Can Induced Gratitude Improve Creative Performance on Repurposing Tasks?

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Urgent societal problems, including climate change, require innovation and can benefit from interdisciplinary solutions. A small body of research has demonstrated the potential of positive emotions (e.g., gratitude, awe) to promote creativity and prosocial behavior, which may help address these problems. This study integrates, for the first time, psychology research on a positive prosocial emotion (i.e., gratitude) with engineering-design creativity research. In a preregistered study design, engineering students and working engineers (pilot N = 49; full study N = 329) completed gratitude, positive-emotion-control, or neutral-control inductions. Design creativity was assessed through rated scores of responses to an Alternate Uses Task (AUT) and a Wind-Turbine-Blade Repurposing Task (WRT). No significant differences among AUT scores emerged across conditions in either sample. As only the pilot-study manipulation of gratitude was successful, recommendations are provided for further studies on the effect of gratitude on engineering-design creativity. The reported work may also inform other strategies to incorporate prosocial emotion to help engineers arrive at more original and effective concepts to tackle environmental sustainability, and in the future, other problems facing society. [DOI: 10.1115/1.4052586]

Keywords: conceptual design, creativity and concept generation, design for the environment, gratitude, positive emotion, sustainable design

1 Introduction

One aspect of creativity commonly studied by engineering-design researchers involves design fixation [1], and how to overcome its detrimental effects on design outcomes [2–4]. A related barrier in engineering design is that of functional fixedness (i.e., an inability to perceive uses for an object other than its intended or common uses) [5], which can make it difficult to generate creative concepts and object uses.

Recent research has documented a relationship between designers' personal characteristics and their tendency towards design fixation and lower creativity. For example, previous work has demonstrated that designers' Need for Closure (i.e., desire for certainty) [6] is correlated with higher design fixation [7] and functional fixedness [8], as well as both increased functional fixedness and reduced creativity when completing an Alternate Uses Task (AUT) [9]. Furthermore, psychology research consistently demonstrates connections between individuals' emotional experiences and their creativity. Specifically, both trait levels of positive affect and induced positive mood (e.g., happiness, gratitude) correlate with greater creativity [10]. Furthermore, emerging links between designers' emotions and computer-aided design (CAD) events reveal that some emotions are more likely to occur with certain CAD actions [11]. Combined, these findings suggest that examining the individual characteristics and experiences of designers may provide insights toward improved creativity by overcoming design fixation and functional fixedness.

One particularly promising approach to promote creativity is through the individual experience of gratitude. While the positive emotion of gratitude has been linked to both increased creativity [12] and prosocial behavior [13] in other contexts, its potential to promote individuals' ability to generate creative engineering concepts has not yet been explored. Therefore, we aimed to investigate the effects of inducing gratitude on individuals' engineering-design creativity while addressing a pressing real-world sustainability system.

1.1 Benefits of Combining Social-Psychological and Engineering Concepts.

Prior research has demonstrated that applying social-psychological theory to engineering-design contexts can help designers overcome design fixation and produce more creative design ideas. In particular, empathic design—whereby designers take on the perspective of their target user or simulate their experiences in the process of needfinding [14–18]—is linked to greater idea originality [16,17] and generation [19].

Inducing the affective component of empathy by sharing the user's emotional experience is particularly effective for generating more original ideas [16] and includes the use of "empathic lead users" [20,21]. The empathic lead-user approach helps designers to understand latent needs that benefit users but may not be immediately obvious from observing or asking users [20].

Combining psychological and engineering theory may be particularly beneficial for the early stages of the design process, as well as challenges that require innovative repurposing of material, which are especially prone to design fixation and functional fixedness. Thus, we aimed to combine psychological research on gratitude with engineering-design creativity research to help designers generate novel ideas when repurposing objects.

1.2 Gratitude and Creativity.

Psychology research has shown the power of gratitude to promote increased prosocial motivation and behavior [13]. In addition to—and perhaps driven by—these prosocial benefits, literature has begun to link gratitude to increased creativity. Specifically, self-reported gratitude has been associated with higher creativity scores among counseling psychologists, including more flexible therapeutic approaches [12]. In addition, feeling grateful for one's coworkers can promote higher employer ratings of employee creativity [22]. Importantly, self-reported gratitude has been correlated with greater perspective-taking [23], and both self-reports and experimental inductions of gratitude (through receiving a favor) have been linked to helping

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others [24]. As such, similar to the benefits of empathic-design approaches, gratitude may help people think more flexibly, understand the needs of others, and promote a desire to help others. Such benefits may help designers persevere in the face of design fixation and functional fixedness to arrive at novel solutions that can fulfill their desire to provide a benefit to others. Though there is less experimental research in this area, experimental effects typically replicate self-report findings [24], and gratitude can be effectively induced in numerous ways, including receiving favors and recalling prior experiences [25].

Initial evidence on the creativity of teams shows promise for this line of thinking, given that teams who report more gratitude—as compared to general positive emotion—generated more creative and elaborated ideas [26]. Although this evidence stems from group contexts, it may not be necessary to feel grateful for one's team members to generate more creative concepts. For example, gratitude can be elicited by both interpersonal (e.g., receiving a costly benefit from a close other) and personal (e.g., appreciating one's surroundings) experiences [27]. Further, appreciating aspects of one's life or the people in it may also prompt a desire to benefit others more generally [28,29], in this case through generating helpful concepts.

As such, feeling grateful may also help individuals think flexibly to overcome design fixation and functional fixedness and generate more creative concepts, potentially through increasing their desire to help others. While generating alternate uses is an underexplored approach for tackling end-of-life environmental problems, engineers may see the possibility to create solutions that benefit society as a positive opportunity to effect change through design. Thus, inducing feelings of gratitude may help engineering designers generate more innovative repurposing concepts.

1.3 Application to Sustainability.

Prior research has highlighted the need for effective tools to overcome barriers of design fixation and functional fixedness to arrive at more innovative design solutions, including new ways to repurpose objects. Thus, a particularly relevant context for examining the potential relationship between gratitude and creative engineering design is the sustainability challenge presented by retired wind-turbine blades. While wind energy is an important component of renewable energy, and wind turbines help meet the rising demand for both energy and reduced fossil-fuel use [30], they come with an under-addressed environmental challenge. Wind-turbine blades are designed to maximize energy production, but for safety reasons, are preemptively retired before they might dangerously fail. A challenge this presents is that these large and uniquely shaped blades have limited end-of-life options [31,32].

Although wind-turbine blades can be disposed of in landfills, this outcome is clearly not environmentally optimal. Another option—incineration—may also be unsuitable due to the materials used in wind-turbine blades. Furthermore, compared to typical wind-turbine blades, more durable wind-turbine blades use more material [33] that is difficult to recycle due to its composition [34]. While repurposing is an avenue ripe with potential to reduce the environmental impact of retired wind-turbine blades, their size, shape, and composition limit reuse options [34]. Thus, the current work aims to improve the ability to generate alternative-use ideas for decommissioned wind-turbine blades [31].

1.4 Current Wind-Turbine-Blade Repurposing Options.

While limited reuse applications for retired wind-turbine blades exist, they are neither widely scalable nor sufficient to address an ever-growing number of retired parts. Wind-turbine blades have an approximately 20-year lifespan, which means that their end-of-life impact on the environment is just beginning to emerge. With over 77,000 turbines currently installed in Europe [34] and another 57,000 in the United States as of 2018 [35], de-commissioned blades will only continue to grow in quantity.

Current repurposing options include architectural and art installations, both of which may require difficult transportation and/or transformation of large wind-turbine blade pieces [30]. Art installations may require less transformation of parts but cannot realistically address the large quantity of currently and soon-to-be decommissioned blades.

Thus, the current study aims to promote engineering-design creativity in general, and increase the quality and number of ways to repurpose wind-turbine blades in particular. Generating new alternate uses for these and other retired parts may reduce their negative environmental impact while providing other useful products and infrastructure to society.

1.5 Research Questions, Hypotheses, and Key Contributions.

In the current work, we aimed to address three research questions. First, can we effectively induce gratitude in individual engineering designers? We chose to induce gratitude by asking designers to recall grateful experiences, which has been shown to be effective in other contexts [25]. Second, can gratitude (or positive emotion in general) promote engineering-design creativity? We hypothesized that gratitude would promote greater engineering-design creativity. Utilizing a preregistered and high-powered study design, we experimentally tested the hypothesis that gratitude (as compared to both a general-positive-emotion and neutral-control condition) can lead designers to be more creative. Creativity was operationalized as generating more and higher-quality alternate uses for objects in general, and retired wind-turbine blades in particular. Third, we tested whether prosocial motivation (i.e., a desire to help others)[2] drives the potential relationship between gratitude and engineering-design creativity.

This study thus makes three key contributions to the literature. First, it integrates psychology research on positive emotions and prosocial behavior with engineering-design research. Second, it tests whether gratitude (as opposed to general positivity) can uniquely promote creative, prosocial engineering design, particularly when design fixation and functional fixedness may be obstacles. Finally, this research tests a mechanism to reveal what may drive the hypothesized link between gratitude and creative design.

2 Materials and Methods

A pilot ($N = 49$) and a high-powered full version ($N = 329$) of the study were conducted to test our hypotheses. Our mediation hypothesis was only tested in the full sample. The following sections describe the participants, study procedures, and materials.

2.1 Open-Science Approach.

To promote transparency and reproducibility in scientific research, we took an open-science approach to our data collection. We preregistered the study design, recruitment, hypotheses, and analyses for both samples on the Open Science Framework at osf.io/GDXBE.

2.2 Participants.

The pilot and full-study sample sizes were both determined by a priori power analyses (calculated in G*Power) [36]. The target pilot-study sample size of 80 participants was recruited, but only 49 participants were (1) interested in completing the study after screening, (2) in one of the three retained conditions,[3] and (3) passed attention checks. This sample of 49 provided us with 80% power to detect a moderate effect size ($f^2 = .20$) among three groups for six outcomes. The target full-study

[2]We also examined decreased need for closure (i.e., a desire for certainty) as a potential mechanism for these effects. Results of these analyses did not support hypotheses. For more information, see our preregistration at osf.io/GDXBE.

[3]Our pilot sample included a fourth condition, in which participants reported an experience of awe. However, awe was not successfully induced in the pilot study, so this condition was not included in the full study. As such, pilot analyses focused on participants in the other three conditions. See our preregistration for more information: osf.io/GDXBE.

sample size was 330, which was achieved, but one participant was removed from the final sample due to failing an attention check. This provided us with 80% power to detect a small-to-moderate effect ($f^2 = .03$) with six outcomes.

2.2.1 Pilot-Study Participants. Pilot-study participants were 49 engineering employees and/or students (42 men, seven women), who ranged in age from 18 to 39 years (M = 23.96, SD = 4.46). Roughly half of the participants (21) were engineering students only, nine participants were engineering employees only, and 19 participants reported being both an engineering employee and student. The most-represented engineering disciplines were computer, mechanical, and electrical. Participants were recruited online through Prolific Academic, which has been shown to promote the recruitment of diverse participants, towards higher-quality data [37].

2.2.2 Full-Study Participants. Full-study participants were 329 engineering employees and/or students (257 men, 71 women, one non-binary), who were 18–52 years old (M = 24.7, SD = 5.9), also recruited from Prolific Academic. Roughly half of the participants (157) were engineering students only, 80 participants were engineering employees only, and 92 participants reported being both an engineering employee and a student. Pilot-study participants were not eligible to take part in the full study. The most-represented engineering disciplines were again computer, mechanical, and electrical.

2.3 Study Design and Procedure Overview. Participants completed all portions of the study through an online survey. Interested participants completed eligibility questions (e.g., engineering employee and student status) and eligible participants were invited to complete the study. Participants first completed our experimental induction. In a between-subjects design, participants in both the pilot and full versions of the study were randomly assigned to one of three experimental inductions or conditions (see Fig. 1), which contained approximately equal numbers of participants.

After completing their respective induction tasks, all participants completed a manipulation check to establish the effectiveness of the inductions. Next, participants (in the full study only) completed a brief assessment of the mechanism we expected to explain predicted links between gratitude and creativity (i.e., prosocial motivation). Participants then completed the Alternate Uses Task (AUT) and Wind-Turbine-Blade Repurposing Task (WRT), before being debriefed and receiving compensation (2.40 GBP). Responses to the study tasks were scored by two research assistants, both of whom were blind to study hypotheses, to gather more objective assessments of creativity.

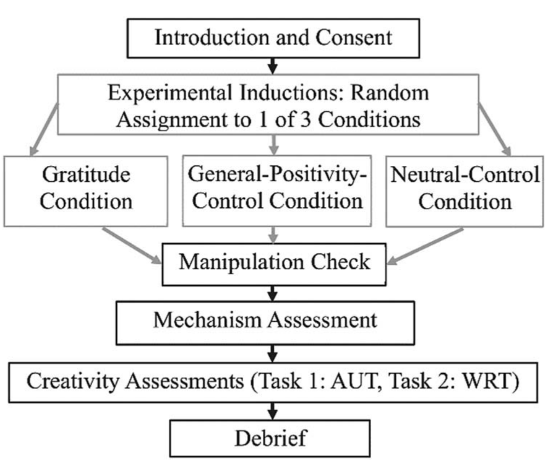


Fig. 1 Study design: note that the mechanism assessment was not completed by the pilot participants

2.4 Experimental Conditions

2.4.1 Gratitude Induction. In a procedure adapted from prior research [26], participants assigned to the gratitude condition read the following prompt encouraging them to recall a vivid experience of gratitude:

> For the next two minutes, please recall a vivid experience of a time you **felt grateful (i.e., thankful, appreciative).** Please describe **how and when** this experience occurred and **why** you felt grateful.

Participants were given a text box in which to type their response and were unable to advance to the next task until two minutes had elapsed to encourage engagement.

2.4.2 General-Positivity-Control Condition. To further discern whether gratitude, compared to general positive affect, could uniquely promote design creativity, our first control condition asked participants to recall a generally positive experience. Specifically, this prompt read:

> For the next two minutes, please recall a vivid experience of a time you **felt positive (e.g., happy, amused)**. Please describe **how and when** this experience occurred and **why** you felt positive.

The procedure in this condition was otherwise identical to the gratitude induction. A common induction method (i.e., recalling a vivid experience) for both the gratitude and positivity conditions also avoids confounding induction method and emotions (i.e., gratitude and general positive affect).

2.4.3 Neutral-Control Condition. If both general positive emotion and gratitude increase creativity, it would be important to know whether these are both effective as compared to feeling neutral. Otherwise, it would be unclear whether the benefit was from recalling an experience alone or from the experience of general positive emotion (or gratitude) in particular. Thus, participants in the neutral-control condition were asked to recall a neutral experience. The prompt in this condition read:

> For the next two minutes, please **recall a recent experience** of a time you engaged in **an ordinary daily activity** (e.g., getting ready in the morning, preparing a meal, doing laundry, etc.). Please describe the **experience** and **when** it occurred.

Otherwise, the procedure matched the other conditions.

2.5 Manipulation Check. Participants in each of the three conditions were then asked to report (in separate items) the extent to which they currently felt grateful, and generally positive (i.e., "To what extent do you feel grateful/positive right now?") on a scale of 0 (not at all) to 6 (extremely).

2.6 Mechanism Assessment. Full-study participants then completed an assessment of prosocial motivation. This measure allowed us to test whether prosocial motivation may be the mechanism through which gratitude can promote creative design. Prosocial motivation was assessed with four items ($\alpha = .70$) (see Appendix A). This scale had a sufficient alpha value, which assesses internal consistency (i.e., the extent to which scale items are related to each other).

2.7 Concept Generation Tasks

2.7.1 Alternate Uses Task. Participants completed an AUT, which asked them to list all the possible uses they could think of for a particular object [38]. A spoon was chosen as the target object, as most people should be familiar with both the object and its size. Participants were given 5 mins (in the pilot study) and 3 mins (in the full study) to complete this task, after which the survey auto-advanced to the next task.

In addition to providing a general measure of creativity [9], the AUT may have helped participants to prepare for the more challenging WRT [31]. Completing an easier task first has been shown to help participants feel more comfortable and less restricted in subsequent tasks [39].

2.7.2 Wind-Turbine-Blade Repurposing Task. In a procedure adapted from prior research [40], participants were then given 15 min to read the WRT instructions and complete the task (see Appendix B for instructions). To promote better performance, these instructions encouraged participants to avoid examples of commonly generated but unsafe alternative uses (e.g., airplane wings).

Participants were provided with isometric and orthogonal views of the section of the blade that they were asked to repurpose (see Appendix B) to promote the generation of concepts that are feasible given the blade's shape. These views also included a depiction of a human to help participants generate concepts of appropriate scale.

2.8 Creativity Assessment Criteria. Task performance (i.e., creativity) was assessed through several criteria, all of which required scoring. Participants' task responses were rated by two independent raters who were blind to the study hypotheses to reduce biasing of the results. As creativity is a socially desirable trait, participant self-reports may be less accurate (i.e., inflated) in this context. These independent ratings thus offered more objective and accurate assessments of creativity.

Our coding procedure was adapted from prior relevant work that assessed creativity [31,40]. The raters were two undergraduate psychology students who had not previously coded AUT or WRT responses. To improve accuracy, these raters completed group training in which they received AUT and WRT instructions, descriptions of each assessment criterion, and examples of scored responses from a previously collected sample of participants [31,40]. Coders did not view any of the pilot or full-study sample responses until training was complete. We then calculated reliability among raters in the form of intra-class correlation coefficients (ICCs). Where reliability was acceptably high (i.e., at least 0.60), ratings were averaged to create one score per participant for each criterion. This technique was implemented in favor of the Consensual Assessment Technique (CAT) for coding [41]. Our psychology-student coders did not have the necessary background knowledge to be considered expert judges without training from us, and it is recommended that consensual assessment judges not be trained by the researcher [42]. However, both techniques utilize inter-rater reliability to determine agreement among the judges, which we have operationalized as ICC values.

Before scoring participants' responses from the full version of the study, raters consulted the engineering-professor co-author with experience in coding AUT and WRT task responses. The raters also met to resolve scoring discrepancies from the pilot-study data. This improved assessment clarity and accuracy, leading to high inter-rater reliability. Assessment criteria are described in turn for each task in the following sections.

2.8.1 Alternate Uses Task Assessment Criteria. AUT responses were scored according to four established criteria (i.e., fluency, flexibility, elaboration, originality) [38,40,43].

Fluency referred to the number of unique uses for a spoon that each participant generated [38,40]. Raters allocated one point per unique use and then summed points to create a fluency score.

Flexibility, the second criterion, referred to the number of unique categories that a participant's list of alternative uses spanned. For example, using a spoon as a coffee stir stick and a tool to scramble eggs would only represent one category (i.e., stirring/mixing). Alternative spoon uses from other categories included digging and measuring quantities of material. Raters allocated one point per unique category, and these points were summed to create a total flexibility score.

Elaboration of the responses was operationalized as the degree to which participants provided detail in their responses. Elaboration was scored on a scale of 0 to 2. Responses that provided little or no detail (e.g., "to stir") received a score of 0. Responses like "to stir food or drinks," which provided some additional detail received a score of 1. Highly detailed responses (e.g., "to stir food or drinks to ensure that ingredients are well-mixed") received a score of 2. A mean of elaboration scores across each participant's list of alternative uses provided an assessment of each participant's average level of response detail.

Originality scores provided an additional key measure of creativity, given that novel and innovative products are highly valued in engineering design [44]. Uses were sorted into one of three originality categories: common (given a score of 0), moderately original (given a score of 1), and highly original (given a score of 2). To do this, raters recorded the number of times each use was generated by the participants. Common uses were defined as those generated by more than half (i.e., $\geq 51\%$) of participants. Uses generated by 11–50% of participants were categorized as moderately original and uses generated by $\leq 10\%$ of participants were categorized as highly original. A mean of each participant's originality scores provided an assessment of that participant's average response originality.

2.8.2 Wind-Turbine-Blade Repurposing Task Assessment Criteria. In a scoring procedure adapted from prior research [31,40], WRT responses that presented safety issues (e.g., wind-turbine part, part of an airplane) were removed prior to scoring. Participants' remaining WRT responses were then assessed for flexibility, fluency, scale, feasibility, appropriateness, and originality. Fluency, flexibility, and originality were scored using the same procedure as the AUT. Elaboration was not scored, given that this difficult concept-generation task inherently requires more elaborate descriptions. As such, elaboration scores would be uninformative due to artificial inflation and low variability.

Feasibility and scale of alternative uses that participants generated for a spoon were not obstacles for the AUT, but feasibility and scale were obstacles in both current and past WRTs [40,45]. Thus, generated concepts were sorted into one of three *scale* categories: shrunk, to-scale, or enlarged [31,40]. *Shrunk* concepts would require the blade part to shrink to feasibly satisfy the listed use, but do not mention cutting the part into smaller pieces (e.g., a ski). These concepts were given a score of 0. *To-scale* concepts refer to correctly scaled wind-turbine blade uses (e.g., children's slides made by cutting parts into pieces). These uses ranged in the amount of cutting necessary (e.g., from children's slides to floor tiles) and were given a score of 1. *Enlarged* uses would not be feasible without combining multiple wind-turbine blade parts, but their description did not mention a combination of blade parts (e.g., for a complete building). These concepts were also given a score of 0. A mean of that participant's scale scores provided an assessment of that participant's average response scale.

Feasibility of generated reuse concepts was categorized as either unfeasible or of low, moderate, or high feasibility. Raters were instructed to consider each use's technical requirements and necessary level of modification. *Unfeasible* uses may violate wind-turbine blade technical capabilities or require too much modification to be practical (e.g., structural and technological enhancements to make a rocket). *Feasible* uses are possible but require modification (e.g., a highly feasible bus-shelter roof versus less-feasible fencing that requires more modification). Unfeasible uses were given a score of 0 and feasible uses were given a score of 1 (if low in feasibility), 2 (if moderately feasible), or 3 (if highly feasible). Feasibility scores were also averaged within participants.

Combining scale and feasibility assessments, generated uses were categorized as *appropriate* if they were both to-scale and at least of low feasibility. Scale, feasibility, and appropriateness thus determined the quality of generated uses. The highest-quality uses were both feasible and possible given the size of wind-turbine blades (i.e., appropriate). Appropriate uses were given a score of

1 and uses that were not appropriate were given a score of 0. Scores of appropriateness were also averaged within participants.

2.8.3 Wind-Turbine-Blade Repurposing Task Response Samples. These WRT assessment criteria prioritize both the quantity (through flexibility and fluency) and quality (through feasibility, scale, appropriateness, and originality) of participant responses. Thus, participant responses that include a large number of uses and use categories, are to-scale, feasible, appropriate, and innovative (i.e., original) would be considered the most creative. For instance, the participant response shown in Fig. 2, Example A, would be considered highly creative, whereas the participant response in Fig. 2, Example B, would be considered low in creativity. Example A includes more reuses and reuse categories (2 versus 1). Example A reuses are both to-scale and include descriptions of how to cut the blade, whereas the reuse in Example B is shrunk (i.e., not-to-scale) because it does not mention cutting the blade. Thus, the reuses in Example A are appropriate, whereas the reuse in Example B is not.

3 Analysis Overview

Participants who passed attention checks and completed at least one task (AUT or WRT) were included in the final samples. All statistical analyses were conducted using IBM SPSS STATISTICS version 26.0, and $p < .05$ was the preregistered threshold for statistical significance. Other than mediation analyses conducted only for the full study, analyses were identical for the pilot and full-study samples.

A multivariate analysis of variance (MANOVA) was first used to simultaneously examine differences in self-reported gratitude and positivity across conditions in both the pilot and full study as a manipulation check.

Additional MANOVAs were conducted to test hypotheses by comparing AUT and WRT performance across conditions (i.e., gratitude, general positivity, and neutral) for each scoring criterion. Two separate MANOVAs were conducted for the AUT and WRT responses, in which we simultaneously examined group differences in each task's respective criteria scores. These analyses were conducted separately for the pilot and full-study samples. Where omnibus MANOVA tests were significant, univariate follow-up analyses consisting of pairwise comparisons of the conditions using Tukey's HSD post-hoc tests were used to reveal which conditions significantly differed from each other.

For each statistically significant mean difference in creativity (i.e., AUT or WRT criteria scores) between groups, we also conducted mediation analyses using the Hayes PROCESS Macro for SPSS [46]. As is recommended for mediation with a multi-categorical independent variable [46], we computed dummy coded variables, with the gratitude condition as the reference group. This allowed us to test the mediating effects of prosocial motivation on the difference between creativity task scores in (1) the gratitude versus the general-positivity condition and (2) the gratitude versus the neutral-control condition.

4 Results of Research Question 1: Can We Effectively Induce Gratitude?

4.1 Pilot-Study Manipulation Check. A MANOVA that compared self-reported gratitude and positivity across conditions was used to determine the effectiveness of the inductions. Consistent with the intended inductions, the omnibus test of the pilot sample revealed that these outcomes significantly differed across groups, Wilk's $\lambda = 0.79$, F (4, 90) = 2.83, $p = 0.029$, partial $\eta^2 = 0.11$ (see Fig. 3).

Univariate follow-up analyses revealed that, as expected, participants in the gratitude condition ($N = 15$) reported significantly more gratitude than those in the neutral-control condition ($N = 18$), $p = 0.009$, 95% CI [0.30, 2.43]. Participants in the general-positivity control condition ($N = 16$) also reported significantly more gratitude than those in the neutral-control condition, $p = .026$, 95% CI [0.12, 2.21]. However, self-reported gratitude did not differ between the gratitude and general-positivity conditions, $p > 0.05$. This suggests that while the gratitude induction was effective, participants in the general-positivity condition reported comparable levels of gratitude to those in the gratitude condition.

Univariate follow-up analyses did not reveal any significant differences in self-reported positivity across groups ps > 0.266. This suggests that participants reported comparable levels of positivity across all three groups.

4.2 Full-Study Manipulation Check. Contrary to the pilot-study results and the intended inductions, the omnibus test of the full-study sample revealed that self-reported gratitude and positivity did not significantly differ across groups, Wilk's $\lambda = 0.98$, F

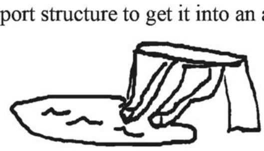
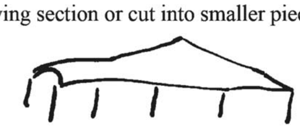
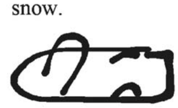
Example A	Example B
1. The blades could be used for a water recreation park, I think the shapes inclined can make a fun way to enter the pool. The blade would be cut in almost half to make use of all the blade and would need a support structure to get it into an angle.  2. A pavilion for park, amusement park, festivals etc. Cut in half. Add ventilations/ sun holes etc. Could be done as whole wing section or cut into smaller pieces. 	1. The wind turbine blades could be repurposed as recreational winter toboggans for use in snow. 

Fig. 2 Example participant Wind-turbine-blade Repurposing Task responses

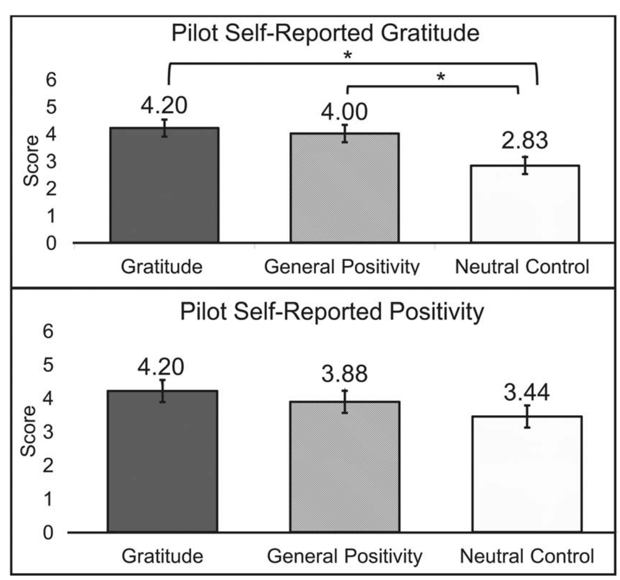


Fig. 3 Pilot-study gratitude and positivity means. Note that error bars are standard errors and * = $p < 0.05$.

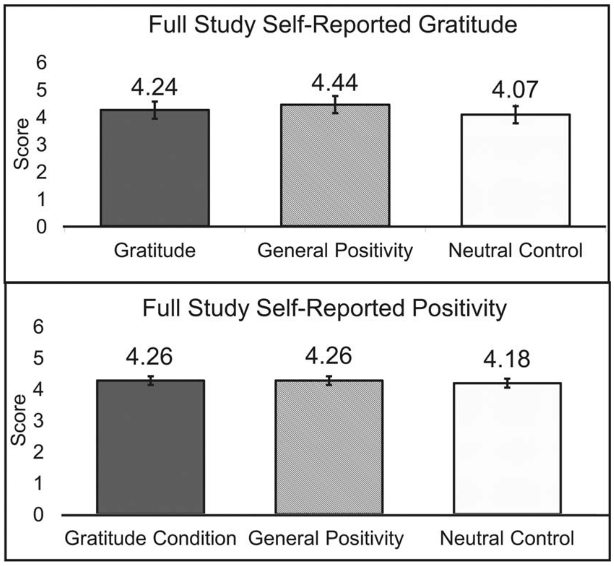


Fig. 4 Full-study gratitude and positivity means. Note that error bars are standard errors.

(4, 650) = 1.28, $p > 0.05$, partial $\eta^2 = 0.01$. This suggests that the manipulation was not effective in the full study (see Fig. 4).

Given this non-significant manipulation check, we qualitatively examined participant responses across conditions and verified that they followed task instructions (see Appendix C). Participants in the gratitude condition frequently mentioned accomplishments at work, feeling thankful, and spending time with loved ones. Participants in the general-positivity condition frequently mentioned feeling happy and having a good day. Participants in the neutral-control condition frequently mentioned preparing breakfast in the morning. Thus, participants in each condition recalled distinct experiences, which may still have influenced their task responses, regardless of the amount of gratitude they reported feeling. As such, we continued with our preregistered analyses, but these results should be interpreted with caution.

5 Results of Research Question 2: Can Gratitude Promote Creativity?

5.1 Pilot-Study Alternate Uses Task Results. A MANOVA comparing AUT response outcomes (i.e., fluency, flexibility, elaboration, and originality) in the pilot-study sample tested the hypothesis that gratitude (as compared to general-positivity and neutral-control conditions) would promote more creativity in the form of higher AUT response scores. All outcomes had acceptable inter-rater reliability: fluency ICC = 0.99, flexibility ICC = 0.99, elaboration ICC = 0.74, originality ICC = 0.90.

Counter to our predictions, the omnibus test revealed that AUT response scores did not significantly differ across groups, Wilk's $\lambda = 0.92$, F (8, 86) = 0.45, $p > 0.05$, partial $\eta^2 = 0.04$. This suggests that participants generated comparably creative AUT responses across conditions.

5.2 Full-Study Alternate Uses Task Results. All AUT outcomes in the full-study sample also had acceptable inter-rater reliability: fluency ICC = 0.99, flexibility ICC = 0.99, elaboration ICC = 0.92, originality ICC = 0.72. A MANOVA conducted with this sample revealed that, consistent with the pilot sample, but contrary to our expectations, there were no significant differences in outcomes across groups, Wilk's $\lambda = 0.96$, F (8, 644) = 1.50, $p > 0.05$, partial $\eta^2 = 0.02$. This suggests that participants generated comparably creative AUT responses across conditions.

5.3 Pilot-Study Wind-Turbine-Blade Repurposing Task Results. An additional MANOVA of the pilot-study sample comparing WRT response outcomes (i.e., fluency, flexibility, scale, feasibility, appropriateness, and originality) was used to test the hypothesis that participants in the gratitude (as compared to those in the general-positivity and neutral-control) condition were more creative in the form of higher WRT response scores. Fluency (ICC = 0.95), flexibility (ICC = 0.93), feasibility (ICC = 0.76), and originality (ICC = 0.74) had acceptable reliability and were included in analyses. Scale and appropriateness did not meet inter-rater reliability standards (ICCs < 0.60; scale ICC = 0.25, appropriateness ICC = 0.34) and were removed from analyses.

Counter to our predictions, the omnibus test revealed that WRT response scores did not significantly differ across groups, Wilk's $\lambda = 0.89$, F (8, 78) = 0.57, $p > 0.05$, partial $\eta^2 = 0.06$. However, mean differences were largely in the predicted direction (see Fig. 5).

5.4 Full-Study WRT Results. An additional MANOVA comparing WRT response outcomes (i.e., fluency, flexibility, scale, feasibility, appropriateness, and originality) in the full-study sample was used to test the hypothesis that gratitude (as compared to general-positivity and neutral-control conditions) would promote more creativity in the form of higher WRT response scores.

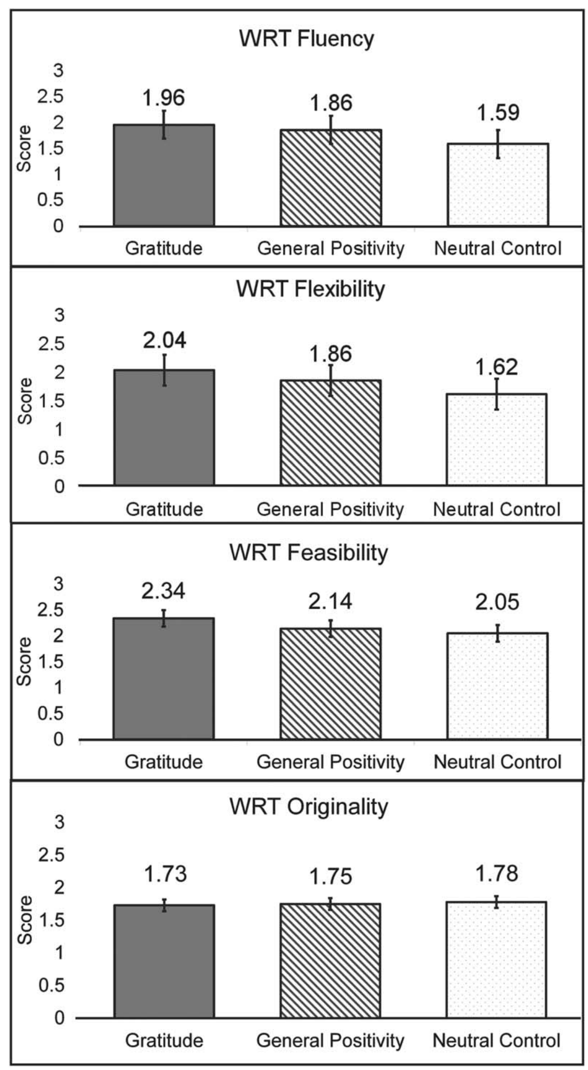


Fig. 5 Pilot-study WRT response means. Note that error bars are standard errors.

Fluency (ICC = 0.95), flexibility (ICC = 0.95), scale (ICC = 0.83), feasibility (ICC = 0.72), and appropriateness (ICC = 0.82) had acceptable reliability and were included in analyses. Originality did not meet inter-rater reliability standards (ICC < 0.60; originality ICC = 0.58) and was removed from analyses.

In line with our predictions, the omnibus test revealed that WRT response scores significantly differed across groups, Wilk's $\lambda = 0.94$, F (10, 628) = 2.03, $p = 0.028$, partial $\eta^2 = 0.03$, despite the induction not being effective (see Fig. 6).

Univariate follow-up analyses revealed that, as expected, participants in the gratitude condition ($N = 109$) scored significantly higher than those in the general-positivity control condition ($N = 111$) on response scale, $p = 0.002$, 95% CI [0.03, 0.14] and appropriateness, $p = 0.001$, 95% CI [0.03, 0.15]. Participants in the gratitude condition scored higher, but not significantly, than those in the general-positivity control group on response fluency, $p = 0.089$, 95% CI [−0.03, 0.54] and flexibility, $p = 0.098$, 95% CI [−0.03, 0.52]. Gratitude-condition participants did not score higher on feasibility than either the general-positivity or neutral-control group, $p > 0.10$. Thus, participants in the gratitude condition produced more to-scale and more appropriate uses for retired wind-turbine blades than participants in the general-positivity control group.

The largest differences between the neutral-control group ($N = 109$) and the general-positivity group were in response scale, $p = 0.069$, 95% CI [−0.11, 0.003] and appropriateness, $p = 0.062$, 95% CI [−0.11, 0.002], but these differences were not significant. No other significant differences were observed between these two groups.

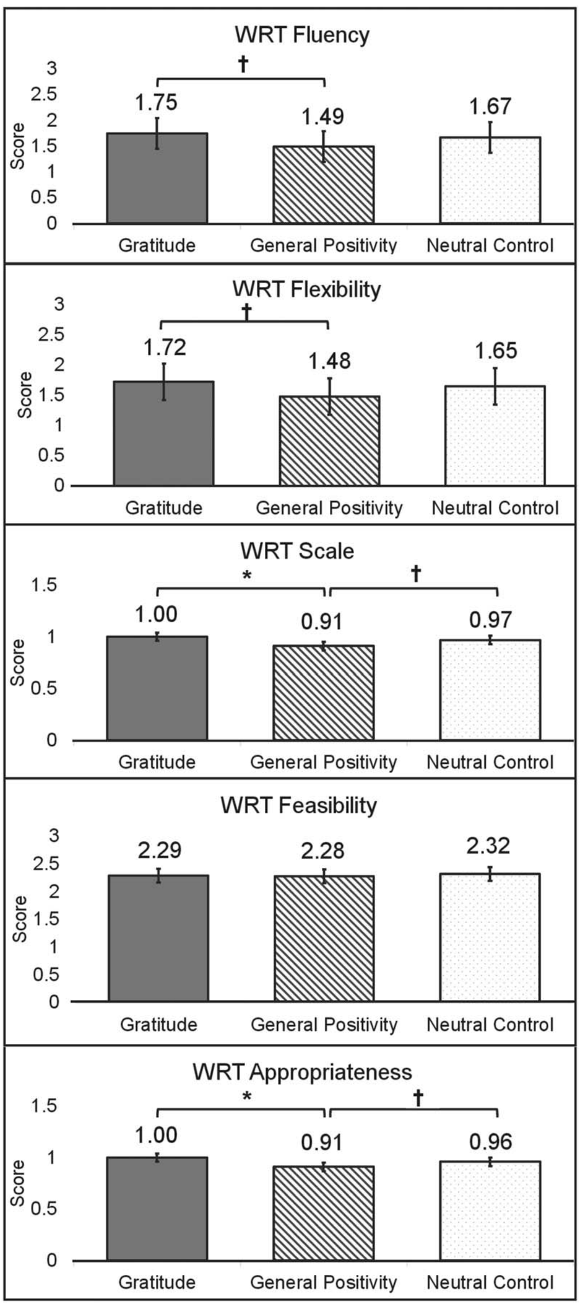


Fig. 6 Full-study WRT response means. Note that error bars are standard errors, * = $p < 0.05$, and † = $p < 0.10$.

5.5 Additional Non-Parametric Analyses. In additional (i.e., not preregistered) analyses, we examined the multivariate normality of AUT and WRT response outcomes in both samples using the R package MVN [47]. These analyses revealed violations of multivariate normality assumptions, such that AUT and WRT outcomes in both samples were significantly skewed and kurtotic (ps < 0.05). Thus, we conducted comparable non-parametric tests of our hypotheses using the R package npmv [48]. These analyses were largely consistent with the MANOVAs reported above. Specifically, these analyses replicated the significance of the MANOVAs (with the same analyses being significant that were before and the same analyses being non-significant that were before), with one exception; the omnibus test of full-study WRT scores no longer revealed significant group differences ($p = 0.175$). Thus, the conclusions from the main analyses are consistent with those from these additional analyses.

6 Results of Research Question 3: Does Gratitude Promote Creativity Through Increased Prosocial Motivation?

Mediation analyses tested the hypothesis that increased prosocial motivation may be a mechanism through which gratitude can promote more creative engineering design. These analyses were conducted for both significant (as preregistered) and non-significant differences in WRT scores across groups.

Contrary to our expectations, all confidence intervals included 0. Thus, prosocial motivation did not mediate the effect of being in the gratitude condition (versus the general-positivity or neutral-control conditions) on WRT response outcomes.

7 Discussion

A high-powered, preregistered experimental design was used to test (1) whether we could effectively induce gratitude, (2) whether gratitude could promote more creative engineering design, and (3) if increased prosocial motivation may be the mechanism for this proposed association. Across two samples, we found that gratitude may be difficult to induce in this context, along with evidence that both somewhat supported and contradicted our main hypothesis. However, we did not find support for prosocial motivation as a mediating link between gratitude and creativity.

Our induction of gratitude was effective in the pilot-study sample, where mean levels of reported gratitude and general-positivity were much higher in the gratitude and positivity conditions than the neutral-control condition (see Fig. 3). However, this did not occur in the full-study sample, in which mean levels of reported gratitude and positivity were much higher in the *neutral-control* condition compared to the pilot-sample *neutral-control* condition (see Fig. 4). At the same time, mean levels of reported gratitude and positivity were similar to the pilot-study sample in the corresponding gratitude and general-positivity conditions. This suggests that participants' baseline gratitude and positivity were higher in the full-study sample, which could have been an unintended effect of study timing. That is, the full-study data were collected very close to and/or overlapping major religious and school holidays (December 19–23, 2020). Perhaps explaining this unexpected effect, empirical evidence suggests that holiday celebrations are linked to greater emotional well-being [49]. Thus, we may not have been able to effectively manipulate feelings of gratitude and general positivity due to the timing of data collection.

7.1 Hypothesis-Inconsistent Results. Contrary to our expectations, participants' AUT response scores in both samples and participants' WRT response scores in the pilot-study sample did not significantly differ across conditions. Results also did not support our hypothesis that gratitude may promote creative engineering design through prosocial motivation.

7.2 Hypothesis-Consistent Results. In line with our expectations, full-study participants in the gratitude condition did produce significantly more to-scale and appropriate alternate uses for retired wind-turbine blades than those in the general-positivity condition. In past iterations of the WRT, scale was a major obstacle in the appropriateness of concepts [40,45], such that an increase in to-scale concepts was a significant advance.

7.3 Implications for Engineering Design. In line with both engineering [7] and psychology [10] literature suggesting that individuals' characteristics may shape their tendency toward design fixation and creativity outcomes, we found some limited evidence suggesting that individuals' positive emotional experiences may promote more creative engineering design. These results are also in line with initial evidence from group settings suggesting that gratitude may promote more design creativity [26]. This work adds to the growing body of literature [14–18] applying interdisciplinary approaches to engineering design challenges. Similar to how empathic design incorporates psychology to enhance needfinding and product improvement [20], this work shows promise for gratitude as an approach for applying psychological theory to engineering design. This approach may be particularly helpful at earlier stages of the design process (e.g., ideation) and for tackling challenges that are especially prone to functional fixedness (e.g., retired wind-turbine blades).

This novel application of psychology to engineering design lays the groundwork for future research combining engineering-design and psychological techniques. Given the environmental impact of retired wind-turbine blades and the difficulty of repurposing them [31,32], the current study also highlights a potential intervention for tackling environmental challenges and providing useful products and infrastructure to society. However, given the inconsistency of the results and normality issues among the creativity outcomes, future work testing the hypothesized relationship between gratitude and creative engineering design is warranted. We list recommendations below to guide this future work.

7.4 Limitations and Future Directions. Despite the strengths of our preregistered and high-powered design, there are limitations to the current work that highlight directions for future study. Specifically, our results suggest that gratitude may be difficult to reliably induce through recalling prior experiences, which is more often used in the context of measuring (versus inducing) gratitude. Other gratitude inductions that involve the designer receiving a prosocial action (e.g., a donation or favor) may have more effectively promoted both gratitude and prosocial motivation. Further, given the sustainability challenge that retired wind-turbine blades pose, inducing gratitude specifically for environmental resources may facilitate more creative solutions for wind-turbine-blade repurposing. Thus, future research including other sustainable-design tasks and inductions of gratitude may provide a better causal test of our hypothesis.

However, research has also demonstrated that gratitude manipulations are not universally effective and may not provide emotional or other benefits when people are close to a maximum of positive affect [50]. Given that participants in the full study generally reported more gratitude and positivity than participants in the pilot study—perhaps due to the timing of data collection—it is possible that the induction could not produce perceptible changes in experienced gratitude and positivity. Future work should investigate whether gratitude inductions may be the most beneficial for promoting design creativity in individuals who generally experience lower positive affect or higher negative affect.

Finally, given that there were no significant differences in reported gratitude or positive affect in the full-study sample and that both control groups scored similarly or better than the gratitude group on some creativity assessments, it is possible that simply recalling previous experiences helps concept generation [40]. Thus, future work might compare both recall and other inductions of gratitude to determine whether recalling experiences alone or the experience of feeling grateful itself better promotes engineering design creativity.

8 Conclusion

In a methodologically rigorous and preregistered study, we demonstrate some limited initial evidence that gratitude may promote more creative engineering design to tackle the sustainability challenge presented by retired wind-turbine blades. As such, the current work further supports the benefits of combining engineering design and psychological theory for increasing creativity by overcoming design fixation and functional fixedness.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request. The authors attest that all data for this study are included in the paper.

Nomenclature

Alternate Uses Task (AUT) = task that asks participants to generate novel purposes for common objects.

Gratitude = a positive emotion defined by thankfulness and appreciation.

Wind-turbine-blade Repurposing Task (WRT) = task that asks participants to generate concepts to repurpose retired wind-turbine blades.

Appendix A: Prosocial Motivation Measure

Instructions. Read each statement and respond by identifying what best represents your agreement with each statement.

Items

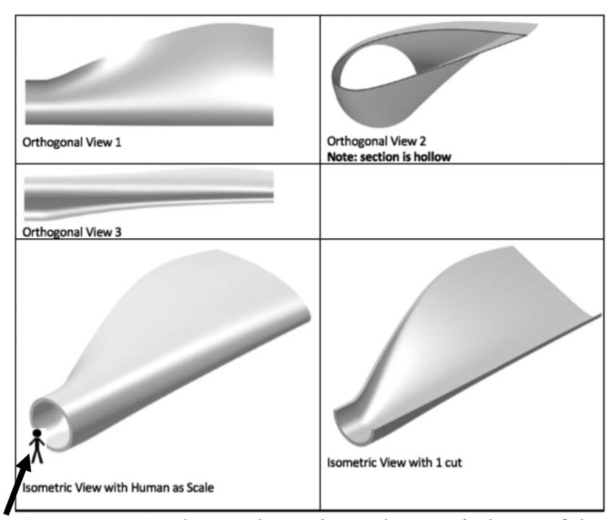
(1) I want to use my engineering knowledge to help people.
(2) I want to promote a more sustainable future for the benefit of society.
(3) Given the opportunity, I would want to design new products that can help others.
(4) Engineering design should prioritize problems that affect many people.

Participants rated their agreement with each statement on a scale of 0 (do not agree at all) to 6 (completely agree). These items were developed for the current study.

Appendix B: Wind-Turbine-Blade Repurposing Task Instructions

The following instructions are adapted from Arabian et al. [40]. Full instructions are available online.[4]

In this activity, you will be given isometric drawings of one section of a single wind-turbine blade. *It is now up to you to find creative uses for the shown section of the wind-turbine blade.* Develop concepts to reuse the part shown that would, for example, allow people to build toward a sustainable future, protect people from the impact of climate change, etc. *Please do NOT reuse such parts in wind-turbine, airplane, or similar applications that risk safety.* You should *maximize the amount of material reused* for each part, which is made of fiber-reinforced polymers (high strength/strong, high stiffness/brittle, low density/light), but *cannot be melted to make new shapes.* You *may further cut* the parts but should *minimize the amount of cutting needed.* If you do cut the parts, *this must be described in your response* (i.e., how many cuts and where are the cuts.) The same part is shown in three different orthogonal (top, front, side) views and one isometric view. In addition, given that the part is hollow, an isometric view of the part cut in half is shown.



A human scale, shown above, is used to remind you of the size of the part on the isometric views.

Appendix C: Illustrative Induction Responses

Below are illustrative examples of participants' responses across induction conditions representing common themes in their recalled experiences.

Gratitude condition	General-positivity condition	Neutral condition
I felt very appreciated recently when I took the time to mentor a brand new member of my project team. It felt very good to be recognized for this, since I took extra time to get them acquainted with the lab.	I felt positive/happy a few hours ago when I was studying on a video call with a friend and she started dancing to a song. It was good to laugh a bit between moments of concentration.	I dress up in the morning in a comfortable but "work" attire (jeans & hoodie & shirt) and prepare breakfast. I sit on the sofa having coffee and toast.
The time I spent with friends, that I don't see that often, makes me feel grateful for having them in my life to support me, and I know I can count on them for everything and they will always be there.	I felt positive because holidays are approaching and I will feel joyful on vacation.	I get up in the morning, I watch Instagram and then I go to have breakfast, then I start to watch my classes and so the morning passes.

[4]http://osf.io/GDXBE

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