly distributions with $\xi < -1$ have a very short bounded upper tail. Both these cases are rarely encountered in practice (Coles (2001)). Thus, the theoretical restriction described above is usually no obstacle in practice.[4] Finally, if the quality distribution is Gumbel, this condition is always satisfied. Thus, all else being equal, in most realistic settings a process with higher variance in idea quality will, on average produce a better best-idea.

Now we have a probabilistic framework to relate the quality of the best idea to the properties of the idea generation process, namely productivity (number of ideas generated), average quality, and variance in quality. Since, there is prior experimental evidence on how these individual properties vary with different idea generation processes; we can use the above results to hypothesize the dependence of the quality of the

[4] For all data generated in our experiments, distributions with $-1 < \xi < 0$ provide the best maximum likelihood fit and the condition is always satisfied.

best idea on the idea generation process employed. The goal of our study is to then test these hypotheses. However, for appropriate statistical testing of the hypotheses we need some additional statistical properties of the quality of the best idea.

Asymptotic Properties and Estimation of the Distribution of the Best Idea: Extreme Value Theory or the Theory of Extremes (Gumbel (1958), Dahan and Mendelson (2001), Coles (2001)) provides a statistical framework to characterize and estimate the asymptotic stochastic behavior of a subset of extreme values of a process. To estimate statistically the quality of the best idea from each idea generation process, we need to understand the distribution of the quality of the best idea. To this end, we employ a result analogous to the central limit theorem for the asymptotic distribution of sample means. This result provides the asymptotic distribution for normalized sample maxima.

As is usually done to estimate the distribution of sample means, we consider the asymptotic distribution of M_n as $n \to \infty$.This distribution degenerates to a point mass on the upper limit of the support of distribution F and is not particularly informative. Of more use is the distribution of linearly transformed M_n, $M_n^* = (M_n - a_n)/b_n$.[5] The existing literature (cf. Coles (2001)) has shown that if there exist sequences of constants $\{a_n, b_n\}$ such that

$$\Pr\{M_n^* \le z\} \to G(z) \; as \; n \to \infty$$

for a non-degenerate distribution function G, then G is a member of the GEV family

$$G(z) = \exp\left\{-\left[1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\},$$

defined on $\{z: 1 + \xi(z-\mu)/\sigma > 0\}$, where $-\infty < \mu < \infty$, $\sigma > 0$ and $-\infty < \xi < \infty$.

Further, given $\{Z_1, Z_2, \dots, Z_m\}$, m *independent* observations of M_n, the parameters of $G(z)$ can be estimated as the argmax of the log-likelihood function.[6]

[5] This linear transformation does not change the interpretation and comparison of the estimated properties of different ideation processes.

[6] We also require that $1 + \xi\left(\frac{z_i - \mu}{\sigma}\right) > 0$, for $i = 1, \dots, m$.

$$l(\mu,\sigma,\xi) = -m \log \sigma - \left(1+\frac{1}{\xi}\right)\sum_{i=1}^{m} \log\left[1+\xi\left(\frac{z_i-\mu}{\sigma}\right)\right] - \sum_{i=1}^{m}\left[1+\xi\left(\frac{z_i-\mu}{\sigma}\right)\right]^{-1/\xi}$$

As always with maximum likelihood estimation, the parameter estimates are asymptotically normal and approximate confidence intervals can be constructed using the observed information matrix.[7] The above statement provides the statistical basis of using data to compare the quality of the best idea across different ideation processes.

Asymptotic Distribution of the Best R-Ideas: Creative problem solving often involves substantial uncertainty which is resolved through subsequent development. As a result, organizations almost always pursue multiple ideas as opposed to a single best idea. To capture such situations we also study the joint distribution of the top *r* ideas. We refer to the r^{th} best idea as $M_n^{(r)}$ or the r^{th} order statistic. If there exist sequences of constants $\{a_n, b_n\}$ such that

$$\Pr\{M_n^* \le z\} \to G(z) \text{ as } n \to \infty$$

for some non-degenerate distribution function G, then for fixed r, the limiting distribution as $n \to \infty$ of

$$\boldsymbol{M}_n^{(r)} = \left(\frac{M_n^{(1)}-a_n}{b_n}, \frac{M_n^{(2)}-a_n}{b_n}, \dots, \frac{M_n^{(r)}-a_n}{b_n}\right)$$

falls within the family having joint probability density function

$$f\left(z^{(1)},\dots,z^{(r)}\right) = \exp\left\{-\left[1+\xi\left(\frac{z^{(r)}-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \times \prod_{k=1}^{r} \sigma^{-1}\left[1+\xi\left(\frac{z^{(k)}-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}-1},$$

defined on $\left\{z^{(k)}: 1+\xi\left(z^{(k)}-\mu\right)/\sigma > 0\right\}$, *for k=1,…,r;* where $-\infty < \mu < \infty$, $\sigma > 0$ and $-\infty < \xi < \infty$; $z^{(r)} \le z^{(r-1)} \le \cdots \le z^{(1)}$. The above expression forms the basis of the statistical estimation of the quality of the best-*r* ideas using maximum likelihood methods.

[7] A potential difficulty with the use of maximum likelihood methods for the GEV concerns the regularity conditions that are required for the usual asymptotic properties associated with the maximum likelihood estimator to be valid. These conditions are not satisfied by the GEV model because the end-points of the GEV distribution are functions of the parameter values: $\mu - \sigma/\xi$ is an upper end point of the distribution when $\xi < 0$, and a lower end point when $\xi > 0$. Smith (1985) considers this problem in detail and find that for $\xi > -1$, the estimators are generally obtainable and often have the usual asymptotic properties.

Role of the Evaluation Step: The preceding discussion established the relationship between the mean quality, variance in quality, the number of ideas generated and the quality of the best idea(s). These analyses assumed that the ranking of ideas during the idea generation process would be accurate or, in other words, the process can truly discern which ideas are the top *r* ideas. In reality this may not be the case, and the true quality of the *best identified* ideas may be lower than the true quality of the true *best ideas.* The difference between these two is a function of the accuracy of the ranking process. In particular, an idea generation process which ranks ideas more accurately will have less of a difference between the true quality of the best identified ideas and the true best ideas and consequently a higher quality of the best idea(s). As an extreme, a perfect ordinal ranking will lead to no difference. Rank correlation metrics[8] can capture the accuracy of these rankings. We postulate that an idea generation process with higher rank correlation will result in a higher true quality of the best ideas.

3.3 Team Versus Individual Idea Generation

There is a vast body of research on the differences between team and individual idea generation. In a comprehensive series of studies, Diehl and Stroebe (1987), Diehl and Stroebe (1991) Stroebe and Diehl (1994), identified that team brainstorming impedes productivity due to production blocking (inability to generate ideas when others in the teams are speaking), evaluation apprehension (leading to censoring of potentially good ideas), and free riding. Further, they found that production blocking contributed to the vast majority of the productivity loss.

4 Hypotheses

Recall that we are comparing (a) a team process in which a group of individuals work together in time and space to generate ideas and (b) a hybrid process in which individuals work alone and independently for some time period and then work together as a team.

[8] Spearman's ρ and Kendall's τ are the two most popular such metrics.

Number of Ideas Generated The existing literature has found that individual idea generation has vastly higher productivity than a team process (normalizing by person-hours invested). Since the hybrid process includes some initial individual idea generation, we expect a benefit in productivity from this phase. On the other hand, the second phase of the hybrid process should be less productive since many of the ideas will already have been brought up in the individual phase. On balance, and based on the magnitudes from existing studies, we expect that the productivity advantages of the initial individual phase of the hybrid will give it an advantage that will outweigh the loss in productivity in the second phase.

Hypothesis 1: The number of ideas created in the hybrid process is larger than the number of ideas created with the team process.

Average Quality of Ideas The team process allocates the full time to idea generation; whereas the hybrid process involves some individual idea generation (H-Individual) followed by team idea generation (H-Team). On the one hand, the prior preparation during H-Individual might increase the quality of the ideas generated in the H-Team phase beyond those generated by teams without prior preparation. On the other hand, the ideas created during the H-Individual phase of the hybrid process do not benefit from the team phase of the hybrid process. As discussed previously, the brainstorming literature, especially the work by Diehl and Stroebe (1987), has found no clear evidence about which process leads to the better average idea quality. Thus, we do not have a clear prior hypothesis about the average quality of the ideas generated by the two processes.

Variance in Quality of Ideas There also exist alternate theories on the impact of team idea generation on the variance of quality of ideas generated from one process. While one school of thought believes that collaborative processes lead to convergence (Sutton and Hargadon (1996), Fleming (2007)) and thus limit the variance; there is another view that diverse knowledge of participants in a team can lead to more combinations, cross fertilizations, conflict, breakdown, and uncertainty in compatibility of the combination of diverse knowledge components (Fleming (2001), Fleming and Sorenson (2001), Taylor and Greve (2006)). Further, teams create conditions of a “status auction” and “provide skill variety” leading to both great and awful ideas (Sutton and Hargadon (1996)). We believe that there is more potential for both breakdown and collaborative success in teams than in individual idea generation; thus team idea generation should have a higher variance in quality. The team process devotes all its time to team idea generation as opposed to a fraction in the hybrid process, leading to Hypothesis 2.

Hypothesis 2: The variance in quality of ideas created in the hybrid process is lower than the variance in quality of ideas created with the team process.

Self Evaluation Ability Individuals and teams are both known to be notoriously ineffective at evaluating the quality of their ideas (Simonton (1985)). In a team, ownership of the ideas, social pressures, team dynamics, and interaction of different personalities limit objectivity. We expect these effects to be stronger in the team structure as all evaluation and perception of the ideas must be done in a team situation; whereas in the hybrid process at least the evaluation in the initial phase is free from these effects. Thus, we hypothesize:

Hypothesis 3: The ability of the hybrid process to correctly identify its best idea(s) is higher than the ability of the team process to correctly identify its best idea(s).

5 Experimental Design

To compare the performance of teams and hybrids, we ran an experiment to estimate the average quality, variance in quality, the number of ideas generated (productivity), and the ability to discern quality for two different treatments. We employed a within-subjects design for this study. In such a design, each subject generates ideas under *both* the treatments– team and hybrid. Such a design helps us control for the substantial differences in individual ability, team composition, and team dynamics. Further, one property of interest, within-team quality variance needs to be separated from across-team quality variance. This is most effectively done in a within-subjects design.

Subjects: Subjects for the experiment were recruited from students in a product design elective course at The Wharton School. All subjects had participated in multiple brainstorming and idea generation exercises prior to the experiment and had received training in idea generation techniques. The subjects came from a wide variety of majors, with engineering and business majors being the majority. Most subjects were juniors, seniors, or masters-degree students. All experiments were conducted after obtaining prior approval from the human subjects committee at the university and participation in the exercise was voluntary and had no bearing on performance in the course. The subjects were informed that this was as an experiment to understand the idea generation process. Since extrinsic incentives are known to limit creative behavior (Amabile (1996)), no explicit incentives or compensation were provided for participation or performance in the experiment.

Treatments: In the team idea generation process, subjects were divided randomly into teams of four. Each team was given 30 minutes to complete an idea generation exercise. The subjects were asked to record each idea on a separate sheet of paper (reproduced in the E-companion as Figure 1). A pre-stapled and pre-ordered bundle of sheets was provided. The sheets had an area for notes related to the idea and a designated area to record a title and a 50-word description. At the end of 30 minutes, the subjects were given an additional 5 minutes and instructed to develop a consensus selection and ranking of the best 5 ideas generated by their team.

In the hybrid process, subjects were asked to work individually on an idea generation exercise for 10 minutes. At the end of 10 minutes, the subjects were asked to rank their ideas. The subjects were then divided randomly into teams of 4 and given a further 20 minutes to discuss their ideas from the first phase and to develop new ideas. All ideas were recorded on the sheets as described for the team process. At the end of this second phase of the hybrid idea generation process, subjects were given an additional 5 minutes and instructed to develop a consensus selection and ranking of the best 5 ideas generated by their team including those generated as individuals. Detailed instructions used by the experimenters are reproduced in the E-companion.

Experiment: The experiment was conducted in two phases— a phase where the subjects created and developed a consensus ranking of the best ideas, and an evaluation phase where a panel of raters rated the ideas. For the creation and self-evaluation phase, participants were divided into two teams– one team was administered the hybrid treatment first followed by the team treatment and the other was administered the team treatment first followed by the hybrid treatment. For each of the two teams, half the subjects were given idea generation Exercise 1 for the first treatment followed by idea generation Exercise 2 for the second treatment, the other half were given idea generation Exercise 2 for their first treatment and idea generation Exercise 1 for their second treatment. The idea generation exercises are described below. This setup allows us to control for effects arising out of the order of treatments (learning, etc.), or out of the order of idea generation exercises, and related to any interaction of treatments with the idea generation exercises.

> Exercise 1: *"You have been retained by a manufacturer of sports and fitness products to identify new product concepts for the student market. The manufacturer is interested in any product that might be sold to students in a sporting goods retailer (e.g., City Sports, Bike Line, EMS). The manufacturer is particularly interested in products likely to be appealing to students. These products might be solutions to unmet needs or improved solutions to existing needs."*

> Exercise 2: *"You have been retained by a manufacturer of dorm and apartment products to identify new product concepts for the student market. The manufacturer is interested in any product that might be sold to students in a home-products retailer (e.g., IKEA, Bed Bath and Beyond, Pottery Barn). The manufacturer is particularly interested in products likely to be appealing to students. These products might be solutions to unmet needs or improved solutions to existing needs."*

A total of 443 ideas were generated. All ideas were independently and anonymously evaluated by a panel of 17 raters using a web-based software tool we developed as part of our research (freely available at www.darwinator.com). Ideas from the two idea generation exercises were rated separately. Half the raters saw the ideas from Exercise 1 first followed by Exercise 2; the other half saw them in the opposite order. The ideas from each idea generation exercise were presented to each rater in a randomized order. All but 1 rater rated all the ideas presented. Most of the raters were affiliated with the product design course (students or teaching assistants), however we ensured that participants did not evaluate ideas generated by them or their group. A sample of ideas generated is provided in the Electronic Companion.

6 Effect of Idea Generation Process on Four Properties Driving the Extreme Values

6.1 Effect of Idea Generation Process on the Mean Quality

Table 2 shows the results for the mean quality across different treatments. In Panel A, we provide an ANOVA analysis of the ratings received by each idea. We include controls for the set of individuals generating the ideas (at the level of a four person team, *creator*), the rater who provided the rating, and the domain to which the idea belonged. We consider the rater and creator effects as fixed effects and random effects. Our results are nearly identical in either case. Further, a Hausman test verifies the appropriateness of the use of the random effects estimators.[9] The ANOVA analysis shows that the team and hybrid process are different in mean quality. In particular, we evaluate and test the statistical significance of this difference and find that the *hybrid process generates ideas of better quality*.

Next, we try to investigate the sources of the mean quality advantage. In particular, we compare each of the two phases of the hybrid idea generation process with the team process. Our results are illustrated in Table 3. As before, we find that the effects of the treatments (now with three levels) on mean quality are significant. Further, we find that each of the two stages of the hybrid process is superior in mean quality to the team process. While the second part of the hybrid process (H-Team) has higher mean quality than the first (H-Individual), the differences are only marginally significant.

6.2 Effect of Idea Generation Process on Productivity (Number of Ideas Generated)

Table 4 illustrates the results of an ANOVA analysis of the productivity of different teams in the two treatments. We control for the effects of individual teams and consider two alternate specifications, one with the creators as a random effect and a repeated measures analysis. Our results are almost identical in

[9] The Hausman test compares the estimates from the more efficient random effects model against the less efficient but consistent fixed effects model to make sure that the more efficient random effects model also gives consistent results.

the different specifications. We find that the productivity is very different across different treatments. In particular, we find that the hybrid process produces many more ideas than the team process. To investigate the source of this productivity advantage we compared the two parts of the hybrid process with the team process. The results are illustrated in Table 5

We find that the individual idea generation phase of the hybrid process contributes largely to the productivity advantage of the hybrid process. The pairwise difference between this individual phase and the two team phases are large and statistically significant. Further, the team phase of the hybrid process produces slightly fewer ideas than the team treatment itself, though this difference is only marginally significant.

These results are completely in line with the existing literature and have been demonstrated multiple times. Though, to the best of our knowledge we are the first to verify these results statistically in a within-subjects design that controls for individual effects.

6.3 Effect of Idea Generation Process on the Within-Process Variance in Idea Quality

From our theory, the variance in quality of ideas generated by each team under the two different treatments influences the quality of the best idea. Note that this is not the variance in the quality ratings of the ideas across treatments or across teams but the variance in the quality of the ideas generated by any one team in a treatment. To operationalize this measure, we construct a variable that is the squared-difference of the rating received by an idea and the average rating received by all ideas generated by the entity in the specific treatment. We then conduct an ANOVA for this variable. The results are reported in Table 6. We find that the quality variance is higher in the team process.

These results support the assertion that the higher uncertainty in combinations generated from diverse knowledge pools, team dynamic effects such as status auctions, etc. are stronger than the convergence effect of teams. In our experiment, teams produced more great and more awful ideas, leading to a higher variance in idea quality.

6.4 Effect of Idea Generation Process on Ability to Discern Quality

We measure ability to discern quality as the rank correlation between the ranks computed using the panel ratings and the ranks provided by the subjects in the self-evaluation phase of the experiment. The results are illustrated in Table 7. We find that the ranks obtained in the team process have no correlation with the panel ratings whereas the for the hybrid process they exhibit a significant positive correlation.[10] Thus, for our experiment, the hybrid process is better at discerning quality. On further investigation (Table 8) we find that it is the individual part of the hybrid process that drives the superior self-evaluation ability.

This result supports the theory that in a team, ownership of ideas, social pressures, team dynamics, and interaction of different personalities limit objectivity and the ability to discern quality.

7 Net Effect of Idea Generation Process on the Best Solutions (Extreme Values)

In the preceding section, we examined how the statistical properties of teams and hybrid idea generation processes are different. In this section, we will examine how these properties come together to change the quality of the best ideas identified. In particular, we found that the hybrid idea generation process has higher mean quality, higher productivity, and more accurate self evaluation, but less variance in the quality of ideas. From the statistical theory developed in Section 3.2, we know that the higher mean quality, productivity, and self evaluation ability (hybrid process) and higher variance (team process) each independently lead to a better best idea.[11] The net effect of these different statistical properties can go either way— the hybrid process could do better or worse. In this section we consider three different situations, each with a different formalization of the best idea. We first build hypotheses on the basis of the results of Section 6, and then test those results.

[10] Note that in our experiment, we only ask for the ranks of the top 5 ideas, thus these results are estimates of the correlation only for the top few ideas. Nevertheless, it is the correlation for this right tail of the quality distribution which drives the difference between the true best ideas and the selected best ideas and is indeed the metric we are most interested in.
[11] Assuming all other parameters are fixed.

7.1 Comparison of the Team and Hybrid Process with no Time Constraints

Our experimental results suggest that given the *same amount of time*, the hybrid process produces more ideas than teams. This result is a strong function of requiring that hybrids and teams generate ideas for the same amount of time. In some organizational settings, this constraint may not apply. In such a setting, the difference in productivity would be irrelevant and the differences in the quality of the best idea would be driven only by the differences in mean quality and the variance in quality. The mean quality for the hybrid process is higher and the variance is higher for the team process. The combined effect of the two would depend on the actual magnitudes of the differences and the distribution.

To build hypotheses about this difference we assume that the quality of ideas is normally distributed. Under this assumption, and using the estimated values of the mean and variance for team idea quality and hybrid idea quality (sections 6.1and 6.3) we can compute the value of any given percentile for the two distributions. The difference between these computed percentiles are shown in Figure 1. This is the difference in idea quality that we would expect to see given the different means and variances that we observed in the previous section. Note that while for measures of central tendency such as the mean, median and the left tail of the distributions, the hybrid process is expected to produce better idea quality; however as we look at higher percentiles, the effect becomes smaller. The higher variability of the team process leads to more ideas that are away from the mean. While this mean itself is lower than that for the hybrid process, for the particular values of mean and variance that were observed in our experiment, the variance effect dominates. More specifically, the difference becomes minor for ideas in 80^{th} or higher percentile. Thus we hypothesize that the difference in quality between the best ideas generated by team and hybrid processes becomes smaller as we look at fewer and fewer of the very best ideas.

Next, we test our prediction from Figure 1, using all the data and without making any distributional assumptions. We employ the technique of *Quantile Regression* (Koenker and Hallock (2001)). While classical regression relates the mean of a response variable (in our case, idea quality rating) to the explanatory variables; quantile regression computes this relationship separately for different percentiles of the data. In other words, this extension allows for the effect of an explanatory variable to differ for different percentiles.[12] Just as the mean gives an incomplete picture of the data, and at times we need to look at the full distribution; linear regression gives an incomplete picture of the dependence of the response variable on the explanatory variables and when we are interested in the behavior of the tails we employ Quantile Regression. Quantile regression has been previously employed to model the dependence of household food expenditure on income, maternal demographic characteristics on infant birth weight, wage premium due to unionization, etc. We estimate a model with the idea quality rating as the dependent variable. We introduce dummies for the rater and the entities associated with the idea. Finally, we introduce a dummy variable for the idea generation process employed— team or hybrid. This dummy variable captures the difference in the quality of the ideas from the team process and the hybrid process. Figure 2 illustrates the estimated value of this difference and the 95% confidence interval. As expected, we see that hybrid processes outperform team for the median quality and for smaller percentiles. But the difference in quality for higher percentiles is statistically no different from zero.

These results suggest that when there are no constraints on time and consequently no productivity differences between hybrid and team process; the difference in the quality of best ideas generated by the two processes is small or negligible, even when the average quality of ideas generated in the two treatments is different.

7.2 Comparison of the Team and Hybrid Process with Time Constraints

If the two idea generation processes must be employed for the same amount of time, the higher productivity of the hybrid process would also play a role (Section 3.2). Now, we have three effects— higher mean and productivity favoring hybrid and higher variance favoring team. As before, the net effect

[12] Quantile Regression is not simply dividing the data based on the observed percentiles and running each regression separately; but this method uses all the data to compute conditional quantiles and then estimates the dependence of these quantiles

of the three will depend on the exact magnitude and nature of interaction of these effects.[13] To build a hypothesis into the net magnitude of these effects, we develop a simulation. For each of the two idea generation processes, we generate random numbers (qualities) from distributions with the same density as observed in our experimental data, a bootstrapping approach. Further, the number of draws from each distribution is itself a random variable with the two different distributions for productivity estimated in section 6.2. For the purpose of the simulation, we assume the productivity is normally distributed. The resulting differences between the top 5 ideas[14] for the team and the hybrid are shown in Figure 3. The difference in the average quality of the top 5 ideas from hybrid and team is also shown. Based on these results we hypothesize that the average quality of the top 5 ideas from the team process will be better than those from the hybrid process.

To test this hypothesis we conduct an ANOVA analysis of the ratings received by the top 5 ideas. Table 9 shows us results from the comparison of the average quality of top 5 ideas in different treatments. In Panel A, we provide an ANOVA analysis of the ratings received by each idea. As before, we include controls for the set of individuals generating the ideas (at the level of a four-person team, creator), the rater who provided the rating, and the domain to which the idea belonged. We consider the rater and creator effects as fixed effects and random effects. Our results are nearly identical in either case. Further, a Hausman test verifies the appropriateness of the use of the random effects estimators. The ANOVA analysis shows that the team and hybrid process are different in the quality of the top 5 ideas. In particular, we evaluate and test the statistical significance of this difference and find that, as predicted, the top 5 ideas from the *team process are of better quality* than those from the hybrid process.

[13] The effect of increasing productivity and variance interact in a non-trivial way, and the actual impact of the interaction is a function of the values of productivity, variance and means. The logic based on partial effects can no longer be safely used to make predictions.

[14] Note that we can no longer use percentiles to compare the two processes, as percentiles ignore the effect of different number of draws. We consider top 5 ideas in this and the following analyses, the choice of five reflects a trade-off between power of the estimation procedure and capturing the right tail of the distribution. If we use fewer than five ideas then we use less and less of the data compromising our ability to find the effects. If we use more than 5 ideas, then our metric is a poorer proxy for the right tail of distribution. Our results are significant under alternate specification such as top 3, 4 or 6 ideas, further all other specifications tested, the results are directionally accurate.

7.3 Comparison of the Team and Hybrid Process with Time Constraints and Self Evaluation

Next consider a scenario, where the same organizational process is used to generate the ideas and also to evaluate and select the best ideas. As in the preceding section, the differences in mean quality, variance in quality, and productivity will influence the best ideas that are generated in each of the different idea generation processes. Further, the ability to correctly evaluate these ideas will also matter. In particular the rank correlations between rankings of the ideas by the idea generation team and the true rankings (analyzed in Section 6.4) will also play a role in this approach. If the self-evaluated rankings were identical to the true rankings, the self selected top 5 ideas would have the best true quality, and if the rankings were completely uncorrelated with the true rankings of the ideas, the self selected top ideas would be no different than an average sample of ideas.

In Section 6.4, we found that the hybrid process has a much better ability to evaluate the ideas than the team process. If there were no self evaluation, we know that the top 5 ideas from the team process are better, but the poorer ability to identify these top 5 ideas will diminish the quality of the self-selected top 5. The identified top 5 ideas from the hybrid will also be worse than before, but the reduction in quality will be less as compared to the team. The net effect will favor hybrid if the loss for the team process due to poorer self evaluation is enough to overcome the advantage that team has in generating the true top 5 ideas.

To test this we conduct an ANOVA analysis on the true quality ratings for the top 5 self-selected ideas. Table 10 shows us results from the comparison of the average quality of top 5 self-selected ideas in different treatments. In Panel A, we provide an ANOVA of the ratings received for each idea. As before, we include controls for the set of entities generating the ideas (at the level of a four person team, Creator), the rater who provided the rating and the domain to which the idea belonged. We consider the rater and creator effects as fixed effects and random effects. Our results are nearly identical in either case. Further, a Hausman test verifies the appropriateness of the use of the random effects estimators. The ANOVA analysis shows that the team and hybrid process are only marginally different in the quality of the top 5 self-selected ideas. The hybrid process has better idea quality reversing the results of the previous section, but the results are only marginally significant.

8 Conclusions and Managerial Implications

In this study, we analytically and experimentally compare the effectiveness of two processes for a group of individuals solving problems that require creative idea generation followed by selection. First, the group of individuals can work as a team. Alternately, the group works individually for some fraction of the time followed by team work (Hybrid). The team approach is most commonly used in successful creative organizations; despite the hybrid approach being strongly advocated in the psychology literature. In contrast with prior literature that has compared the average quality of the ideas and the number of ideas generated, we focus on the quality of the best ideas. Based on statistical theory, we find that better average quality of ideas, greater number of ideas, higher variance in the quality of ideas, and a better ability to discern the best ideas *each* independently improve the quality of the best identified ideas. From a novel experiment, we find that the hybrid process generates more ideas, with better average quality, and is superior in identifying the best ideas. The team process, on the other hand, exhibits higher variance. We then conduct a holistic examination of the net influence of these properties on the quality of the best ideas.

We find that when there are no time constraints the best idea generated by the team process may be better than for the hybrid, but the difference is small. On other hand, when there are time constraints, the quality of the best ideas generated by the team process is significantly better than those generated by the hybrid process. In contrast with the recommendations from prior experimental research against team idea generation, we find that the previously ignored higher variance of team processes tips the balance in favour of employing team processes with respect to the quality of the best idea. However, team processes are worse at identifying the best ideas and in situations where the team must also evaluate and select the ideas. This weakness makes the advantage of the team process marginal.

These results suggest that it would be best to employ team processes in the idea generation stage and then use an independent individual evaluation process. The higher variance of the team process will generate more great ideas, and an independent evaluation will avoid the deleterious effects of teams on evaluation.

8.1 Limitations

Our results on the quality of the best ideas depend not just on the directional comparisons between the two processes, but also on the magnitude of these differences. While our experiment was set up to closely match problems in real-world settings, the subjects' limited time, resources, and prior exposure to the problem solving context limit our ability to mimic perfectly a real situation. These raise the possibility that our results may not generalize. An empirical study based on a real life setting would be valuable to verify these results.

We measured idea quality and the differences in idea quality on a 10-point subjective rating scale. Potentially, these do not map linearly onto the economic value of the ideas. Thus, effects which appear as marginal differences in our results may be of much higher or lower consequence in economic terms. This would be a function of the domain. For instance, while marginal differences in quality can make or break a new business venture, they may have little impact on innovation efforts aimed at internal process improvements.

In all our results, we found that differences in performance among individuals are large and highly significant. It would be interesting to examine if these differences are persistent and systematic. If they are, an optimal process may be to first select the best individuals and then only employ them in subsequent idea generation efforts. However the dynamics of the interaction between these high ability individuals may differ significantly from the existing evidence. This presents an interesting opportunity for further research.

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Figures and Tables

Literature Review

Research	*Setting/ Methodology*	*Measure of Idea Quality*	*Metrics*	*Results*
Osborne (1957)				Introduced Brainstorming
Social Psychology Literature Diehl & Stroebe (1987,1991, 1994) (See Table 1 of the E-Companion for details)	Lab, Experimental	Rating by an assistant (Second assistant used for reliability) Rating by an expert	Mean & Productivity	Productivity: Individual > Teams Mean Quality: Equivocal Results **No Reason to work in teams!**
Sutton & Hargadon (1996,..)	IDEO, Observational			Contextual differences between lab and the real world
Taylor & Greve (2006)	Comic book industry, Empirical	Collector market value of a comic	Mean & Variance	Variance: Teams > Individuals Moderating effects of knowledge diversity, team experience, workloads, tenure, organizational resources
Fleming (2007)	Patent Data, Empirical	No of patents, citations (use of patent)	Mean, Variance & Productivity	Mean: Teams > Individuals Variance: Individuals > Team
Kavadias & Sommer (2007)	Analytical			Depends on problem structure and team diversity (experience and knowledge)
Dahan & Mendelson (2001)	Analytical	Best Idea (Extreme Value)	Extreme Value	
Girotra, Terwiesch & Ulrich	Lab (with trained subjects), Experimental	Ratings by a large number of peers using a web based interface	Mean, Variance, Productivity, **Self Evaluation ability, Extreme Value**	? ?

Table 1: Comparison of the Existing Literature with this Study

ANOVA: Type III Tests of Effects

Effect	*# of Levels*	Random Effects for Raters and Creators♪ *F-Value*
CreatorID	11	6.23 (R.E.)
Rater	17	55.11 (R.E.)
Treatment	2	14.62*** (<0.0001)
Domain	2	0.71 (0.3997)
N		7318

*** Significant at <0.01% Level; ♪ Identical results are obtained when Rater and Creator are introduced as Fixed Effects

Panel A: ANOVA Analysis

Least Square Means†

Treatment	*Estimate*
Hybrid	5.1072
Team	4.9029

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Quality Rating

Differences of Least Square Means

Difference	*Hybrid — Team*
Estimate	0.2043
t-Value	3.82
Pr > |t|	<.0001

Panel C: Comparison of Means

Table 2: Comparison of Mean Quality between Hybrid and Team

ANOVA: Type III Tests of Effects

Effect	*# of Levels*	Random Effects for Raters and Creators♪ *F-Value*
CreatorID	11	6.04 (R.E.)
Rater	17	55.13 (R.E.)
Treatment	3	9.43*** (<0.0001)
Domain	2	0.72 (0.3978)
N		7318

*** Significant at <0.01% Level; ♪ Identical results are obtained when Rater and Creator are introduced as Fixed Effects

Panel A: ANOVA Analysis

Least Square Means†

Treatment	*Estimate*
H-Team	5.2035
H-Indiv	5.0716
Team	4.9047

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Quality Rating

Differences of Least Square Means

Difference	*H-Team — H-Indiv*	*H-Indiv — Team*	*H-Team — Team*
Estimate	0.1318	0.1669	0.2988
t-Value	2.06	2.96	4.24
Pr > |t|	0.0398	0.0031	<0.0001
Adj P♯	0.0992	0.0087	<0.0001

♯Tukey-Cramer Adjustment for Multiple comparisons

Panel C: Comparison of Means

Table 3: Comparison of Mean Quality between H-Team, H-Indiv and Team

ANOVA: Type III Tests of Effects

		Random Effects for Creators ♪
Effect	*# of Levels*	*F-Value*
CreatorID	11	0.01 (R.E.)
Treatment	2	26.23*** (0.0004)
N		33

*** Significant at <0.01% Level; ♪ Identical results are obtained under a Repeated Measures Analysis

Panel A: ANOVA Analysis

Least Square Means^

Treatment	*Estimate*
Hybrid	28.4545
Team	11.8182

^Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Productivity

Differences of Least Square Means

Difference	*Hybrid — Team*
Estimate	16.6364
t-Value	5.12
Pr > |t|	0.0004

Panel C: Comparison of Means

Table 4: Comparison of the Mean Productivity of the Team and Hybrid Process

ANOVA: Type III Tests of Effects

		Random Effects for Raters ♪
Effect	*# of Levels*	*F-Value*
CreatorID	11	0.01 (R.E.)
Treatment	3	16.402*** (<0.0001)
N		33

*** Significant at <0.01% Level; ♪ Identical results are obtained under a Repeated Measures Analysis

Panel A: ANOVA Analysis

Least Square Means†

Treatment	*Estimate*
H-Indiv	20.7273
Team	11.8182
H-Team	7.7273

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Productivity

Differences of Least Square Means

Difference	*H-Indiv — Team*	*Team — H-Team*	*H-Indiv — H-Team*
Estimate	8.9091	4.0909	13.0000
t-Value	3.17	2.41	5.59
Pr > |t|	0.0099	0.0367	0.0002
Adj P♯	0.0246	0.0856	0.0006

♯Tukey-Cramer Adjustment for Multiple comparisons

Panel C: Comparison of Means

Table 5: Comparison of Mean Productivity between H-Team, H-Indiv and Team

ANOVA: Type III Tests of Effects

Effect	# of Levels	Random Effects for Raters and Creators♪ F-Value
CreatorID	11	1.35 (R.E.)
Rater	17	72.13 (R.E.)
Treatment	2	12.40*** (0.0004)
Domain	2	6.95*** (0.0084)
N		7318

*** Significant at <0.01% Level; ♪ Identical results are obtained when Rater and Creator are introduced as Fixed Effects

Panel A: ANOVA Analysis

***Least Square Means*†**

Treatment	*Estimate*
Team	4.7741
Hybrid	4.3436

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Value of Squared Deviations

Differences of Least Square Means

Difference	*Team — Hybrid*
Estimate	0.4305
t-Value	3.52
Pr > |*t*|	0.0004

Panel C: Comparison Mean Squared Deviations

Table 6: Comparison of the Within-Team-Treatment Variance

Rank Correlation Between Self Assigned Ranks and True Ranks

Treatment	*Spearman*	*Kendall tau b*	*Hoeffding Dependence*
Hybrid	0.19652*** (0.0024)	0.14952*** (0.0020)	0.00849*** (0.0066)
Team	0.18139 (0.2173)	0.11972 (0.2844)	-0.00502 (0.6400)

*** indicates significance at <0.01% Level

Table 7: Rank Correlation between Self Assigned Ranks and True Ranks

Rank Correlation Between Self Assigned Ranks and True Ranks

Treatment	*Spearman*	*Kendall tau b*	*Hoeffding Dependence*
H-Indiv	0.36097*** (<.0001)	0.29676*** (<.0001)	0.03510*** (<.0001)
H-Team	0.07266 (0.6087)	0.04868 (0.6496)	-0.01082 (0.9954)
Team	0.18139 (0.2173)	0.11972 (0.2844)	-0.00502 (0.6400)

*** indicates significance at <0.01% Level

Table 8: Rank Correlation between Self Assigned Ranks and True Ranks

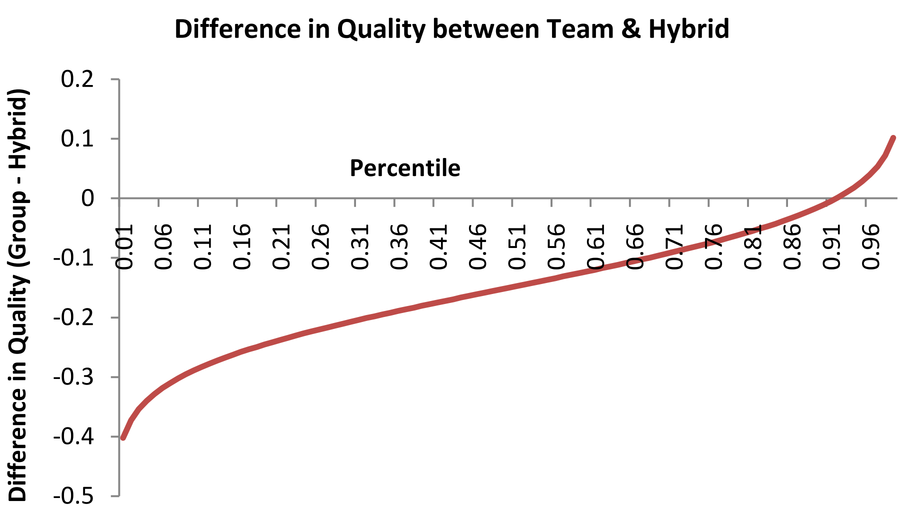

Figure 1 : Hypothesized Difference in Quality of Different Percentiles (The difference is computed assuming the qualities are normally distributed, the mean and variance are estimated using the data collected from the experiments. For each of the treatments, the x^th percentile quality is computed as $\mu + \sigma Z_x$; where μ is the mean of the quality distribution and σ is the variance of the quality distribution for that treatment.

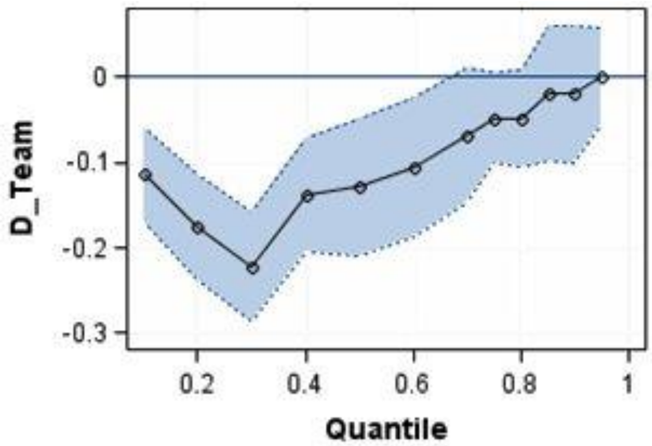

Figure 2: Estimated Difference in Idea Quality for Different Percentiles (using Quantile Regression). The bands indicate estimated 95% confidence intervals

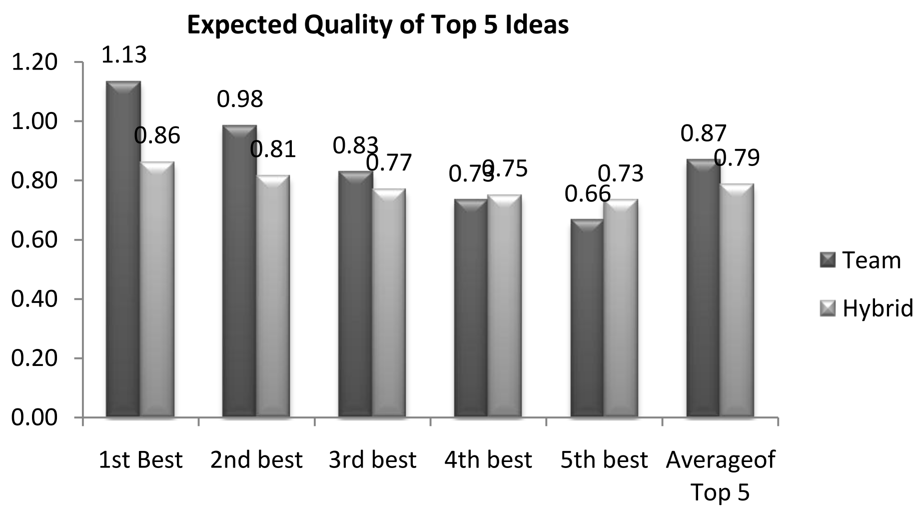

Figure 3: Expected Quality of Top 5 ideas (from simulation calibrated with observed quality distribution density (mean, variance) and productivity). The quality ratings were standardized for rater and ideator effects.

ANOVA: Type III Tests of Effects

Effect	*# of Levels*	*Random Effects for Raters and Creators*♪ *F-Value*
CreatorID	11	7.60 (R.E.)
Rater	17	37.07 (R.E.)
Treatment	2	4.98** (0.0257)
Domain	2	1.56 (0.2125)
N		4715

*** Significant at <0.01% Level; ♪ Identical results are obtained when Rater and Creator are introduced as Fixed Effects

Panel A: ANOVA Analysis

***Least Square Means*†**

Treatment	*Estimate*
Team	5.4639
Hybrid	5.2963

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Quality Rating

Differences of Least Square Means

Difference	*Team — Hybrid*
Estimate	0.1675
t-Value	2.23
Pr > |t|	0.0257

Panel C: Comparison of Means

Table 9: Effect of Organizational Process on the Quality of the Top 5 Ideas

ANOVA: Type III Tests of Effects

Effect	*# of Levels*	*Random Effects for Raters and Creators*♪ *F-Value*
CreatorID	11	4.41 (R.E.)
Rater	17	34.50 (R.E.)
Treatment	2	1.61 (0.2039)
Domain	2	0.02 (0.8838)
N		4571

*** Significant at <0.01% Level; ♪ Identical results are obtained when Rater and Creator are introduced as Fixed Effects

Panel A: ANOVA Analysis

***Least Square Means*†**

Treatment	*Estimate*
Hybrid	5.1543
Team	5.0493

†Least Square means are the mean residual after taking into account the other effects

Panel B: Mean Quality Rating

Differences of Least Square Means

Difference	*Hybrid — Team*
Estimate	0.1051
t-Value	1.27
Pr > |t|	0.2039

Panel C: Comparison of Means

Table 10: Effect of Organizational Process on Top 5 Selected Ideas

This page is intentionally blank to separate the paper from its Appendix.

E-companion to Girotra et al: Idea Generation and the Quality of the Best Idea

1 Formal Statement of Theorems and Proofs from Section 3.2

Theorem 1(Effect of Number of Ideas): $\boldsymbol{E}[M_n] \leq \boldsymbol{E}[M_{n+1}]$

Proof: Note that the $\Pr[M_n \leq z] = \prod_{i=1}^{n} \Pr[X_i \leq z]$. Thus, the Cumulative Distribution Function of the distribution of M_n, $G(z)$ is $F^n(z)$. $\mathbf{E}[M_n] = \int_0^\infty z g(z) dz = \int_0^\infty \big(1 - G(z)\big) dz = \int_0^\infty \big(1 - F^n(z)\big) dz$. Since $F(z) \leq 1$, $F^{n+1} \leq F^n$ and $1 - F^{n+1} \geq 1 - F^n$. The result now follows. ■

Lemma 1: If the quality of ideas generated follows a Generalized Extreme Value Distribution (GEV) (Coles (2001)) with parameters (μ, σ, ξ) the quality of the best of n ideas also follows a Generalized Extreme Value distribution with parameters

$$\mu' = \mu + \frac{\sigma}{\xi}\left(n^{\xi} - 1\right)$$
$$\sigma' = \sigma n^{\xi}$$
$$\xi' = \xi$$

Proof: The result follows from substituting the cumulative distribution functions and reparameterizing. ■

A similar result has been shown by both Dahan and Mendelson (2001) and Kavadias and Sommer (2007). While Dahan and Mendelson (2001) work with the three different sub-families of the generalized extreme value distributions, we present our result within the unifying framework of the generalized extreme value distribution. Kavadias and Sommer (2007) present this result for the Gumbel Distribution. Also, note that the generalized extreme value distribution represents a fairly flexible family of distributions that can capture a wide variety of censored data. Since idea generation often involves some internal censoring by the ideator, this family is an ideal candidate for capturing idea quality. Further, from data collected under a variety of ideation settings in real organizations, we find this family to be a reasonable fit.

Theorem 2 (Effect of the mean of the idea quality distribution) Consider two ideation processes with GEV quality distributions with different means. All other central moments of the distributions are identical.

The processes generate the same number of ideas. The expected quality of the best idea from the ideation process with the higher mean is higher.

Proof: Since all moments besides the mean are identical for the two distributions, only the location parameter of the two quality distributions μ can be different say $\mu_1 > \mu_2$. From Lemma 1, the best idea from each of the ideation processes will also be distributed GEV, with all parameters identical except the location parameters $\mu_1^{'} > \mu_2^{'}$. The mean of GEV distribution increases in the location parameter and the result now follows. ■

This result shows that all else being equal, the quality of the best idea from a process with a higher average quality is higher.

Theorem 3 (Effect of the variance of the idea quality distribution): Consider two ideation processes with GEV quality distributions with different variance. All other central moments of the distributions are identical. The processes generate the same number of ideas. The expected quality of the best idea from the ideation process with the higher variance is better iff $\Gamma(1-\xi) > 0$

Proof: Consider two GEV distributions (μ_1, σ_1, ξ_1) and (μ_2, σ_2, ξ_2). The conditions on the central moments of the two distributions imply that $\xi_1 = \xi_2 = \xi$. $\sigma_1 \neq \sigma_2$; say $\sigma_1 > \sigma_2$ and $\mu_1 - \mu_2 = (\sigma_1 - \sigma_2)\frac{(1-\Gamma(1-\xi))}{\xi}$. From Lemma 1, the quality of the best idea from each of the ideation processes will also be distributed GEV, with parameters $\left(\mu_1 + \frac{\sigma_1}{\xi}\left(n^{\xi} - 1\right), \sigma_1 n^{\xi}, \xi\right)$ and $\left(\mu_2 + \frac{\sigma_2}{\xi}\left(n^{\xi} - 1\right), \sigma_2 n^{\xi}, \xi\right)$ and means $\mu_1 + \frac{\sigma_1}{\xi}(n^{\xi}\Gamma(1-\xi) - 1)$ and $\mu_2 + \frac{\sigma_2}{\xi}(n^{\xi}\Gamma(1-\xi) - 1)$, Γ is the gamma function. The result will hold if $\frac{(n^{\xi}-1)\Gamma(1-\xi)}{\xi} > 0$. Now note $n > 1 \Rightarrow \frac{(n^{\xi}-1)}{\xi} > 0$. The result follows. ■

Corollary: Consider two ideation processes with Gumbel quality distributions with different variances. All other moments of the distributions are identical. The processes generate the same number of ideas. The expected quality of the best idea from the ideation process with the higher variance is better.

Proof: The Gumbel distribution belongs to the GEV family with $\xi \to 0$. The result follows from an application of the above theorem and assuming n > 1. ■

Theorem 4: a) (Coles (2001)) If there exist sequences of constants $\{a_n,\ b_n\}$ *such that*

$$\Pr\{M_n^* \le z\} \to G(z)\ as\ n \to \infty$$

for a non-degenerate distribution function G, then G is a member of the GEV family

$$G(z) = \exp\left\{-\left[1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\},$$

defined on $\{z: 1 + \xi(z-\mu)/\sigma > 0\}$, *where* $-\infty < \mu < \infty$, $\sigma > 0$ *and* $-\infty < \xi < \infty$.

b) Given $\{Z_1, Z_2, \ldots, Z_m\}$, *m observations of* M_n, *the parameters of* $G(z)$ *can be estimated as the argmax of the log-likelihood function*

$$l(\mu,\sigma,\xi) = -m\ log\ \sigma - \left(1 + \frac{1}{\xi}\right)\sum_{i=1}^{m} log\left[1 + \xi\left(\frac{z_i-\mu}{\sigma}\right)\right] - \sum_{i=1}^{m}\left[1 + \xi\left(\frac{z_i-\mu}{\sigma}\right)\right]^{-1/\xi}$$

provided that $1 + \xi\left(\frac{z_i-\mu}{\sigma}\right) > 0$, *for i=1,…,m. As always with maximum likelihood estimation, the parameter estimates are asymptotically normally and approximate confidence intervals can be constructed using the observed information matrix.*[1]

Proof a) The result is well known and we refer the reader to Coles (2001) for an outline of the proof and to the references therein for a more technical version of the proof.

b) Under the assumption that $\{Z_1, Z_2 \ldots, Z_m\}$ are independent variables having the GEV distribution, the above log likelihood follows from simple computation and absorbing the constants within the estimated parameters in the usual way. ■

[1] A potential difficulty with the use of maximum likelihood methods for the GEV concerns the regularity conditions that are required for the usual asymptotic properties associated with the maximum likelihood estimator to be valid. These conditions are not satisfied by the GEV model because the end-points of the GEV distribution are functions of the parameter values: $\mu - \sigma/\xi$ is an upper end point of the distribution when $\xi < 0$, and a lower end point when $\xi > 0$. Smith (1985) considers this problem in detail and find that for $\xi > -1$, the estimators are generally obtainable and often have the usual asymptotic properties.

2 Review of Social Psychology Literature

A Review of The Social Psychology Literature (Adapted from Diehl & Stroebe (1987))

Study	***Team size***	***Productivity***	***Quality***
Taylor, Berry and Block (1958)	4	R<N	TQ:R<N AQ:equivocal* NO:R<N
Cohen, Whitmyre and Funk (1960)	2	R=N	NO:equivocal
Dunette, Campbell and Jaastad (1963)	4	R<N	TQ:R<N AQ:equivocal
Milton (1965)	4	R<N	TQ:R<N
Gurman (1968)	3	R<N	TQ:R<N
Bouchard (1969) Experiment 2	4	R<N	TQ:R<N AQ:equivocal NG:R<N
Rotter and Portugal (1969)	4	R<N	-
Vroom, Grant and Cotton (1969)	4	R<N	TQ:R<N AQ:equivocal NG:R<N
Bouchard and Hare (1970)	5, 7, 9	R<N	-
Torrance (1970) Experiment 1 Experiment 2	2 2	R=N R=N	NO:R<N NO:R<N
Dillon, Graham and Aidells (1972)	4	R<N	-
Bouchard (1972) Experiment 2	4	R<N	NG:equivocal
Bouchard (1974) Conditions E and F	4	R<N	-
Street (1974)	3	R<N	-
Harari and Graham (1975)	4	R<N	-
Chatterjea and Mitra (1976)	3	R<N	-
Madsen and Finger (1978)	4	R<N	-
Maginn and Harris (1980)	4	R<N	-
Jablin (1981)	4	R<N	-
Barkowski, Lamm and Schwinger (1982)	2	R<N	-
Pape and Bölle (1984)	2	R=N	NO:R=N

Note: The following quality measures were used: total quality (TQ), average quality (AQ), number of original or unique ideas (NO), and number of good ideas (NG). Dashes indicate that quality was not assessed. * Findings vary across different topics, subjects teams, or experimental conditions.
Adapted from Dielhl & Streobe (1997), Journal of Personality and Social Psychology

Table 1: A Review of the Social Psychology Literature (Diehl & Stroebe (1987))

3 Experiment Design

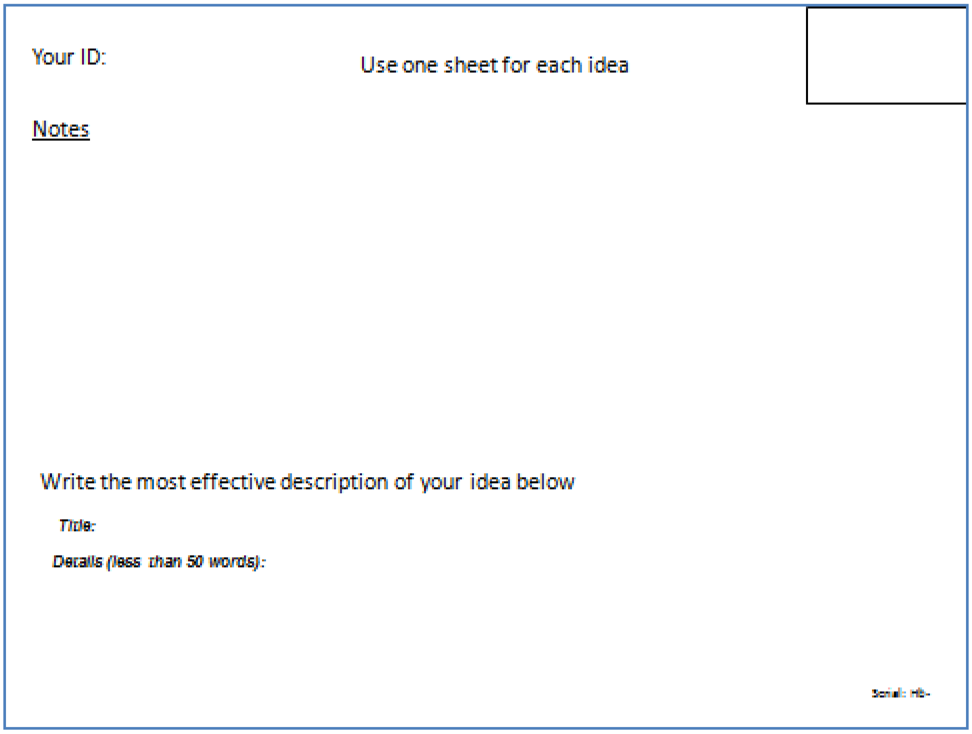
Your ID:
Use one sheet for each idea
Notes
Write the most effective description of your idea below
Title:
Details (less than 50 words):

Figure 1 : Sheet used to Record Individual Ideas

Instructions for Experimenters

Instructions for Room that does team in Domain 1 followed by hybrid in Domain 2, (Team IDs 9, 10, 11, 12)

1. Give participants ID cards in the order which they are stacked. The ID card is a small sheet of paper with numbers such as 1-1, 1-2, 1-3, 1-4, 2-1,2-2,2-3,2-4,2-5, etc. a space for names and the Darwinator username that they had used before. If they don't remember the Darwinator username, don't worry about it.

2. Introduce experiment "This is an experiment to study the effectiveness of idea generation processes."

3. Ask participants to get into teams based on their id #. (these are the same teams as formed before)

4. Hand out blue bundles G2[2]. Each team gets one bundle. Ask students to record their team # on the sheets.

5. Explain sheets. Explain box to enter ID, notes, and final recording.

6. G2: Tell students that they have 30 minutes to ideate about

   D1: Sports and Fitness Products (1)

   "You have been retained by a manufacturer of sports and fitness products to identify new product concepts for the student market. The manufacturer is interested in any product that might be sold to students in a sporting goods retailer (e.g., City Sports, Bike Line, EMS). The manufacturer is particularly interested in products likely to be appealing to students. These products might be solutions to unmet needs or improved solutions to existing needs.

7. After 30 minutes, tell participants to rank their top 5 ideas. Use the box on the top right hand to enter rating.

8. Collect blue bundles.

   This should be about 40 minutes into the experiment. Now, we enter the team phase (G2).

1. Hand out green bundles Ha. *Each student gets a bundle.* Ask students to record their ID # on the sheets.

2. Explain sheets. Explain box to enter ID, notes, and final recording. Do not explain the evaluation box. ID may be recorded only on top sheet of bundle. Bundles should not be separated.

3. Ha-1: Tell students that they have 10 minutes to ideate about

   D2: Dorm and Apartment Products

   "You have been retained by a manufacturer of dorm and apartment products to identify new product concepts for the student market. The manufacturer is interested in any product that might be sold to students in a home-products retailer (e.g., IKEA, Bed Bath and Beyond, Pottery Barn). The manufacturer is particularly interested in products likely to be appealing to students. These products might be solutions to unmet needs or improved solutions to existing needs."

4. After 10 minutes ask students to stop working. Ask students to rate their top 5 ideas, using the box of the top right corner. Then, ask students to form teams based on the first number in their ID. i.e. all students with ID #s starting with 1 should get together.

5. Hand out bundles pink bundles Hb. *Each team gets one bundle*. Ask students to enter Team # on their bundles.

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[2] There are three kinds of bundles Ha, Hb and G, bundle types are specified on the bottom left corner, bundle ha is handed out to each *participant*, and bundle hb and G are handed out to each *team*. All bundles are printed on different colors.

6. Hb-1: Now describe the hybrid 2 processes: “You have 20 minutes to work in a team. First describe to each other the ideas you generated as individuals. Then, as a team, generate new ideas or modifications of previously generated ideas. Each new or modified idea should be recorded on a new team (pink) sheet. If the idea is a modification of an existing idea, please note on the new sheet, the title of the parent idea and the id of the individual. DO NOT USE INDIVIDUAL (GREEN) SHEETS.

7. After 20 minutes. Ask teams to stop working. Teams should now identify their top 5 ideas from the ideas generated by the team. Use the box on the top right of either the pink sheets to note top five status.

8. Collect all green sheets from each individual and then collect pink bundles from each team. Keep teams separate.

4 Subsample of Ideas Generated

Title	**Descriptions**	**Mean Rating**
Mouth guard Holder	A small, convenient, removable pocket that can be used to hold a mouth guard in between uses on the field.	4.1
Odor Reducing Trash Can	A trash can that reduces odor of garbage inside it.	6.5
Water Bottle with Filter System	A water bottle with a built-in filtration system.	5.9
Transforma-Racquet	An athletic racquet that can be adjusted to accommodate any racquet sport.	4.2
Waterproof Reading System	A system for reading in the shower.	3.2
Disposable Desktop Cover	This product is meant to be placed over a clean desktop. As clutter builds up, just fold up the cover and pull the draw string to trash the collected garbage.	3.5
Toilet Table	A foldable table that attaches to the toilet so you can read, eat, or do work while going to the bathroom.	3.8
Coffee Table with Built-in Remote	A coffee table that has a TV remote built into it so that you don't have to move far to change channels, but at the same time you don't have to search for a lost remote.	3.7
Ball Bag	A ball that functions as a bag until it is time to use it. When the ball is emptied, it then turns into a ball to use.	3.4
Motion Detection Light	A light that detects that someone is trying to turn it on. When it senses motion at close proximity to the senor, it will automatically turn on or off.	3.6
Hair Collecting Comb	A comb that collects stray hairs and makes them easy to dispose.	5.3
Chore Meter	A system that logs who did what chores at a certain time to establish who isn't carrying their load.	3.9
Noise Reduction Pad	A pad that is placed on the floor of a dorm room to reduce the level of noise heard by the room below. Designed for students that work out in their rooms.	5.5

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