Supplementary Materials

1 Demographic information

Among the 288 participants we recruited from Amazon Mechanical Turk, 167 were male and 121 were female. Their ages ranged from 18 to 55+ (18y-24y: 30, 25y-34y: 129, 35y-44y: 81, 45y-54y: 23, 55y+: 25). The racial distribution was: White: 224, Asian: 15, Black or African American: 22, American Indian or Alaska Native: 15, other: 12. Among them, 15 participants belonged to Hispanic or Latino ethnicity.

2 Supplementary figures

Figures S1 through S10 present additional results from the analysis, as referred to from the main manuscript.

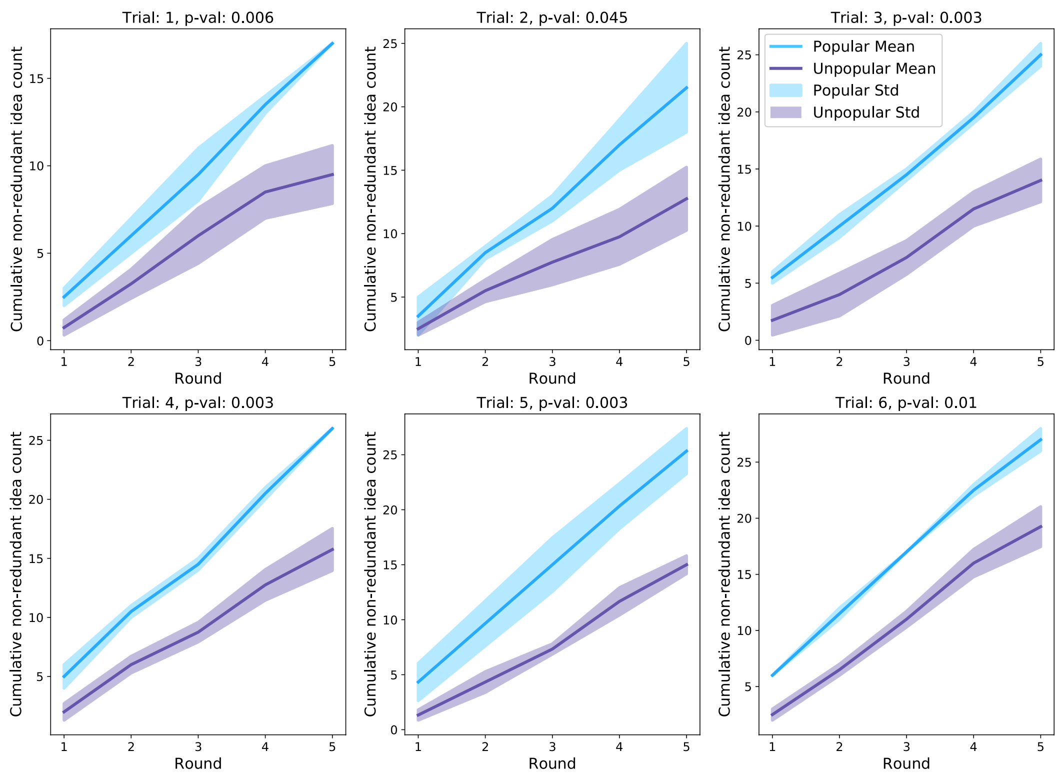


Figure S1: Trial-wise comparisons of cumulative non-redundant idea counts between popular and unpopular alters. 2-tailed tests show the popular alters (p) to have significantly higher cumulative counts over all rounds than unpopular alters (u) in all 6 trials, detailed as follows. Trial 1: $m_p = 17.0$, $m_u = 9.5$, $t(4) = 5.222$, $p = 0.0064$, 95% C.I. for $m_p - m_u = [4.0, 11.0]$; Trial 2: $m_p = 21.5$, $m_u = 12.8$, $t(4) = 2.879$, $p = 0.045$, 95% C.I. for $m_p - m_u = [2.1, 15.4]$; Trial 3: $m_p = 25.0$, $m_u = 14.0$, $t(4) = 6.351$, $p = 0.0031$, 95% C.I. for $m_p - m_u = [6.9, 15.1]$; Trial 4: $m_p = 26.0$, $m_u = 15.8$, $t(4) = 6.629$, $p = 0.0027$, 95% C.I. for $m_p - m_u = [6.5, 14.0]$; Trial 5: $m_p = 25.3$, $m_u = 15.0$, $t(4) = 6.609$, $p = 0.0027$, 95% C.I. for $m_p - m_u = [6.8, 13.9]$; Trial 6: $m_p = 27.0$, $m_u = 19.3$, $t(4) = 4.66$, $p = 0.0096$, 95% C.I. for $m_p - m_u = [3.8, 11.7]$.

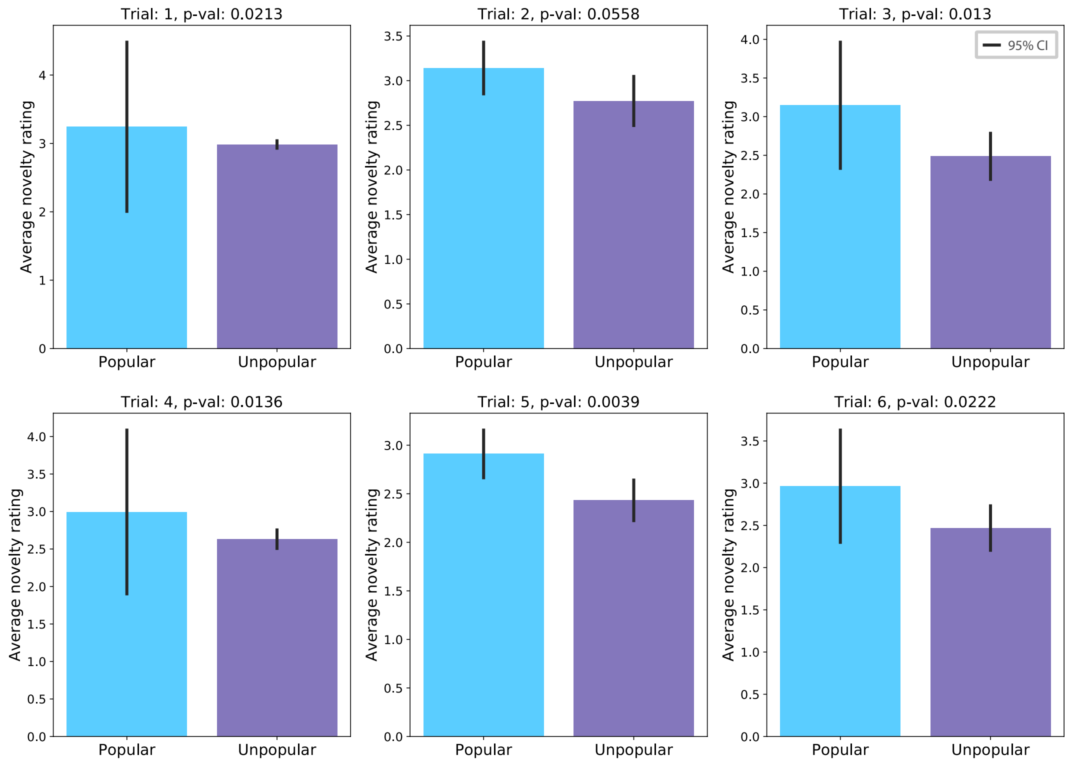


Figure S2: Trial-wise comparison of average novelty ratings between popular and unpopular alters. 2-tailed tests show the popular alters (p) to have significantly higher average novelty ratings over all rounds than unpopular alters (u) in 5 out of 6 trials, detailed as follows. Trial 1: $m_p = 3.2$, $m_u = 3.0$, $t(4) = 3.675$, $p = 0.021$, 95% C.I. for $m_p - m_u = [0.1, 0.4]$; Trial 2: $m_p = 3.1$, $m_u = 2.8$, $t(4) = 2.67$, $p = 0.0558$, 95% C.I. for $m_p - m_u = [0.04, 0.7]$; Trial 3: $m_p = 3.2$, $m_u = 2.5$, $t(4) = 4.264$, $p = 0.013$, 95% C.I. for $m_p - m_u = [0.3, 1.0]$; Trial 4: $m_p = 3.0$, $m_u = 2.6$, $t(4) = 4.207$, $p = 0.0136$, 95% C.I. for $m_p - m_u = [0.2, 0.6]$; Trial 5: $m_p = 2.9$, $m_u = 2.4$, $t(4) = 5.98$, $p = 0.0039$, 95% C.I. for $m_p - m_u = [0.3, 0.7]$, Trial 6: $m_p = 3.0$, $m_u = 2.5$, $t(4) = 3.63$, $p = 0.022$, 95% C.I. for $m_p - m_u = [0.2, 0.8]$

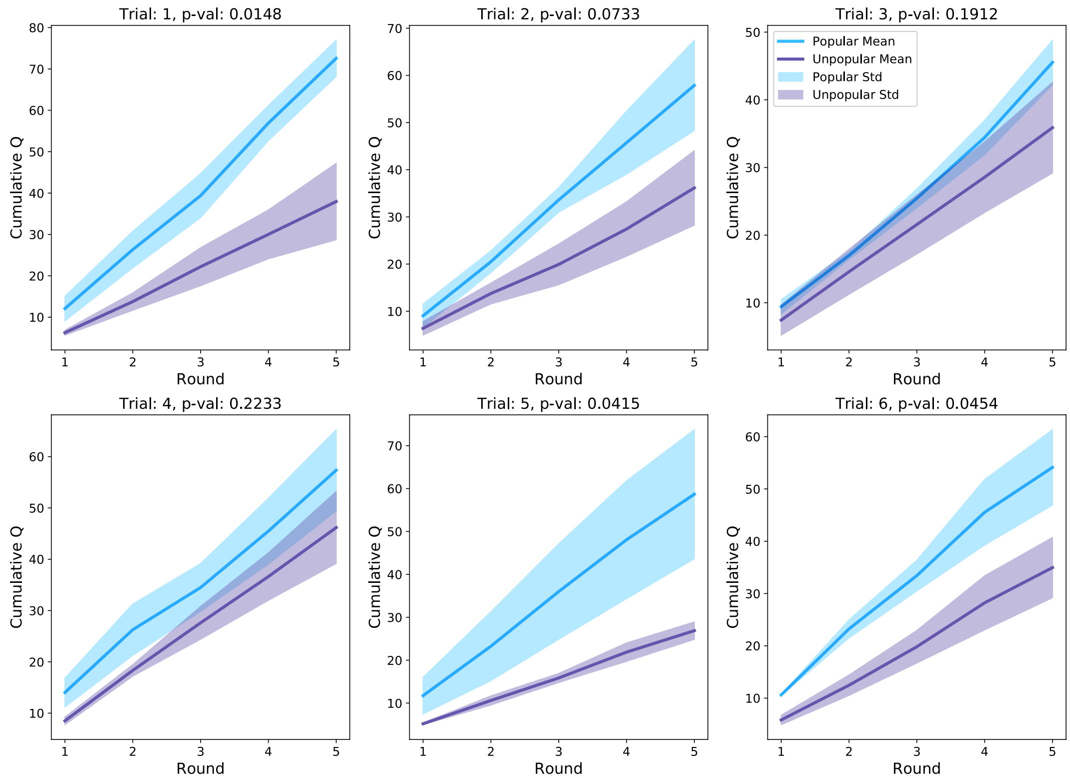


Figure S3: Trial-wise comparison of cumulative Q between popular and unpopular alters. 2-tailed tests show the popular alters (p) to have significantly higher total Q scores over all rounds than unpopular alters (u) in 3 of the trials, detailed as follows. Trial 1: $m_p = 72.6$, $m_u = 38$, $t(4) = 4.102$, $p = 0.015$, 95% C.I. for $m_p - m_u = [14.7, 54.6]$; Trial 2: $m_p = 57.9$, $m_u = 36.1$, $t(4) = 2.41$, $p = 0.073$, 95% C.I. for $m_p - m_u = [1.7, 41.8]$; Trial 3: $m_p = 45.5$, $m_u = 35.9$, $t(4) = 1.572$, $p = 0.19$, 95% C.I. for $m_p - m_u = [-4.9, 24.2]$; Trial 4: $m_p = 57.4$, $m_u = 46.2$, $t(4) = 1.44$, $p = 0.223$, 95% C.I. for $m_p - m_u = [-6.2, 28.6]$; Trial 5: $m_p = 58.7$, $m_u = 26.9$, $t(4) = 2.962$, $p = 0.041$, 95% C.I. for $m_p - m_u = [7.5, 56.2]$; Trial 6: $m_p = 54.1$, $m_u = 35$, $t(4) = 2.872$, $p = 0.045$, 95% C.I. for $m_p - m_u = [4.3, 34.0]$

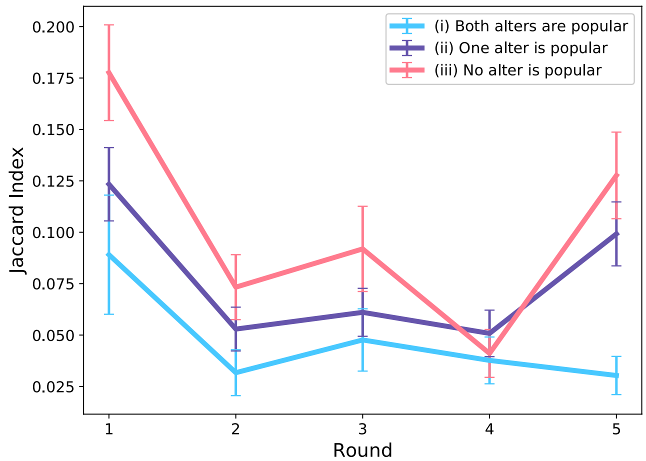


Figure S4: Average overlap (measured with Jaccard Index) between idea-sets of egos' turn-1 ideas and their alters in various rounds. Comparisons are made among three cases of egos: those with (i) both, (ii) only one and (iii) no alter(s) who are round-wise popular. As can be seen, egos who follow 2 popular alters consistently show a lower overlap compared to the other two cases. 2-tailed test results on the fifth round is given below. (i) vs (ii): $m_1 = 0.03$, $m_2 = 0.1$, $t(145) = -7.03$, Bonferroni-corrected $p < 0.001$, 95% C.I. for $m_1 - m_2 = [-0.088, -0.05]$; (i) vs (iii): $m_1 = 0.03$, $m_3 = 0.13$, $t(131) = -8.223$, Bonferroni-corrected $p < 0.001$, 95% C.I. for $m_1 - m_3 = [-0.121, -0.074]$

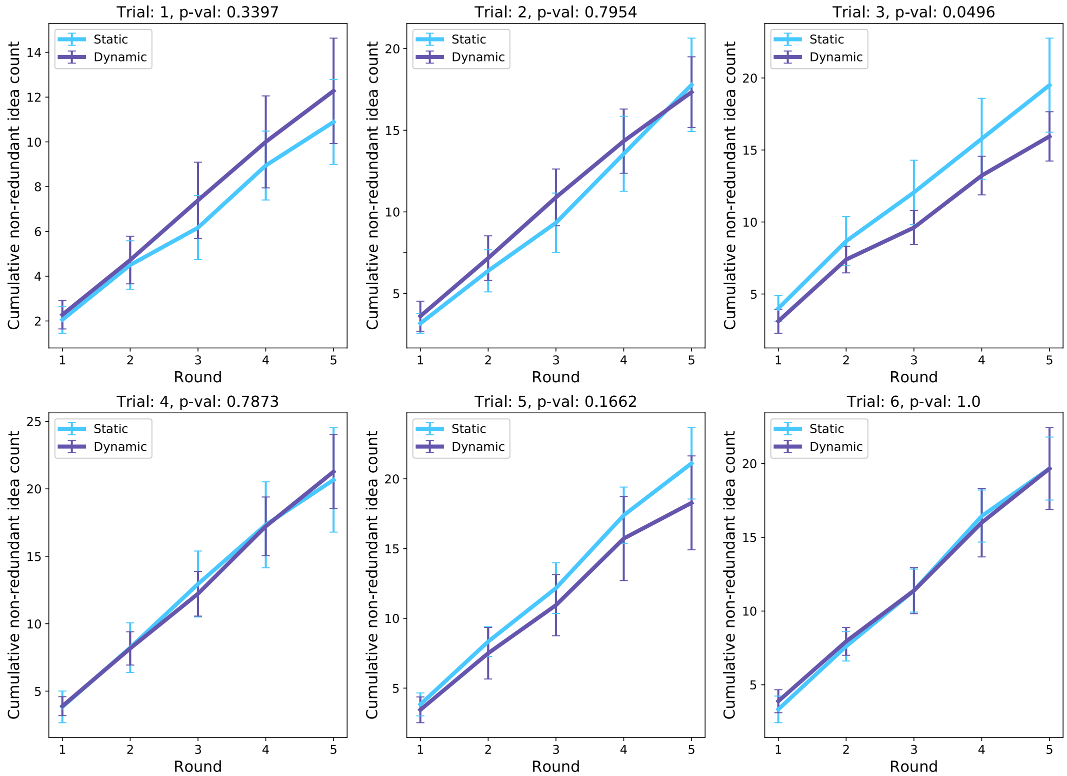


Figure S5: Trial-wise comparison of non-redundant idea counts between static and dynamic egos. 2-tailed tests are performed between the cumulative counts of static (s) and dynamic (d) conditions at the end of all 5 rounds, as detailed in the following: Trial 1: $m_s = 10.89$, $m_d = 12.28$, $t(34) = -0.968$, $p = 0.3397$, 95% C.I. for $m_s - m_d = [-4.221, 1.444]$; Trial 2: $m_s = 17.78$, $m_d = 17.33$, $t(34) = 0.261$, $p = 0.7954$, 95% C.I. for $m_s - m_d = [-2.914, 3.803]$; Trial 3: $m_s = 19.5$, $m_d = 15.94$, $t(34) = 2.036$, $p = 0.0496$, 95% C.I. for $m_s - m_d = [0.106, 7.005]$; Trial 4: $m_s = 20.67$, $m_d = 21.28$, $t(34) = -0.272$, $p = 0.7873$, 95% C.I. for $m_s - m_d = [-5.050, 3.828]$; Trial 5: $m_s = 21.11$, $m_d = 18.28$, $t(34) = 1.415$, $p = 0.1662$, 95% C.I. for $m_s - m_d = [-1.122, 6.789]$; Trial 6: $m_s = 19.67$, $m_d = 19.67$, $t(34) = 0.0$, $p = 1.0$, 95% C.I. for $m_s - m_d = [-3.280, 3.280]$. Whiskers represent 95% CI.

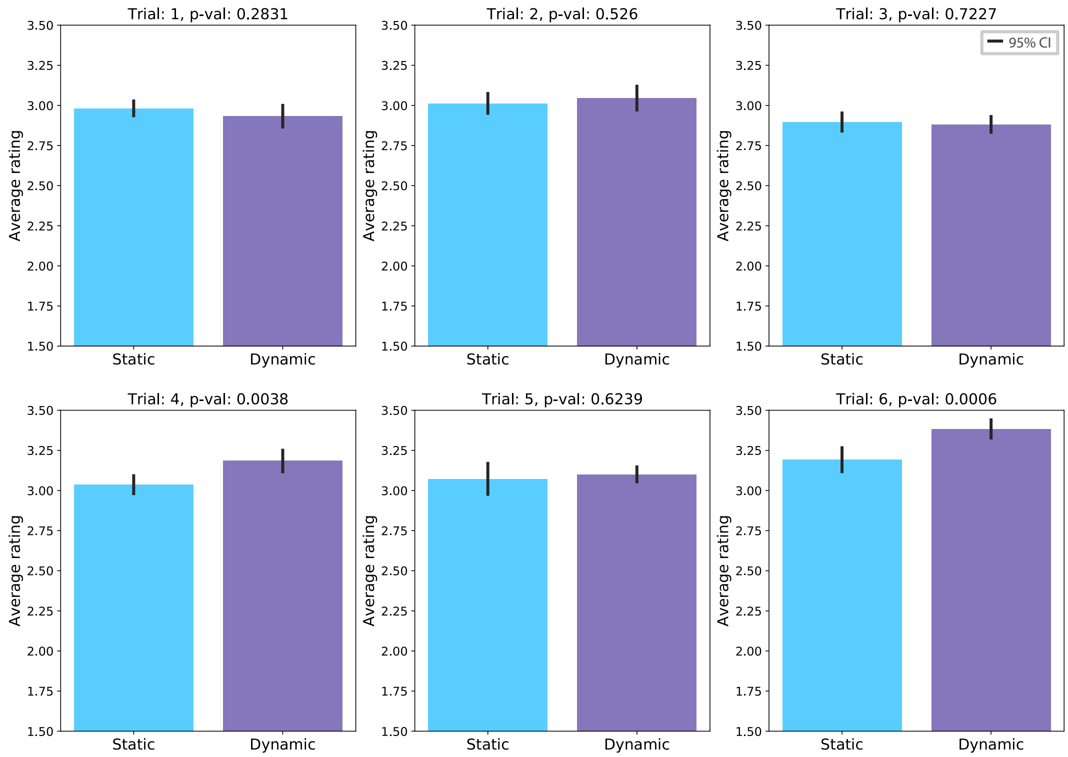


Figure S6: Trial-wise comparison of average novelty ratings between dynamic and static egos. 2-tailed tests are performed between the average novelty ratings of dynamic (d) and static (s) conditions over all 5 rounds, as detailed in the following: Trial 1: $m_d = 2.93$, $m_s = 2.98$, $t(34) = -1.091$, $p = 0.283$, 95% C.I. for $m_d - m_S = [-0.137, 0.04]$; Trial 2: $m_d = 3.05$, $m_s = 3.01$, $t(34) = 0.641$, $p = 0.526$, 95% C.I. for $m_d - m_s = [-0.069, 0.136]$; Trial 3: $m_d = 2.88$, $m_s = 2.9$, $t(34) = -0.358$, $p = 0.723$, 95% C.I. for $m_d - m_s = [-0.097, 0.067]$; Trial 4: $m_d = 3.18$, $m_s = 3.04$, $t(34) = 3.107$, $p = 0.0038$, 95% C.I. for $m_d - m_s = [0.054, 0.241]$; Trial 5: $m_d = 3.1$, $m_s = 3.07$, $t(34) = 0.495$, $p = 0.624$, 95% C.I. for $m_d - m_s = [-0.084, 0.14]$; Trial 6: $m_d = 3.38$, $m_s = 3.19$, $t(34) = 3.801$, $p = 0.00057$, 95% C.I. for $m_d - m_s = [0.092, 0.292]$.

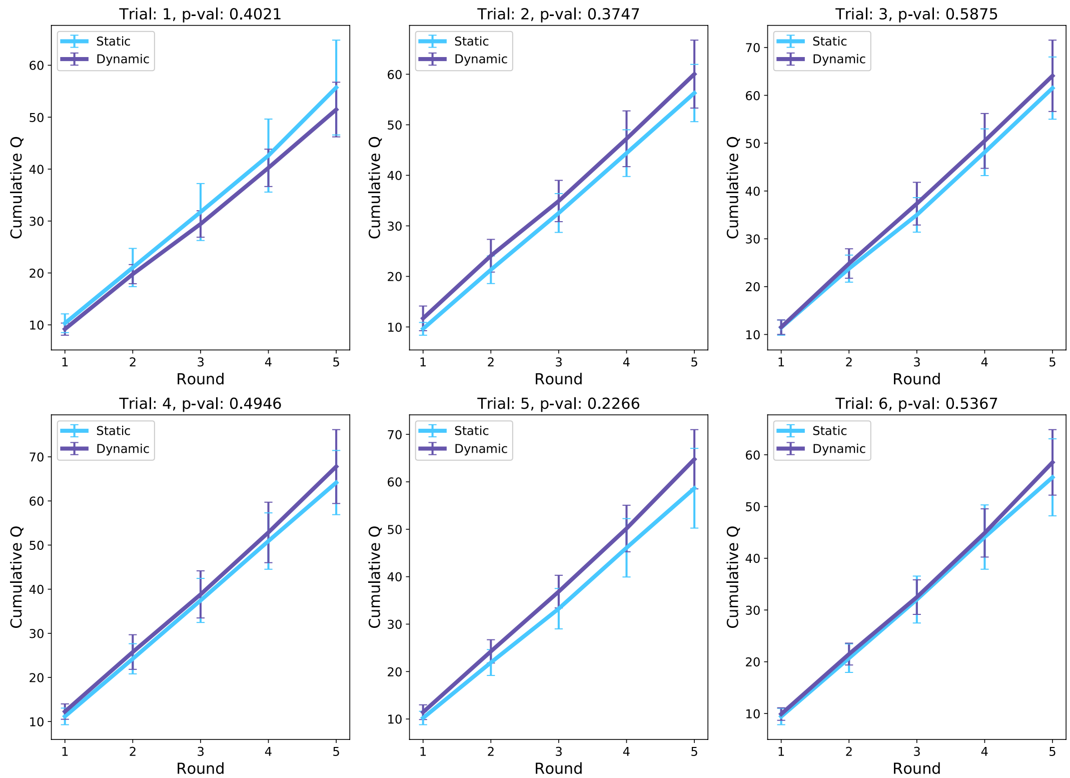


Figure S7: Trial-wise comparison of creativity quotients between static and dynamic egos. 2-tailed tests results between the cumulative Q counts of the static (s) and dynamic (d) conditions at the end of all 5 rounds is given in the following: Trial 1: $m_s = 55.71$, $m_d = 51.47$, $t(34) = 0.848$, $p = 0.402$, 95% C.I. for $m_s - m_d = [-5.628, 14.104]$; Trial 2: $m_s = 56.28$, $m_d = 60.03$, $t(34) = -0.9$, $p = 0.375$, 95% C.I. for $m_s - m_d = [-11.976, 4.481]$; Trial 3: $m_s = 61.52$, $m_d = 64.08$, $t(34) = -0.548$, $p = 0.588$, 95% C.I. for $m_s - m_d = [-11.833, 6.695]$; Trial 4: $m_s = 64.17$, $m_d = 67.8$, $t(34) = -0.69$, $p = 0.495$, 95% C.I. for $m_s - m_d = [-14.01, 6.752]$; Trial 5: $m_s = 58.65$, $m_d = 64.76$, $t(34) = -1.232$, $p = 0.227$, 95% C.I. for $m_s - m_d = [-15.912, 3.689]$; Trial 6: $m_s = 55.64$, $m_d = 58.53$, $t(34) = -0.624$, $p = 0.537$, 95% C.I. for $m_s - m_d = [-12.033, 6.254]$. Whiskers denote 95% CI.

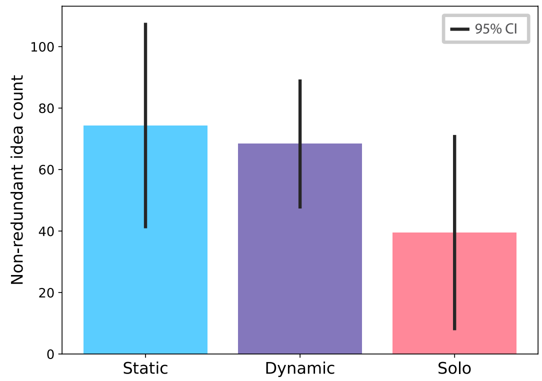


Figure S8: Collective-level comparison of non-redundant idea counts between solo, static and dynamic groups. 2-tailed tests show that the differences are insignificant between each condition-pair: Dynamic (d) vs solo (c): $m_d = 68.33$, $m_c = 39.5$, $t(6) = 1.928$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_c = [-4.538, 62.205]$; Dynamic (d) vs static (s): $m_d = 68.33$, $m_s = 74.33$, $t(10) = -0.391$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_s = [-37.235, 25.235]$; Static (s) vs solo (c): $m_s = 74.33$, $m_c = 39.5$, $t(6) = 1.465$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_s - m_c = [-18.240, 87.906]$.

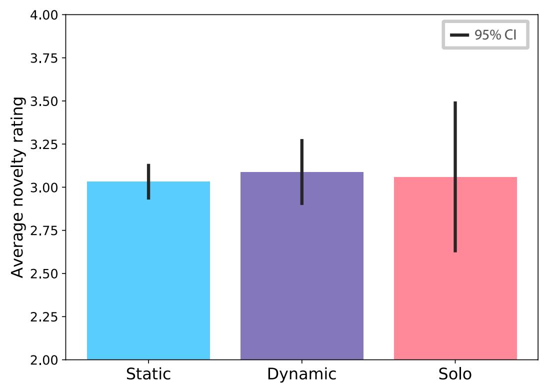


Figure S9: Collective-level comparison of average ratings between solo, static and dynamic groups. 2-tailed tests show that the differences are insignificant between each condition-pair: Dynamic (d) vs solo (c): $m_d = 3.09$, $m_c = 3.06$, $t(6) = 0.206$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_c = [-0.276, 0.332]$; Dynamic (d) vs static (s): $m_d = 3.09$, $m_s = 3.03$, $t(10) = 0.665$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_s = [-0.116, 0.228]$; Static (s) vs solo (c): $m_s = 3.03$, $m_c = 3.06$, $t(6) = -0.372$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_s - m_c = [-0.195, 0.139]$.

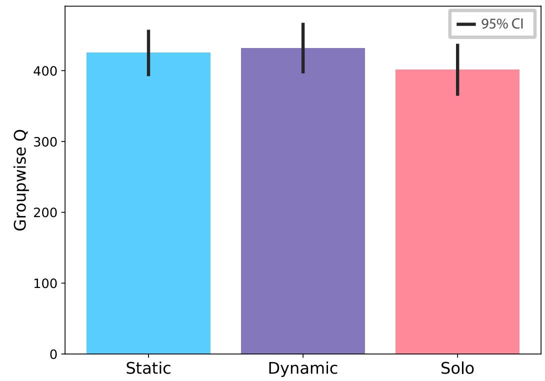
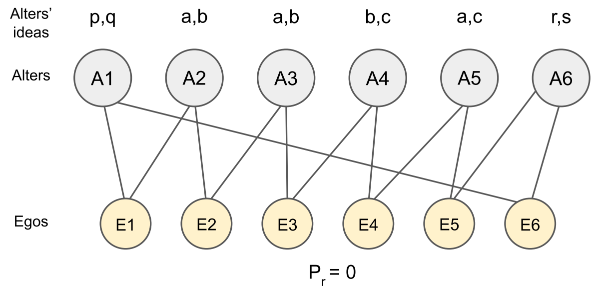
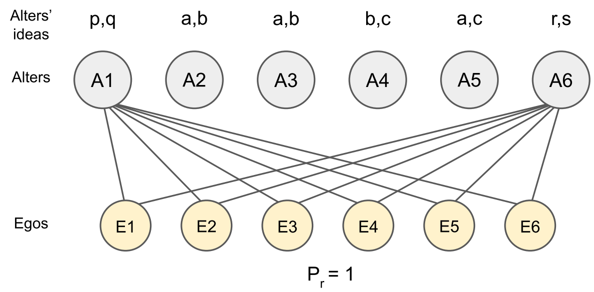


Figure S10: Collective-level comparison of creativity quotients between solo, static and dynamic groups. 2-tailed tests show that the differences are insignificant between each condition-pair: Dynamic (d) vs solo (c): $m_d = 431.84$, $m_c = 401.22$, $t(6) = 1.205$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_c = [-26.107, 87.348]$; Dynamic (d) vs static (s): $m_d = 431.84$, $m_s = 424.97$, $t(10) = 0.365$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_d - m_s = [-31.49, 45.243]$; Static (s) vs solo (c): $m_s = 424.97$, $m_c = 401.22$, $t(6) = 1.018$, Bonferroni-corrected $p > 0.05$, 95% C.I. for $m_s - m_c = [-28.317, 75.805]$.



Ego	Alters	Exposure set *E*
E_1	A_1, A_2	{a,b,p,q}
E_2	A_2, A_3	{a,b}
E_3	A_3, A_4	{a,b,c}
E_4	A_4, A_5	{a,b,c}
E_5	A_5, A_6	{a,c,r,s}
E_6	A_6, A_1	{p,q,r,s}



Ego	Alters	Exposure set *E*
E_1	A_1, A_6	{p,q,r,s}
E_2	A_1, A_6	{p,q,r,s}
E_3	A_1, A_6	{p,q,r,s}
E_4	A_1, A_6	{p,q,r,s}
E_5	A_1, A_6	{p,q,r,s}
E_6	A_1, A_6	{p,q,r,s}

Figure S11: (*Top row*) Simulation of the initial condition of the bipartite network (rewiring probability $P_r = 0$). One realization of the stimuli idea set is shown here, where alters A1 and A6 generated non-redundant ideas (p, q and r, s respectively). Alters A2 through A5 generated ideas a, b and c, which are not unique and were submitted by multiple alters. Thus, A1 and A6 are the top-performing alters here. The egos are connected to the alters in the same pattern as used in the original experiment. 6 egos are shown for demonstration purposes, although we simulate for 18 egos using by repeating this same connectivity pattern thrice. The table to the left shows the computation of the exposure sets of the egos. (*Bottom row*) The evolved network for $P_r = 1$, where all the egos follow the same top-performing alters. This results in making all of the egos' exposure sets the same, as shown in the table on the left.

3 Simulation

3.1 Network initialization

We simulate the study outcomes using the same bipartite network setting as adopted in the empirical explorations. Namely, we take $m = 6$ alters and $n = 18$ egos, and initialize their connections in the same initial pattern as the original experiment. Each of the alters i have an idea set A_i, that is used as the exposure to the ego.

3.2 Stimuli set generation

Following empirical observations in our study, we generate the idea-sets A_i for alters i such that some of the alters have larger unique idea counts than others (popular and unpopular alters, respectively). To simulate this, we start with two pools (sets) of symbols representing unique ideas: U_1 and U_2. By having $|U_1| << |U_2|$, we ensure that ideas sampled with replacement from U_1 will be more common than those from U_2. In other words, we simulate U_1 to include ideas that occur to people with a high probability, and U_2 to consist of rare ideas.

We assume that each alter i generates a fixed number of $|A|$ ideas. Each idea in A_i comes from pool U_1 with probability α_i, or from U_2 with probability $1 - \alpha_i$. For a random one-third of the alters, we take $0 \leq \alpha_i \leq 0.5$ (high-performing alters), and for others $0.5 < \alpha \leq 1$ (low-performing alters). This makes the idea sets A_i non-uniform, with the high-performing alters having a higher unique idea count than the low-performing alters, as shown in the top row of Figure S11.

3.3 Exposure set calculation

For each ego j, we take the set of ideas they are exposed to as the exposure set $E_j = A_{i_1} \cup A_{i_2}$, where alters i_1 and i_2 are ego j's peers.

3.4 Evolution of exposure set

With time (e.g., with rounds in our study), the egos in the dynamic condition can rewire their connections to the alters, which the static egos cannot. In the empirical results, we saw that the connection changes per ego dropped with time ($p < 1e - 4$ for the negative slope) as more egos followed the high-performing popular alters. We define a rewiring probability P_r that captures how much the network deviates from its initial configuration ($P_r = 0$) to the extreme case where two popular alters win the attention of all the egos ($P_r = 1$). Therefore, instead of simulating the dynamic network through time to explore its temporal effects, we can equivalently sweep over the rewiring probability P_r and explore its effects on the exposure sets of the egos. Figure S11 shows the idea. With time, the exposure sets become more uniform, as even the rare ideas from pool U_2 become common due to increased exposure.

3.5 Generation of stimulated ideas set

Given the exposure set E_j, an ego j can generate the following: with probability p_1, s/he can generate ideas that are substantially inspired/stimulated by ideas from the exposure set, with probability p_2 s/he can generate ideas with negligible or no stimulation from the exposure set ideas, and with probability p_3 s/he can generate ideas that are inspired by the exposure set but do not fulfill the study requirements of being substantially different than the stimuli and also feasible. For our purposes of exploring the effects of the network dynamics, we can set $p_2 = p_3 = 0$, which makes $p_1 = 1$. In other words, we are assuming that an ego only generates ideas that are inspired by the exposure set. Any effect from p_2 and p_3 should occur similarly in both static and dynamic conditions as the participants are randomly placed, and therefore act as mere random noise that we set to 0. This leads to the set of stimulated ideas for ego j, $S_j = \{e'_1\} \cup \{e'_2\} \cup ... \cup \{e'_k\}$ where each idea in the exposure set $e_k \in E_j$ leads to a set of ideas $S^{(e_k)} = \{e'_k\}$, and the union of all such idea sets from all $e_k \in E_j$ are contained in S_j.

The empirical results show a positive stimulation of ideas in the dynamic and static conditions compared to the solo condition (no stimuli). Therefore we can reasonably ignore the possibility that a stimulus can hurt the ideation process (negative association between $|E|$ and $|S|$). Also, our choice of having $p_1 = 1$ in the previous paragraph gets rid of the possibility of no association between $|E|$ and $|S|$. This leaves a positive stimulation effect, captured by a positive association between $|E|$ and $|S|$.

As argued in the main manuscript, less overlap between an ego's own ideas and his/her alters' ideas can help in stimulating further novel ideas in the ego. Again, the rare a stimulus idea e is, the less overlap can be expected to exist between e and the ego's own ideas, which can lead to a higher chance of stimulation. We measure the rarity of each stimulus idea as $R_e = 1 - \frac{\text{Number of times the idea was submitted by the alters}}{\text{total number of alters' ideas}}$. Therefore, we have the number of ideas stimulated by e, $|S^{(e)}| \propto f(R_e)$, where f is a stimulation function. We consider three cases of this stimulation relation: (1) linear: $|S^{(e)}| = kR_e$, (2) sub-linear: $|S^{(e)}| = k\sqrt{R_e}$, (3) super-linear: $|S^{(e)}| = kR_e^2$, where k is a proportionality constant.

3.6 Redundancy among egos' ideas and final outcomes

Every ego j generates stimulated ideas S_j independently of other egos. However, when the network evolves such that the high-performing alters become highly popular (high rewiring probability P_r), the exposure sets of the egos can become similar. We consider two extreme cases in this regard: (1) No redundancy: every ego j with the same stimulus idea e generates completely different stimulated ideas in $S^{(e)}$, and (2) Full redundancy: every ego j with the same stimulus idea e generates exactly the same stimulated ideas in $S^{(e)}$.

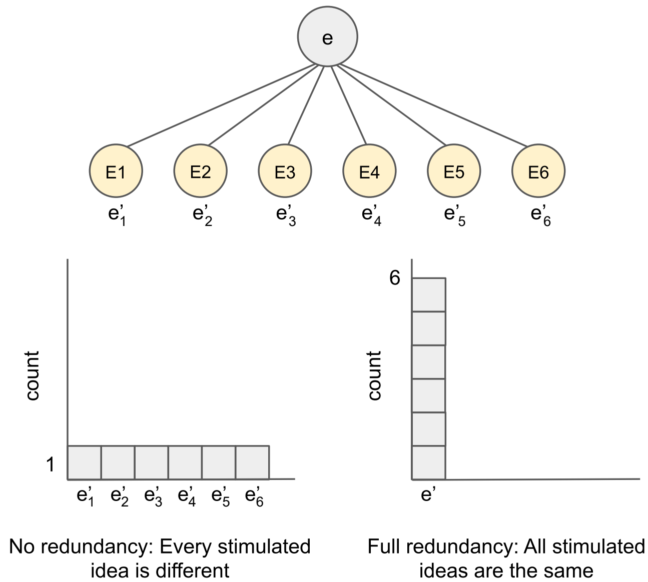


Figure S12: (*Top row*) An illustration of one stimulus e being shown to 6 independent egos, where the egos generate one stimulated idea each. (*Bottom row*) Two extreme cases: (1) No redundancy, where each stimulated idea is unique from each other, and (2) Full redundancy, where all the stimulated ideas turn out to be the same. The dynamic network suffers in case of increased redundancy, since the rewiring process exposes an increased number of people to the same stimulus e.

The first case will have the least network effect due to the complete uniqueness of every stimulated idea. But in the second case, the dynamic network will suffer from generating more redundant ideas among the participants. An example is shown in Figure S12.

3.7 Results

The results are shown in Figure S13. When there is no redundancy among the egos' ideas generated in response to the same stimuli, the dynamic condition enjoys an advantage over the static condition as the rewiring probability P_r increases. But when there is full redundancy, none of the ideas in the dynamic condition remains unique anymore as P_r approaches 1, thereby hurting the creative outcomes. This result is robust to various stimulation functions we chose in Section S3.5.

3.8 Discussion

The simulation highlights the roles played by the network dynamics and the cognitive stimulation mechanism in the creative ideation process. First, the rewiring process makes the stimuli set similar with time for the egos in the dynamic condition, which is a purely network-driven process. Second, the redundancy among the egos' ideas in response to the same stimulus also becomes a manifestation of the network dynamics, as the redundancy is initiated/facilitated by the egos' similar choices of peers. These two factors, taken together, negatively impact the creative outcomes in the dynamic condition. On the other hand, the stimulation process of the egos' ideas is driven by cognitive mechanisms. The various stimulation functions we experimented with (f) benefit the creative outcomes in varying degrees. However, as the simulation demonstrates, sufficient redundancy in the egos' ideas has the ability to overpower the cognitive stimulation benefits. In our empirical data, we find evidence of both of the network and cognitive factors to be present concurrently, which are captured by this simulation model.

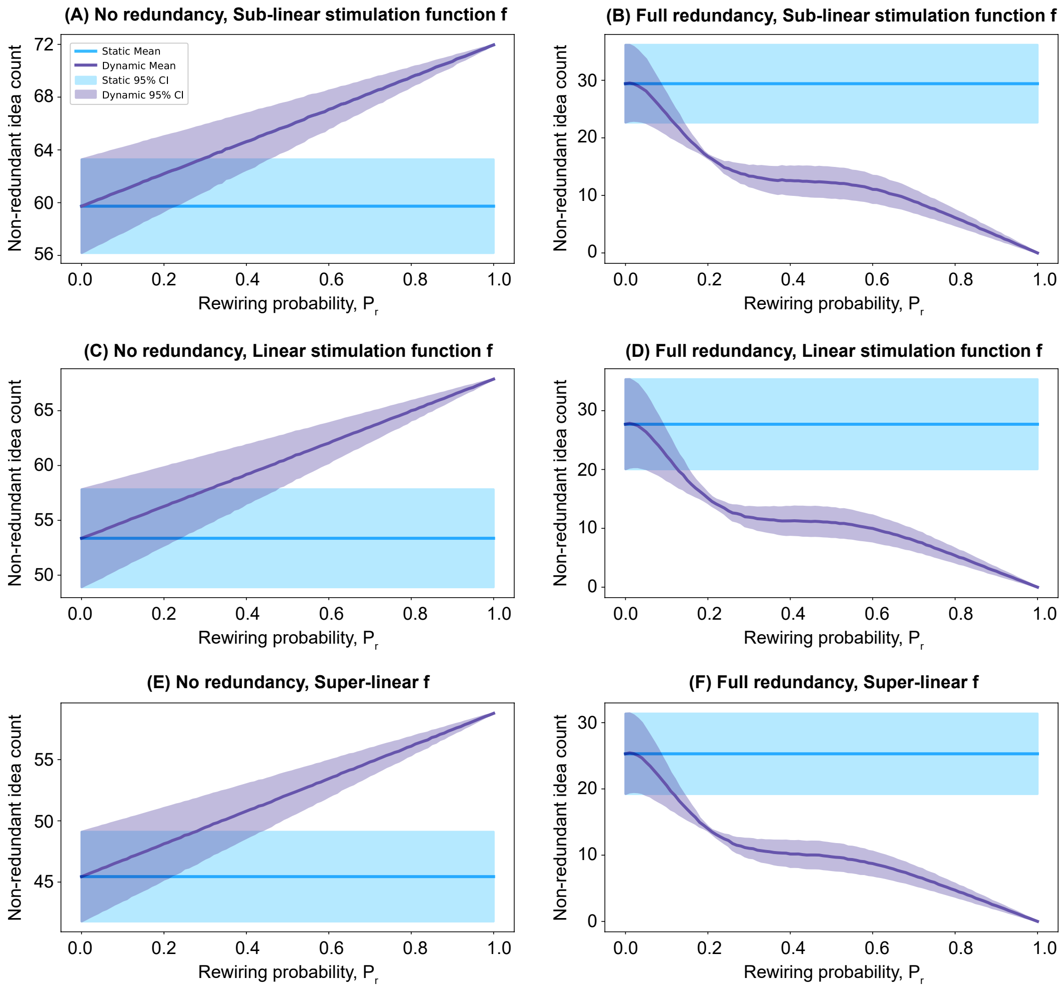


Figure S13: Simulation results aggregated over $10,000$ runs of the model (200 runs each for 50 different instances of alters' idea sets) for each of the three stimulation functions. The x-axis denotes rewiring probability P_r, where $P_r = 0$ denotes the initial network structure and $P_r = 1$ denotes the extreme case where all the egos follow the same two popular alters. The left column panels (A, C and E) show the simulation results for the case of no redundancy among the ideas generated by different egos in response to the same stimulus. The right column panels (B, D and F) show results for full redundancy cases. The top row, middle row and bottom row are the simulation results for the sub-linear, linear and super-linear stimulation functions, respectively. As can be seen, when there is no redundancy, the dynamic networks outperform the static ones as P_r increases. However, when there is redundancy, the dynamic network suffers as more egos follow the same alters at higher P_r, eventually making all the stimulated ideas redundant and therefore not creative. Slope parameter $k = 20$ has been used in the stimulation functions. An idea is taken to be non-redundant if it is given by ≤ 7 egos, although any threshold in the range $m \leq th < n$ gives the same insights.

4 Study interface

The study was conducted with approval from the University IRB. No personally identifiable information was collected from the participants. The web interfaces used in the experiment are shown below, using pseudo usernames. Some of the materials are redacted to ensure copyright compliance of using materials from Guilford's Alternate Uses test.

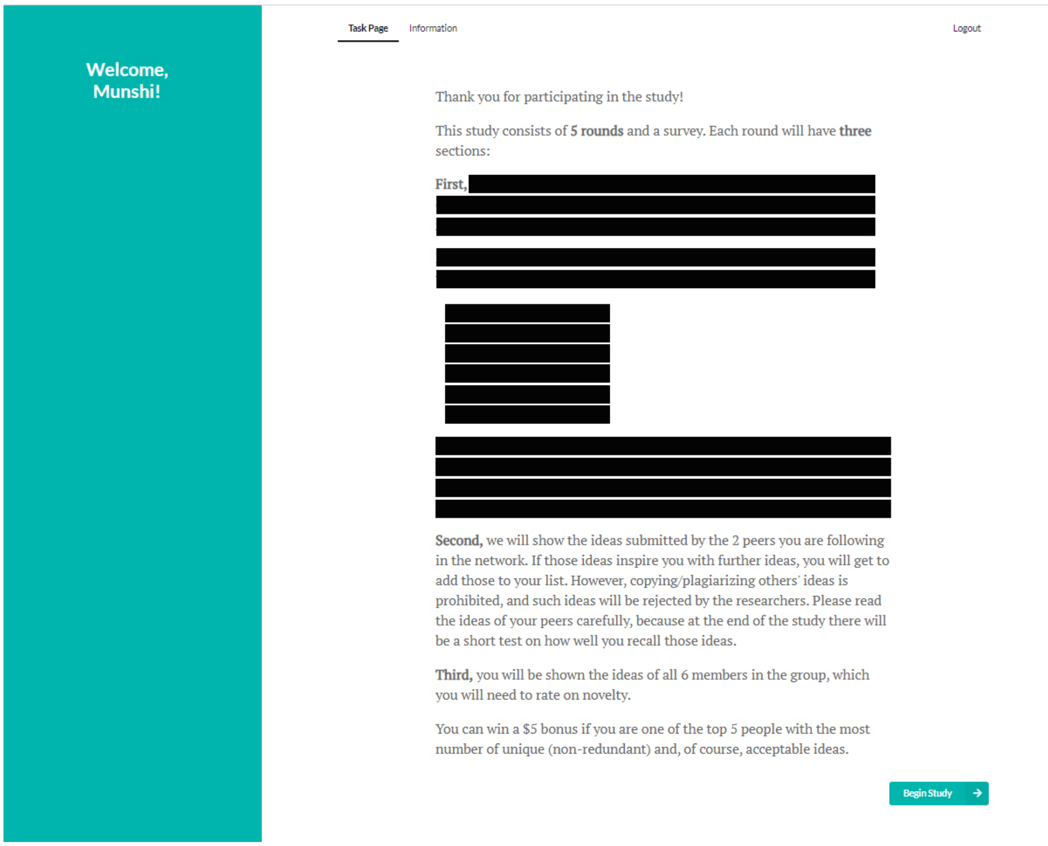


Figure S14: Instruction page for the egos of the static condition. Here, the first point is redacted to ensure copyright compliance of using the Guilford's test. This first point provides instructions for idea generation with examples. For the alters and solo participants, only the first point was shown.

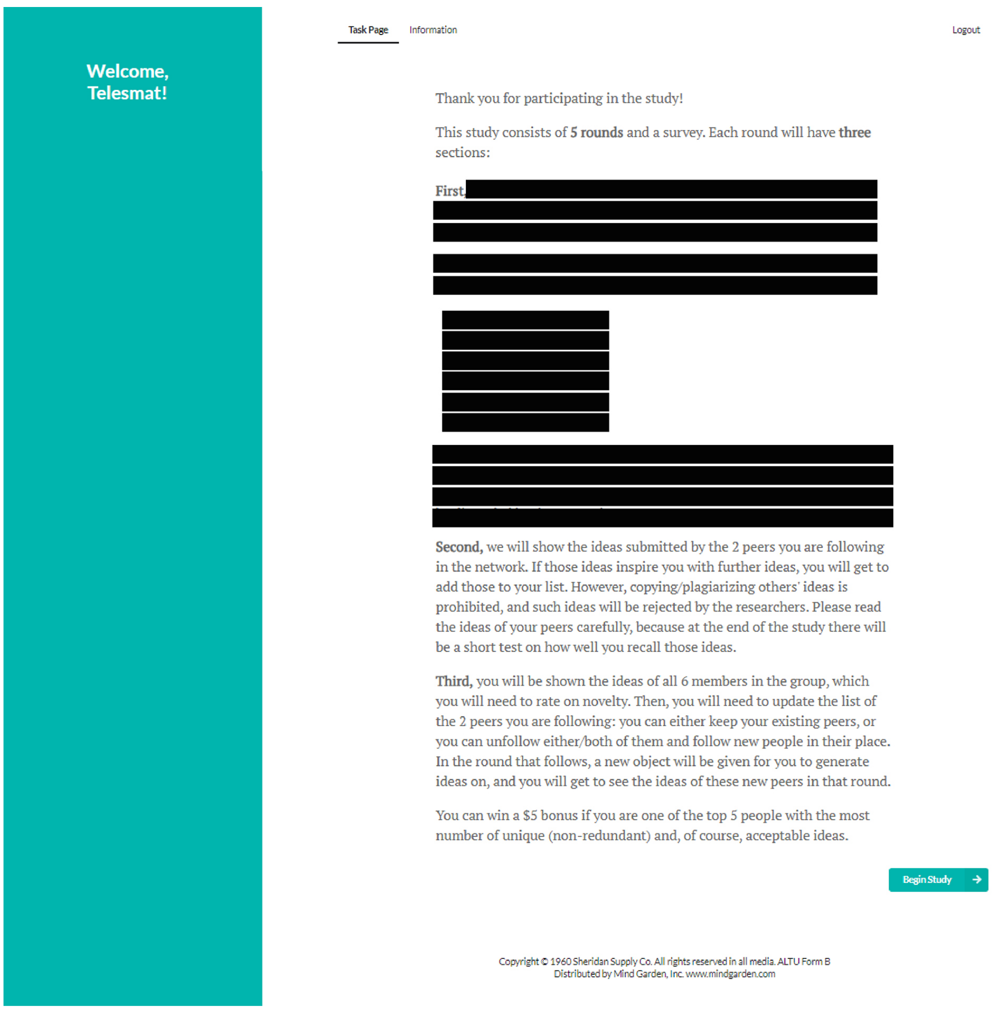


Figure S15: Instruction page for the egos of the dynamic condition.

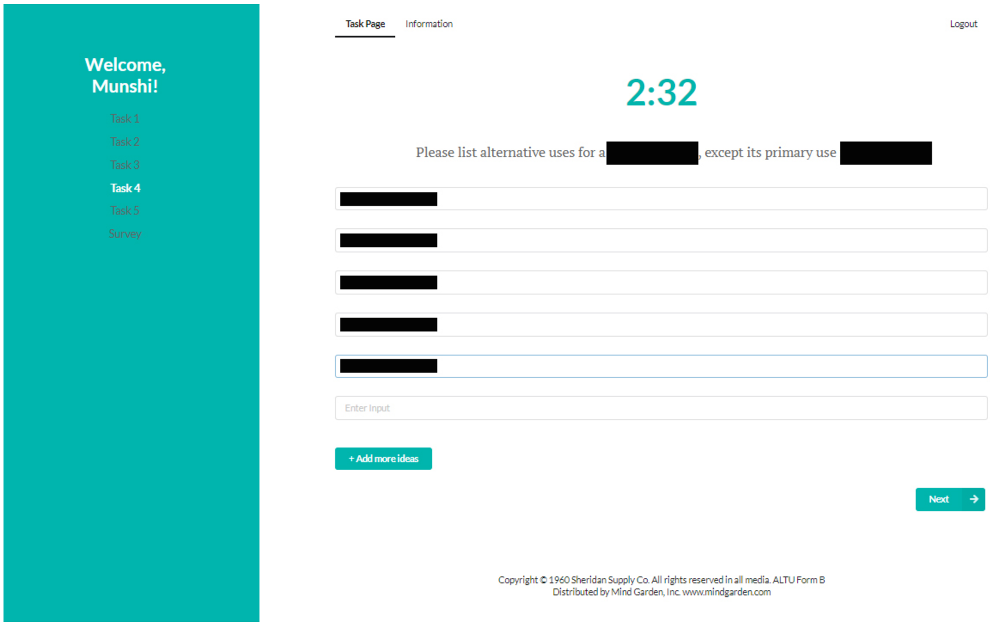


Figure S16: Initial idea submission interface. This was used in turn-1 for the egos of static and dynamic conditions, as well as for the alters and solo participants.

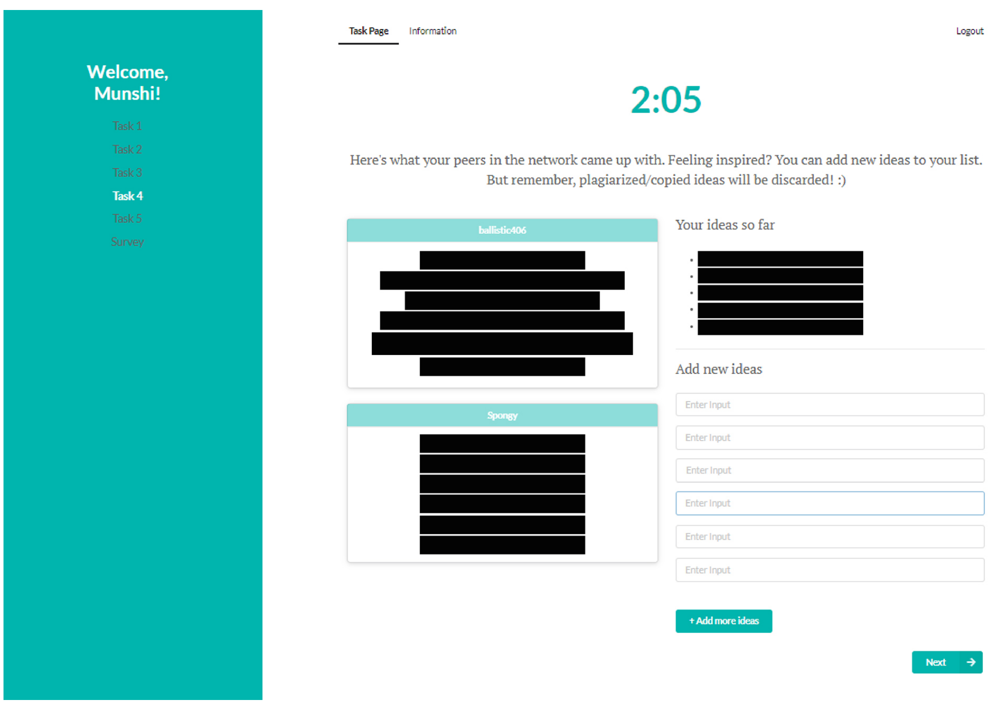


Figure S17: Turn-2 interface for the egos of static and dynamic conditions. The alters' ideas are shown on the left-side cards.

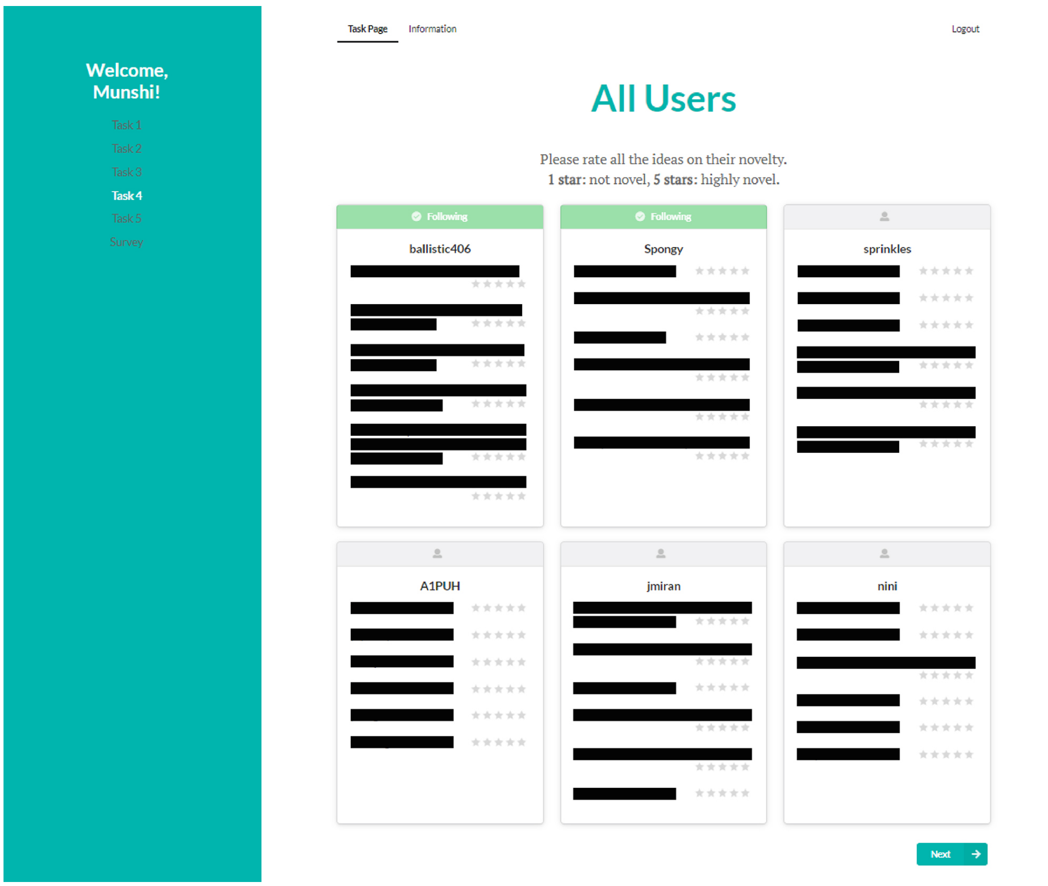


Figure S18: Rating interface for the egos in the static condition. The egos rated the ideas of all 6 alters in the respective trial.

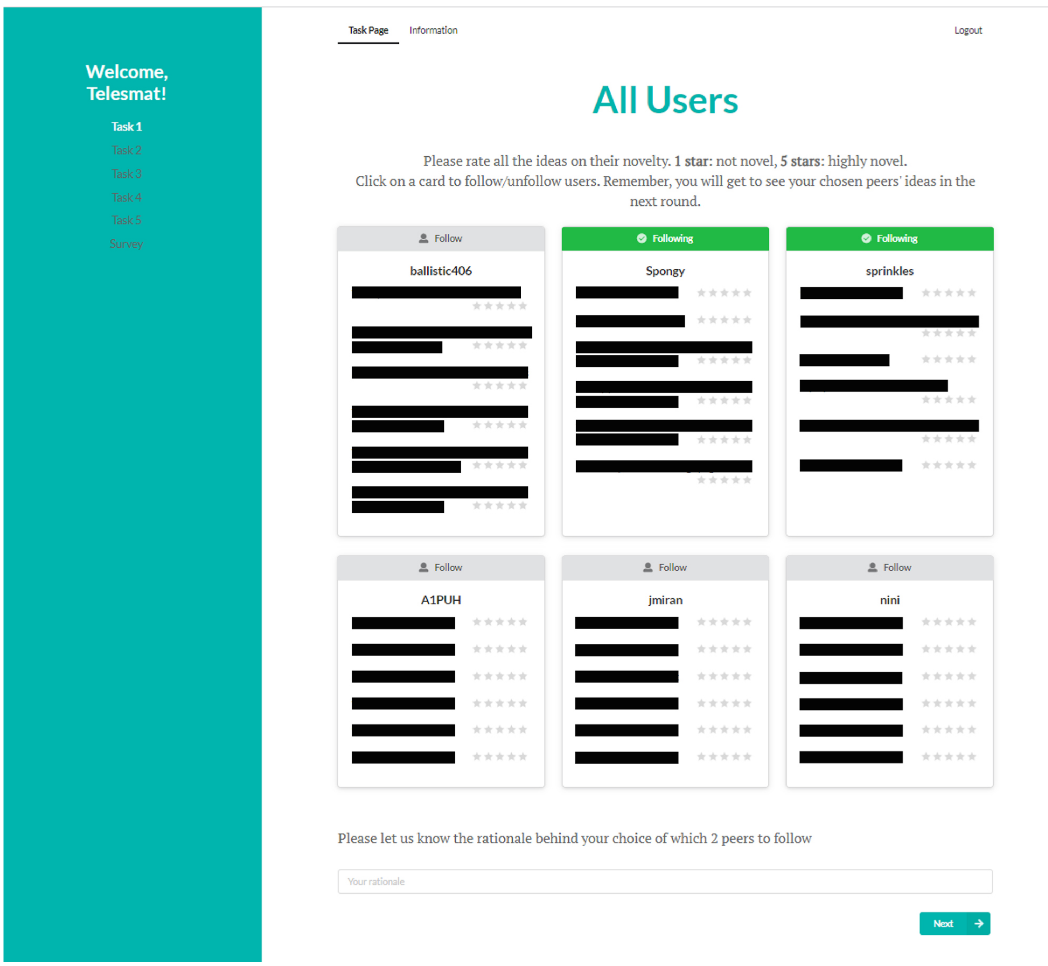


Figure S19: Rating and following/unfollowing interface for the egos in the dynamic condition.