Sustainable Creativity: Overcoming the Challenge of Scale When Repurposing Wind-Turbine Blades

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With the growing adoption of wind-energy technology to help address climate change, we must now also consider the disposition of retired wind-turbine blades, which are not easily recycled. This pressing environmental problem was used as the prompt in a creativity study, where participants were asked to identify potential reuses in a wind-turbine-blade repurposing task (WRT). In past iterations of this study, participants consistently struggled with correctly incorporating the large physical size of wind-turbine blades in their reuse concepts. The Alternate Uses Task (AUT) is an established measure of creativity that involves asking participants to identify uses for common objects like bricks and paper clips. The current work explored whether an AUT can be adapted as an intervention to help overcome the WRT scale challenge so that the appropriateness of reuse concepts can be improved. Students in a fourth-year undergraduate engineering-design course (N = 28) underwent both of two conditions, a scaled-AUT intervention and a typical-AUT control, before the WRT. The results support that a main difficulty with the WRT is object size. Both fluency and flexibility (number and categories of ideas) for the relatively common AUT objects were significantly lower in the scaled AUT than in the typical AUT. However, correctly scaled WRT concepts significantly increased after the scaled AUT, supporting the intervention's effectiveness. While motivated by the real-world problem that decommissioned wind-turbine blades present, the current work focuses on conceptual design and creativity, where incorporating real-world problems may provide value beyond more typical AUTs, which have fewer real-world applications. Thus, for future work, the WRT is proposed as a standard design-study task whose solutions help address a real-world problem. [DOI: 10.1115/1.4054632]

Keywords: creativity and concept generation, design for the environment, sustainable design

1 Introduction

How can we harness our creativity toward addressing environmental challenges? Ideas flow easily enough and include investing in renewable resources, encouraging sustainable practices and, of course, reducing waste. Unfortunately, these suggestions are more easily made than successfully and sustainably implemented. Research is underway to mitigate the life-cycle impacts of mass-produced objects where sustainability is not the main goal [1]. However, for technologies that aim to improve sustainability, some that are key to reducing the climate-change problem have not been optimized from a life-cycle perspective.

Significant investment in alternative-energy technology, including solar, wind, and other renewable sources of power, is promising. However, end-of-life considerations of the physical components used to deliver such sustainable energy, including solar panels and batteries, have not matched the pace of their production. Notably, wind-turbine blades are, on average, preemptively decommissioned every 20 years to reduce the risk of catastrophic failure during operation. These blades are currently made of difficult-to-recycle materials. In addition, while their shape is optimized for their intended function, this aerodynamic (versus more consistently flat or round) geometry limits the ways in which wind-turbine blades can be reused.

Several past studies involved asking participants to propose how retired wind-turbine blades could be repurposed [2–5]. These studies' participants consistently struggled with incorporating the large size of wind-turbine blades in their reuses. Thus, the current study's goal is to improve the generation of correctly scaled wind-turbine-blade repurposing ideas.

1.1 Current Wind-Turbine-Blade End-of-Life Disposal.

Steel components of wind turbines can be easily recycled. The same is not true for its blades, which are made of fiberglass, bonded with a thermoset resin, to resist separation. Wind-turbine blades are designed for high-stress operation, including extreme weather conditions, without much consideration for their end-of-life disposition [6]. Existing end-of-life options for wind-turbine blades include occasional and industrial solutions [7].

Past industrial solutions included refurbishing the decommissioned blade, but this was challenging as it is difficult to transport blades longer than 50 m. In more recent developments, the blades' fiberglass composites are transformed into small pellets and then injectable plastics or highly waterproof boards that can be used in construction [8]. Another option for wind-turbine blades is pyrolysis, which breaks down the composite fibers of blade sections in ovens with an inert atmosphere between 450 °C and 700 °C. Pyrolysis produces: (1) materials that can be used in glues, paints, and concrete; (2) gas that can be used in combustion engines; and finally (3) charcoal that can be used in fertilizer [9].

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Occasional solutions for large wind-turbine-blade sections are typically architectural in nature, with the advantage that minimal re-processing is required. Examples include playgrounds, where sections of blades are repurposed as slides, tunnels, and ramps. In Denmark's city of Alborg, two 55-meter-long blades have even been repurposed as a bridge.

Despite such examples, currently existing industrial and occasional reuses are unlikely to keep up with the rapidly increasing number of decommissioned wind-turbine blades. In the United States alone, approximately 32,000 wind-turbine blades will have been retired by 2024 [10]. By 2040 in Germany, there will be 30,000 tons of end-of-life wind-turbine-blade waste produced every year [11]. The disparity between the quantity of wind-turbine-blade waste and possible reuse options motivates the desire to facilitate repurposing-idea generation. While the sheer quantity of decommissioned wind-turbine blades is motivating in general, the current work aims to address a different sense of the word "scale." Here, "scale" refers to a challenge observed in past studies due to the large size of individual wind-turbine blades [2–5].

1.2 Scale Challenge When Developing Repurpose Ideas.

Wind-turbine blades are only increasing in size, with one of the largest at 107 m long, which can produce 12 MW of power [8]. Generating this much power is exciting and beyond what could have been imagined even 20 years ago. In fact, wind turbines with these new blades are estimated as being able to provide power to half a million people.

However, the size of more modest wind-turbine blades already causes difficulty in conceptualizing their reuse. Past studies have attempted to address wind-turbine-blade repurposing with varying degrees of success and share an underlying theme—incorrect scaling in generated concepts. Kwon et al. reported that participants tended to shrink the blade parts in their reuse ideas [3]. For example, several participants suggested using one of four sections of an entire wind-turbine blade as a surfboard. This is despite participants being provided pictures that show wind-turbine-blade sections with a human as a scale. Arabian et al. studied an intervention to improve wind-turbine-blade repurposing, but observed no effect on the quantity of correctly scaled concepts [4]. Accurately perceiving the wind-turbine blade's size is evidently challenging, leading to inappropriate reuse ideas that cannot be viably implemented.

1.3 Alternate Uses Task as Creativity Measure.

Guilford referred to divergent thinking as the ability to generate creative ideas by combining diverse information in new ways [12]. The Alternate Uses Task (AUT) is an established way to measure this divergent-thinking aspect of creativity. AUT participants are asked to list as many uses as possible for a given object, most commonly a brick or paper clip.

While the AUT is one of the most widely used creativity assessments, it is unclear whether naming uses for common objects is directly relevant to engineering design. On the other hand, design researchers have shown that warm-up activities help reduce inhibition during concept generation [13]. Our recent work used the AUT as a warm-up exercise before the much more challenging task of generating concepts to reuse wind-turbine blades [4].

A key AUT consideration is how objects are presented, for example, using text or pictures. AUT performance has been positively related to the ability to represent a given stimulus in multiple ways [14], that is, by showing AUT objects in multiple views [15]. Other manipulations include showing objects in different perspectives and orientations [16].

1.4 Alternate Uses Task as Intervention.

The current authors propose that an AUT can be adapted from a creativity assessment into an intervention and pose the following Research Question:

Can a scale intervention incorporated into an AUT be used to improve the proper scaling of concepts developed in a subsequent Wind-turbine-blade Repurposing Task (WRT)?

On an exploratory basis, does this intervention affect other measures, like feasibility and novelty?

2 Methods

The current study hypothesized that an AUT, incorporating a change in scale, would improve performance with respect to scale on a subsequent WRT. Details of a study (i.e., participants, conditions, and idea-generation task) conducted to test this hypothesis (and answer the research question) follow below.

2.1 Participants.

Participants were students in a fourth-year undergraduate engineering-design course at the University of Toronto. A total of 38 participants gave written informed consent for the study approved by the University's Research Ethics Board. Ten participants did not fully complete the study and were excluded from the analyses. The general characteristics of the remaining participants (gender, age, and discipline within engineering) are shown in Table 1.

Participants were also asked to rate their familiarity with key components of the study. Regarding wind-turbine-blade technology, almost 50% of participants indicated they were "not at all familiar," while the remaining indicated that they were either slightly or moderately familiar. Over 85% of participants indicated they had never completed an AUT before.

Table 1 Characteristics of the participant sample

Characteristic	Number of participants
Gender	Female: 15
	Male: 13
Age	21 Years old: 4
	22 Years old: 19
	23 Years old: 2
	24 + Years old: 3
Engineering Discipline	Mechanical: 10
	Industrial: 14
	Engineering Science: 2
	Computer Science: 2

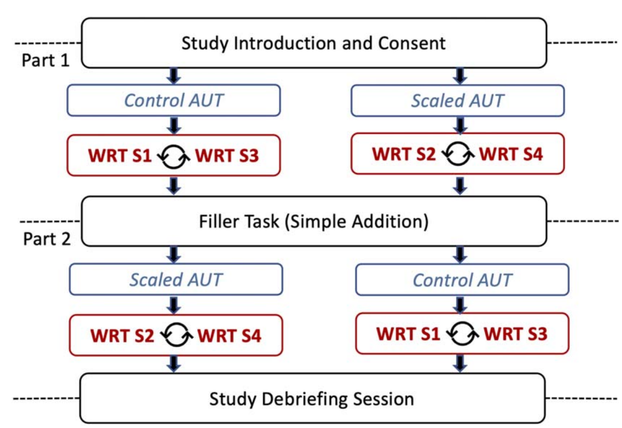

Fig. 1 Study design: All participants completed both study parts (following either the left or right set of arrows). Counterbalanced were (1) order of condition, i.e., Control versus Scaled Alternate Uses Task (AUT), shown in italicized blue, as intervention; and (2) order of blade section for the Wind-turbine-blade Repurposing Task (WRT), shown in bolded red.

2.2 Study Design and Procedure Overview. Due to restrictions on in-person events, participants completed the study using the online survey platform, Qualtrics, and were monitored through virtual-meeting software, Zoom. Figure 1 outlines the within-subject study design. Participants were assigned to one of two groups, who completed the study one part after the other within a single three-hour period.

2.2.1 Condition and Object-Stimuli Counterbalancing. The order of the conditions was counterbalanced between groups. That is, one participant group ($n = 13$) underwent the scaled-AUT condition before the control-AUT condition, while the other group ($n = 15$) underwent the conditions in the reverse order, such that all participants underwent both conditions. The slight difference between the final number of participants between groups is because 10 participants did not complete the study and were excluded.

The order of items for both the AUT and WRT was also counterbalanced. Individual AUT items were not counterbalanced across conditions due to a limited number of participants. However, AUT items were linked by form similarity across conditions, as shown in Fig. 2.

The following pairs were deemed similar in form: brick and book (solid); paper clip and wire hanger (malleable), and glass bowl and glass bottle (hollow/breakable). Thus, each AUT condition contained one item from each similar-form pair. WRT objects were also paired by form similarity, such that each condition had both a hollow (sections 1 or 2) and a solid (sections 3 or 4), as shown in Figs. 3 and 4.

2.2.2 Study Overview and Introduction. At the start of the study, participants were given a link that led to a Qualtrics survey and were told that they would be completing a study with approximately two 30-min parts. Each part of the study corresponded to either the scaled-AUT or control-AUT condition, and the two parts were separated by a 5-min filler task. The study ended with a demography questionnaire and a short debrief of the study's main objectives.

For each of the two participant groups, the study began in a Zoom breakout room with a short introduction explaining the schedule of events for the activity. Participants were instructed to always keep their Zoom video on and to not multitask. To avoid disturbing other participants in the same breakout room, they were instructed to send a private Zoom chat to the study administrator if they had questions. Between the first and second study parts (conditions), participants completed a 5-min filler task of simple arithmetic, i.e., adding single-digit integers.

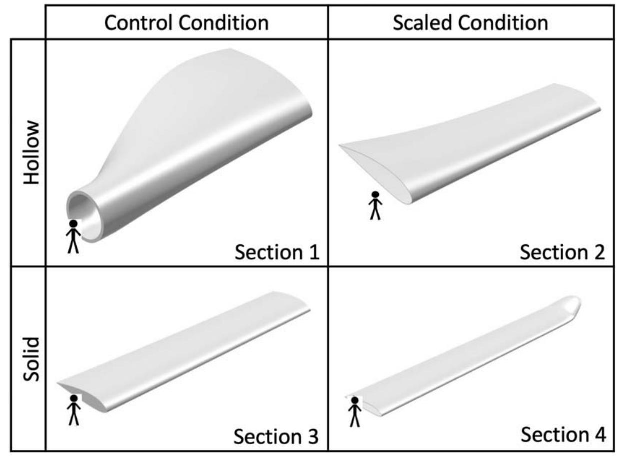

Fig. 3 Four wind-turbine-blade sections shown in isometric view: rows show hollow versus solid sections, and columns show sections following control- versus scaled-AUT conditions

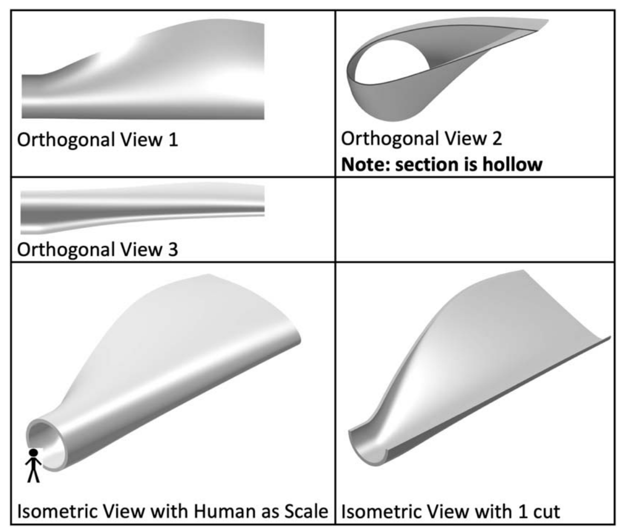

Fig. 4 All views shown for section 1 for the WRT

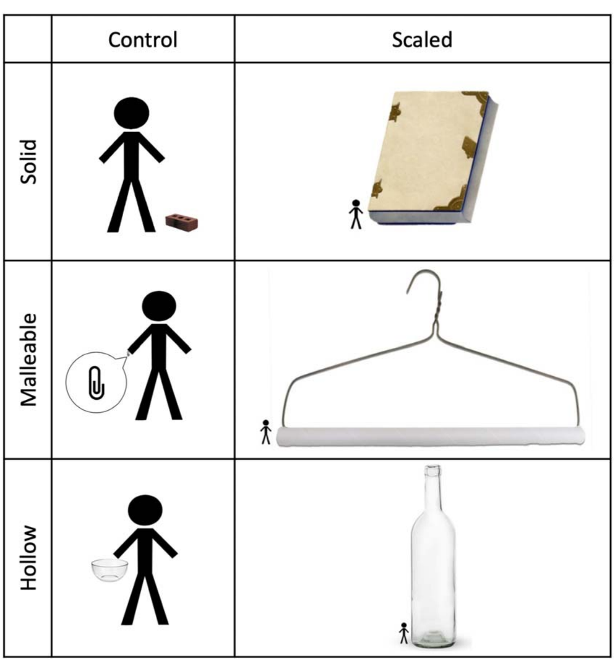

Fig. 2 AUT-object visual presentation, with conditions in columns and similar-form objects paired in rows

2.3 Study Conditions. Figure 2 shows the visual presentation of all AUT objects, with similar-form pairs in each row, and control versus scaled versions in columns.

2.3.1 Control Alternate Uses Task. In the control-AUT condition, participants were asked to complete typical AUTs for three common objects. Participants were given three minutes per object and asked to list as many uses as possible for a "brick," "paperclip," and "glass bowl." AUT objects were shown correctly scaled next to a human stick figure. Control-AUT objects were counterbalanced for order within the condition and paired with similar-form objects in the scaled-AUT condition, described next.

2.3.2 Scaled Alternate Uses Task. In the scaled-AUT condition, participants were asked to complete three AUTs for standard objects, but to imagine that they themselves had been shrunk to the size of a small insect. Participants were shown a visual representation of the object with a shrunk stick-figure to convey scale. Given three minutes per object, they were asked to list as many alternate uses as possible for a "book," "wire hanger," and "glass bottle" from this reduced scale. For example, from the scale of an insect, alternate uses for a book could be a wall or shelter. From this same perspective, examples of alternate uses for a hanger could be a frame for a house or a footbridge. The right column of Fig. 2 shows how scaled-AUT objects were visually presented.

2.4 Wind-Turbine-Blade Repurposing Task. After receiving background information on the challenges of wind-turbine-blade reuse, participants were given 20 min per condition to complete two WRTs. Under each condition, participants were asked to find creative reuses for two of four sections of a single retired wind-turbine blade. The full instructions in Appendix A include the statement, "Please do NOT reuse such parts in wind-turbine, airplane or similar applications that risk safety." These instructions were added after previous-study participants listed such infeasible uses, which limit the practical aim to identify potential real-world reuses for these parts [3].

Figure 3 shows human stick-figure scales used to convey part size for both the hollow sections in the top row and the solid sections in the bottom row. In each condition, participants were asked to identify reuses for two sections of a single wind-turbine blade, one hollow and one solid. The control-condition AUT was followed by WRT sections 1 and 3, while the scaled-AUT intervention was followed by WRT sections 2 and 4. Section order was counterbalanced, and each section was presented in multiple views, for example, as shown in Fig. 4 for section 1.

To reduce the effect of one study condition on the next condition, a 5-min filler task of simple arithmetic was inserted between the two parts of the study. The filler was also intended to reduce the likelihood that participants repeat the same uses named during the first condition for the second. Overall, fewer than 15% of ideas were repeated from previous conditions.

3 Evaluation Criteria

To answer the Research Question, "Can a scale intervention incorporated into an AUT be used to improve the proper scaling of concepts developed in a subsequent Wind-turbine-blade Repurposing Task (WRT)?", the main variables of interest measure whether concepts are correctly scaled. To test the hypothesis, "An AUT, incorporating a change in scale, would improve performance with respect to scale on a subsequent WRT," variables that reflect whether WRT concepts are properly scaled are compared following the control-AUT versus the scaled-AUT intervention.

While the current work uses the AUT as an intervention vehicle, exploratory scoring of both the scaled and control versions of the AUT may reveal possible mechanisms that underlie its effects. AUT fluency and flexibility, calculated as described below, were selected post hoc for scoring after WRT results revealed that the scale intervention had significant effects on WRT fluency and flexibility.

Table 2 summarizes the current study's main as well as exploratory variables. Details on how these variables are calculated are as follows.

3.1 Alternate Uses Task Scoring. Although performed on a post hoc exploratory basis, the scoring of AUT fluency and flexibility is described first, as it introduces concepts upon which WRT scoring builds.

- Fluency is the total number of use ideas a participant identified for the target item. Fluency was determined by attributing one point to each distinct use idea and summing these points.
- Flexibility is the number of categories of use ideas identified by a participant. Flexibility was determined by attributing one point to each category and summing these points.

Scores were calculated per participant by averaging the participant's use ideas. For example, for a participant with five use ideas for a paperclip, four for a brick and three for a bowl, this participant's final fluency score would be the average of the fluency per object, i.e., $12/3 = 4$. Three raters performed the scoring, with high reliability, i.e., average intra-class correlation (ICC) > 0.9 in all cases.

3.2 Wind-Turbine-Blade Repurposing Task Scoring. Consistent with the instructions provided to participants, WRT reuse concepts similar to or matching those listed below were eliminated due to safety concerns before scoring:

- wind-turbine/mill part/blade;
- rotor blade;

Table 2 Evaluation criteria

	Measure	Characterization/ Level	Scoring	Description
AUT	*Fluency*	*Raw Data*	*# of ideas*	*Number of participant-generated ideas.*
	Flexibility	*Raw Data*	*# of categories*	*Number of participant-generated idea categories.*
WRT	**Fluency**	**Correctly scaled**	• **Shrunk** • **To-Scale** • **Enlarged**	**Classification of concept scale, quantified as number of to-scale concepts over all concepts.**
		Feasible	• *Unfeasible* • *Low* • *Medium* • *High*	*Classification of concept feasibility, quantified as number of feasible concepts over all concepts.*
	Flexibility	**Correctly scaled**	• **Shrunk** • **To-Scale** • **Enlarged**	**Classification of concept-category scale, quantified as number of to-scale concept categories over all concept categories.**
		Feasible	• *Unfeasible* • *Low* • *Medium* • *High*	*Classification of concept-category feasibility, quantified as number of feasible concept categories over all concept categories.*
	Novelty	*Object*	*0–3*	*Score of 0–3 based on uniqueness within concepts generated by participants.*
		Category	*0–3*	*Score of 0–3 based on uniqueness within concept categories generated by participants.*
		Average	*0–3*	*Average of the object and category score of concept.*

Note: Main study variables bolded and exploratory variables italicized.

- airfoil (unless specified for wind-tunnel studies);
- airplane part/whole; and
- propeller.

The remaining concepts were then scored on fluency and flexibility with respect to two measures. The first measure, scale, is key to answering the Research Question (whether the intervention increases to-scale concepts). In addition, exploratory analyses were performed to determine whether the intervention affects other metrics of interest in conceptual design, so the effects on feasibility are also reported. Concept feasibility is relevant in general and for wind-turbine-blade reuse concepts especially. Prior WRT work also included the metric of appropriateness [3,4], which combined scale and feasibility, but is not reported here, as appropriateness is not an independent measure. Finally, concepts were also scored on novelty, another measure of interest in conceptual design. Here, novelty reflects the uniqueness of concepts within the participant group, and is described further in Sec. 3.2.3. Scoring was performed by three raters, with a medium degree of reliability between them, i.e., average intra-class correlation (ICC) >0.75 in all cases.

3.2.1 Scale Scoring. Wind-turbine-blade reuse concepts were classified as shrunk, to-scale, or enlarged. Shrunk refers to a part being impractically reduced in scale, without mention of cutting, to meet the identified reuse. An example of *shrunk* would be using section 2 of Fig. 3 as an eye-glass holder. *To-scale* refers to using the wind-turbine blade at the correct scale. This includes reshaping it by, for example, cutting the flatter parts of section 4 into tiles. Reuses larger than the wind-turbine-blade section without mention of combining multiple wind-turbine-blade parts were considered enlarged. An example of *enlarged* would be using section 3 as a building. Examples of differently scaled concepts are also listed in Appendix B. Concepts that were classified as either shrunk or enlarged were excluded from "correctly scaled" results. Correctly scaled results are expressed as the ratio of properly scaled concepts to the total number of concepts generated.

3.2.2 Feasibility Scoring. While concepts that require many cuts or combinations may be "to-scale," they may be less technically achievable. Feasibility accounts for the degree of modification required for participants' reuses. Concepts were scored as unfeasible, or of low, medium, or high feasibility. Scoring was also informed by current or expert-suggested reuses, for example, tables, playgrounds, and construction material [7].

Concepts that were deemed unfeasible usually exceeded the wind-turbine blade's technical potential, for example, to use as a rocket. Low-to-medium feasibility scores were given to concepts that, while technically possible, would require an increasing degree of modification. For example, bathroom tiles would be scored low in feasibility due to the significant work required to turn a wind-turbine blade into such tiles. Furniture or roofing material was rated medium in feasibility, as larger pieces of the wind-turbine blade could be reused directly. Finally, concepts were scored as highly feasible if they were technically simple to implement with few or no modifications, for example, playground/skate-park structures and bus-shelter roofs. Appendix B lists examples of concepts with varying levels of feasibility. Feasibility results are expressed as the ratio of feasible to total concepts generated.

3.2.3 Novelty Scoring. Novelty was scored in two stages, both on a four-point scale. The scoring method rewarded uniqueness within concepts generated by the participant group. Concepts for each wind-turbine-blade section were first divided into 16 distinct categories listed in Table 3.

For object novelty, a score was assigned based on the number of times a reuse concept was named by all participants. A value of 0–3 was determined based on the minimum and maximum number of times a concept was repeated for each wind-turbine-blade section. For example, if the number of times a unique concept was identified by all participants ranged from 1 to 8, scores would be assigned as follows. Concepts identified once earned a score of 3, concepts identified eight times earned a score of 0, and concepts identified between 1 and 8 times earned a score proportionally between 0 and 3.

Next, to assess category novelty, for each wind-turbine-blade section, reuses were scored based on uniqueness in the set of all concepts generated. Again, each reuse was scored 0–3 based on how frequently its category occurred in concepts generated by the participant group. Lastly, the final novelty score of each reuse concept was determined by averaging each concept's category novelty and object novelty scores. To summarize, the novelty was scored at two levels (category and object), and the scores at these two levels were averaged to determine the final novelty score.

3.3 Statistical Analyses. The software, IBM SPSS Statistics 27.0, was used to perform statistical analyses. Data sets were checked for outliers based on a visual inspection of a boxplot. Data located more than 1.5 box lengths from the edge of the plot were considered outliers, whose treatment is described below in the Results section. Samples were assessed for normality using the Shapiro–Wilk's test. As the AUT data were not normally distributed, they were compared across conditions using Wilcoxon signed-rank tests (the non-parametric equivalent of the paired *t*-test).

Normally distributed WRT data were evaluated using paired t-tests. A one-way repeated-measures analysis of variance (ANOVA) was used when comparing normally distributed results across wind-turbine-blade sections. For not-normally distributed results, the non-parametric equivalent, Friedman Test, was used. For all analyses, statistical significance was established at a nominal alpha value of 0.05.

4 Results

In Figs. 5–8 that summarize results, opaque (darker) points represent mean results of all participants while translucent (lighter) points indicate individual participants' results.

4.1 Alternate Uses Task Results. Complete data sets from 28 participants were analyzed. A Wilcoxon signed-rank test was used to check whether statistically significant differences existed in fluency and flexibility between the scaled- and control-condition AUTs. The difference in scores between the two conditions were approximately symmetrically distributed, as assessed by a histogram with a superimposed normal curve. Figure 5 and Table 4 summarize the AUT results.

Table 3 WRT Reuse categories and examples

Category	Examples
Art	Sculpture, home décor
Building	Restaurant, storage
Play structure	Slide, skate park
Tool	Shovel, ladder
Shelter	Roof, bus stop
Piping structure	Water pipe, drain
Mechanical component	Rudder, car rim
Furniture	Table, bench
Research	Simulator, education
Passageway	Bridge, tunnel, ramp
Barrier	Windbreaker, road barrier
Home construction	Gate, pool, insulation
Heavy equipment	Funnel, sifter
Transportation	Boat, car
Household item/appliance	Container, backpack
Toy/entertainment	Snowboard, instrument

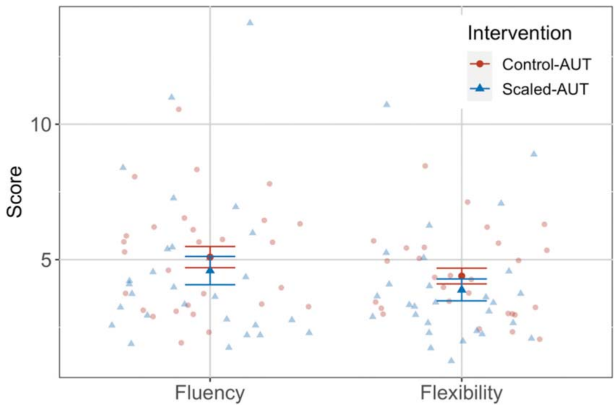

Fig. 5 AUT fluency and flexibility scores during scaled and control conditions. Opaque (darker) points represent mean results of all participants while translucent (lighter) points indicate individual participants' results. Differences for both are significant ($p < 0.05$).

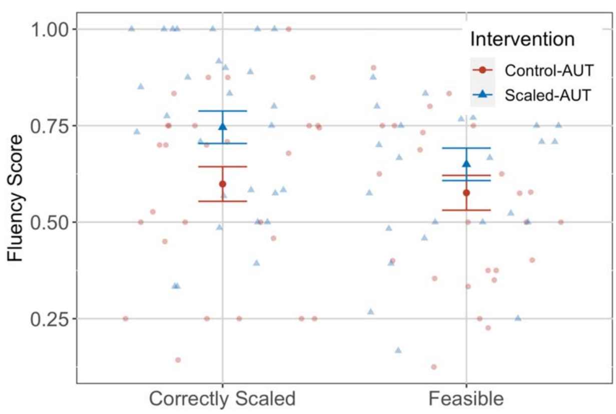

Fig. 6 WRT fluency results. Opaque (darker) points represent the mean results of all participants while translucent (lighter) points indicate individual participants' results. The difference in Correctly Scaled Fluency is significant ($p < 0.05$).

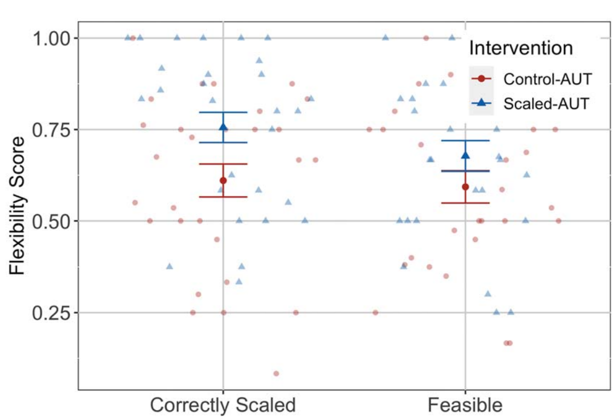

Fig. 7 WRT flexibility results. Opaque (darker) points represent the mean results of all participants while translucent (lighter) points indicate participants' individual results. The difference in Correctly Scaled Flexibility is significant ($p < 0.05$).

4.1.1 Fluency. A Wilcoxon signed-rank test was conducted to determine the effect on fluency of the scaled versus control versions of the AUT.

The scaled-AUT condition elicited fewer alternate uses in 20 of 28 participants compared to the control. One participant showed no difference, and seven participants generated more alternate uses after the scaled-AUT condition. Statistically significantly fewer uses were generated during the scaled AUT (Mdn = 3.83) than the control AUT (Mdn = 5.50), $z = -2.083$, $p = .037$, and $r = -0.39$.

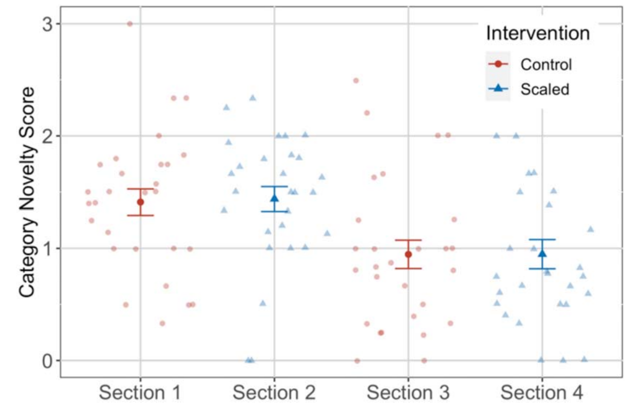

Fig. 8 WRT category novelty results. Opaque (darker) points represent the mean results of all participants while translucent (lighter) points indicate individual participants' results. Significantly fewer novel categories were generated for wind-turbine-blade (as shown in Fig. 3) sections 3 and 4 than sections 1 and 2 ($p < 0.05$).

Table 4 AUT Results summary

	Control AUT (Mdn)	Scaled AUT (Mdn)	z	p	r
Fluency	5.50	3.83	−2.083	0.037*	−0.39
Flexibility	4.55	3.33	−2.332	0.020*	−0.44

4.1.2 Flexibility. Similar to fluency, the scaled version of the AUT elicited lower use flexibility for 20 of 28 participants compared to the control version of the AUT. Two participants showed no difference, and six participants had higher use flexibility for the scaled than the control version of the AUT. There was a statistically significant decrease in use flexibility generated during the scaled version of the AUT (Mdn = 3.33) compared to the control version of the AUT (Mdn = 4.55), $z = -2.332$, $p = .020$, and $r = -0.44$.

4.2 Wind-Turbine-Blade Repurposing Task Fluency Results.

Fluency assessments for 28 participants' WRT concepts were separated into two categories: (1) correctly scaled and (2) feasible. Figure 6 and Table 5 summarize WRT fluency results.

4.2.1 Correctly Scaled Fluency. There were no outliers identified and the assumption of normality was not violated ($p = 0.239$). Participants generated more correctly scaled WRT concepts after the scaled-AUT intervention ($M = 0.746$, SD = 0.222) than after

Table 5 WRT Fluency results summary

	Control AUT		Scaled AUT				
	M	SD	M	SD	t-value	p	d
Correctly Scaled	0.599	0.237	0.746	0.222	3.478	0.002**	0.657
Feasible	0.576	0.238	0.650	0.222	1.712	0.098	–

** $p \leq 0.01$.

the control AUT ($M = 0.599$, SD = 0.237), a statistically significant mean increase of 0.147, 95% CI [0.0603, 0.234], $t(27) = 3.478$, $p = 0.002$, and $d = 0.657$.

A Friedman test was used to determine whether the quantity of correctly scaled reuses differed across the different sections of the wind-turbine blade. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Correctly scaled reuses were statistically significantly different across the wind-turbine-blade sections, $\chi^{2(3)} = 24.197$, $p < 0.001$. Post hoc analyses revealed statistically significant differences in correctly scaled reuses from section 3 (Mdn = 0.50) to section 1 (Mdn = 0.775) (p = 0.043) and section 2 (Mdn = 1.00) ($p < 0.001$), but not for any other comparison.

4.2.2 Feasible Fluency. No outliers were detected in this section of data, and the assumption of normality was not violated ($p = 0.276$). Participants generated more feasible reuses following the scaled-AUT intervention ($M = 0.650$, SD = 0.222) than in the control-AUT condition ($M = 0.576$, SD = 0.238), but the difference was not statistically significant $t(27) = 1.712$, $p = 0.098$.

4.3 Wind-Turbine-Blade Repurposing Task Flexibility Results. Data from 28 participants who completed the WRT were analyzed. Similar to fluency, flexibility results were also separated into two categories: (1) correctly scaled and (2) feasible. Paired *t*-tests were conducted to determine the effects of the scaled-AUT intervention versus control-AUT condition on WRT flexibility. Figure 7 and Table 6 summarize the results for WRT flexibility.

4.3.1 Correctly Scaled Flexibility. Excluding one outlier in the correctly scaled flexibility data did not significantly affect the results, so the outlier was retained in the analysis. The assumption of normality was not violated ($p = 0.481$). The scaled-AUT intervention increased correctly scaled WRT flexibility ($M = 0.765$, SD = 0.233) compared to the control-AUT condition ($M = 0.611$, SD = 0.238), a statistically significant mean increase of 0.154, 95% CI [0.066, 0.242], $t(27) = 3.591$, $p = 0.001$, and $d = 0.679$.

A Friedman test was conducted to determine whether the quantity of correctly scaled reuse categories differed across the different wind-turbine-blade sections. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Correctly scaled reuse categories were statistically significantly different across the wind-turbine-blade sections, $\chi^{2(3)} = 18.013$, $p < 0.001$. Post hoc analysis revealed statistically significant differences in correctly scaled flexibility in reuses from section 3 (Mdn = 0.50) to section 2 (Mdn = 1.00; $p < 0.001$), but not for any other comparison.

4.3.2 Feasible Flexibility. No outliers were detected in this section of data, and the assumption of normality was not violated ($p = 0.957$). Participants generated reuses with higher feasible flexibility following the scaled-AUT intervention ($M = 0.678$, SD = 0.222) than the control-AUT condition ($M = 0.593$, SD = 0.234), but the difference was not statistically significant $t(27) = 1.857$, $p = 0.074$.

4.4 Wind-Turbine-Blade Repurposing Task Novelty Results. Results of 28 participants' WRT were assessed for (1) category (2) object, and (3) final average novelty. The effect of the scaled-AUT intervention on novelty was not significant across conditions. However, a one-way repeated-measures ANOVA was used to check whether novel concept generation differed between the sections of the wind-turbine blade.

Table 6 WRT Flexibility results summary

	Control		Intervention				
	M	*SD*	*M*	*SD*	*t-value*	*p*	*d*
Correctly Scaled	0.611	0.238	0.765	0.233	3.591	0.001**	0.679
Feasible	0.593	0.234	0.678	0.222	1.857	0.074	–

** $p \leq 0.01$.

4.4.1 Category Novelty. Excluding two outliers did not significantly affect results, so the outliers were retained in the analysis. The data were sufficiently normally distributed ($p > 0.03$). The assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^{2(5)} = 1.401$, $p = 0.924$. There was a statistically significant difference in novel concept generation at the category level across the different sections, $F(3, 81) = 4.912$, $p = 0.003$, partial $\eta^2 = 0.154$, with fewer novel categories generated for sections 3 and 4 (M3 = 0.95, SD3 = 0.67; M4 = 0.95, SD4 = 0.69) than sections 1 and 2 (M1 = 1.41, SD1 = 0.62; M2 = 1.44, SD2 = 0.58). Post hoc analysis with a Bonferroni adjustment revealed that category novelty for section 2 was significantly higher than for section 3 (M2–M3 = 0.492, 95% CI [0.18, 0.965], $p = 0.039$), but not from section 4 (M2–M4 = 0.490, 95% CI [−0.014, 0.993], $p = .06$). Figure 8 summarizes the results for WRT category novelty.

4.4.2 Object Novelty. Excluding one outlier did not significantly affect results, so the outlier was retained in the analysis. The data were normally distributed ($p > 0.05$), and the assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^{2(5)} = 3.029$, $p = 0.696$. However, there was no statistically significant difference in novel concept generation at the object level across the different sections, $F(3, 81) = 1.341$, $p = .267$, partial $\eta^2 = 0.047$.

4.4.3 Final Novelty. The exclusion of three outliers did not significantly affect the results, so the outliers were retained in the analysis. The data were normally distributed ($p > 0.05$), and the assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^{2(5)} = 1.954$, $p = 0.856$. However, similar to novelty at the object level, there was no statistically significant difference in average final novelty across the different wind-turbine-blade sections, $F(3, 81) = 0.797$, $p = .49$, and partial $\eta^2 = 0.029$.

5 Discussion

5.1 Alternate Uses Task and Scale Intervention. While the AUT is typically used to measure divergent thinking and creative output, it was mainly used as a design intervention in the current work. This did not, however, preclude analyzing the alternate uses produced during its completion. Both fluency and flexibility significantly decreased in the scaled version compared to the control version of the AUT. This result is of particular interest because the AUT stimuli presented are familiar items (i.e., book, bottle, and wire hanger) that shared physical characteristics with their control-condition counterparts.

Interpreting this AUT result toward improving WRT performance, the wind-turbine blade's unfamiliarity may not be the main difficulty when generating reuse concepts. The factor that remains in the intervention version of the AUT is the object scale. This suggests that WRT participants may be as challenged by the size as the unfamiliarity of the wind-turbine blade. This insight may be relevant for generating reuses for other large or difficult-to-conceptualize objects.

These results are consistent with the work of Kirjavainen and Hölttä-Otto, which identifies framing as an idea-promoting mechanism [17]. In the current work, the scaled-AUT helps frame both the AUT itself and the subsequent WRT in a different scale environment. While this scaled intervention significantly decreased fluency and flexibility during the AUT itself, it improved participants' ability to perceive a different context, leading to improved WRT concepts, detailed in the next section.

Other scale interventions are possible. One could ask participants to identify alternative uses for other large objects, like a wall, that are similar in size to the wind-turbine blade. However, such objects may act as stimuli, where the objects and their reuses are likely to be carried over into WRT responses. Walls were also identified as reuses in past WRTs [2]. Similarly, the scale could be conveyed in the WRT other than through a human stick figure, for example, by placing it next to other large objects. Other work (1) showed photos of wind-turbine blades in the context of other objects, e.g., in a field with power-line poles and in a landfill with a fork-lift truck, and (2) described using text, a wind-turbine blade's size compared to common landmarks, e.g., Big Ben in the United Kingdom and the Statue of Liberty in the United States [5]. However, the other studies' interventions did not involve scale, so the above were provided to all study participants. Again, a main consideration is that such contexts and corresponding objects may prime participants on specific uses and use contexts.

5.2 Wind-Turbine-Blade Repurposing Task. Following the scaled-AUT intervention were significant increases in properly scaled wind-turbine-blade reuse concept fluency and flexibility. This result confirms the benefit of using the scaled-AUT intervention before performing an idea-generation task that involves an atypical scale. These findings are crucial for problems where the large (or possibly small) scale of an object challenges conceptualization.

While the current study's sample size was small due to practical limitations, a post hoc power analysis using *G**power [18] showed that correctly scaled results for the WRT were properly powered (over 90%). That is, using a two-tailed *t*-test, Alpha = 0.05, a sample size of 28 had a 92% power to detect an effect size of 0.657 (correctly scaled fluency) and 93% power to detect an effect size of 0.679 (correctly scaled flexibility).

Having achieved our main goal to improve scale perception, other aspects of wind-turbine-blade reuses were analyzed in an exploratory manner to check whether the intervention produced any other effects. The scaled-AUT intervention did not significantly affect raw idea fluency nor flexibility nor any measure of feasibility.

Independent of the intervention, significant differences did exist in categorical novelty between different wind-turbine-blade sections, with fewer novel categories of reuse concepts generated for sections 3 and 4 than sections 1 and 2. This is likely due to their different physical characteristics, i.e., sections 1 and 2 are hollow, possibly enabling more reuse opportunities than solid sections 3 and 4.

5.3 Cognitive Context: Previous Work on Alternate Uses Test and Wind-Turbine-Blade Repurposing Task. In related previous work, familiar-scale AUT objects were presented to participants in different orientations [16]. As expected, some participants identified uses in these novel orientations, for example, an inverted bowl as a drum, step stool, or lampshade. Less expected, other participants continued to reorient the object as they named additional uses. For example, in addition to a drum, step stool, or lampshade for an inverted bowl, a bowl turned 90 deg could be used as a shield or wall decor, and a typically oriented bowl could be used as expected, for example, to store items.

In related previous work using a WRT, participants were asked to imagine the section of wind-turbine blade at different orientations with respect to themselves, for example, under, over, in front, behind, and to both sides [2]. As could be expected, this intervention led to many concepts involving floors, walls, and roofs.

Each past WRT iteration had participants who struggled with the large size of the wind-turbine blade, producing uses that were incorrectly scaled [2–5]. Intuitively, familiar-scale objects are easier for participants to imagine different uses. Furthermore, Kleibeuker et al. [19] noted that generating alternative uses increases activity in left hemisphere brain regions, including the supramarginal gyrus (SMG) and middle temporal gyrus (MTG). These regions are specifically related to tool use and action knowledge, including imaginative tool use [20]. Compared with common AUT objects, the large size of wind-turbine blades may reduce the likelihood of participants associating them with tool use to activate the AUT-relevant SMG and MTG.

Thus, the developed intervention aimed to bridge the process of completing an AUT (using familiar objects) with the process of shifting in scale (by imagining oneself as shrunk). The decreased fluency and flexibility results for the scaled AUT compared to the control AUT support that imagining alternative uses from a different scale is more difficult than from a familiar scale. However, the intervention developed and reported in the current work appears effective at helping participants overcome the difference-in-scale obstacle for the WRT, perhaps by introducing the shift in scale using familiar AUT objects first.

6 Conclusion and Future Work

In several previous iterations of the WRT, participants had considerable difficulty identifying reuses for retired wind-turbine blades at the correct scale. The current work devised and tested a scale intervention through an AUT that preceded the WRT. The results support the effectiveness of this intervention, which could also augment existing work on the information-structuring strategies of designers [21].

The impact of the current study is twofold. First, we have successfully repurposed the AUT from a creativity-measurement tool to a practically relevant design tool. Second, and arguably, more importantly, this work is a step toward addressing a pressing real-world problem, by facilitating the development of concepts to reuse decommissioned wind-turbine blades.

While reuse novelty varied between sections of the wind-turbine blade, novelty did not differ significantly between study conditions. This result is not surprising, as the intervention specifically aimed to address scale. However, the finding supports that wind-turbine-blade sections (as well as AUT objects) with similar characteristics should be balanced across different study conditions. Novelty is a measure that is often associated with creativity. However, novelty and other measures of design creativity can benefit from further refinement in engineering design.

6.1 Improved Metrics in Engineering-Design Studies. Several researchers recently reported mixed results on the use of existing creativity metrics in engineering-design studies. These metrics, for example, fluency, flexibility, novelty, and quality are typically positive measures of creativity, where the higher their value, the more creative a process or outcome. However, higher values for one have not always correlated with higher values for the others.

Regarding fluency and novelty, Mirabito and Goucher–Lambert found that idea fluency and timing did not affect quality when using a holistic innovation measure rather than novelty alone [22]. Regarding novelty and flexibility, Spivey et al. found that allowing designers to use a preliminary conceptual sketch improved the resulting requirement typology and novelty, but did not affect variety [23]. Regarding novelty and quality, Miller et al. found that two different methods can lead to similar quality ratings, but dissimilar novelty assessments [24]. In addition, even when novelty ratings were similar, quality assessments may differ. Thus, improved and more consistent measures may be required to assess the overall quality of wind-turbine-blade reuse ideas and engineering-design concepts in general.

6.2 Standardized Tasks in Engineering-Design Studies. The above work by many in the engineering-design community points to the need for improved metrics by which design concepts are evaluated. However, as argued by just as many others, there is also a need for standardized design tasks to compare the effects of interventions across studies. Kumar and Mocko assessed problems used in engineering-design creativity studies and called for reusing and developing standard problems to reduce a source of difference between studies [25]. Patel et al. described a systematic approach to compare design prompts or problem statements such that similar problems can be used for within-subject replication [26]. To help address the often-limited number of participants in engineering-design studies, using similar problems under different study conditions enables comparison of their effects on the same participants' results. In fact, Sosa developed four metrics for researchers to objectively select design tasks that best fit the purpose of their creativity studies [27].

6.3 Wind-Turbine-Blade Repurposing as Standard Design Task. Outside of engineering design, the AUT is a standard task used to evaluate the divergent-thinking aspect of creativity. Thus, the AUT has been used to compare the effects of many interventions on creativity. Within engineering design, one can argue whether identifying alternative uses for bricks and paperclips is relevant to design and whether such ideas solve the real-world problems that engineers address.

In contrast, the challenge of repurposing wind-turbine blades has real-world implications. The WRT is structurally like the AUT, as both involve identifying alternate uses for objects. While past WRT participants struggled, the current study suggests that object scale may be a larger source of difficulty than object unfamiliarity. With a main cognitive obstacle successfully addressed, the WRT becomes a candidate standardized task by which engineering-design interventions can be compared.

If the WRT becomes a standard engineering-design-study task, a repository of generated reuse concepts would facilitate developing standard assessment criteria, for example, related to novelty and feasibility. To account for potentially inconsistent ratings of idea quality and novelty, machine-learning-based design-concept evaluation could be applied to select stronger concepts [28,29]. Such evaluation could also include actual or perceived social impacts [30]. The WRT concept-generation process could potentially benefit from adaptive inspirational design stimuli [31], possibly based on visual similarity [3]. Furthermore, this repository of ideas has enormous potential to address an urgent, real-world problem that currently lacks sufficient solutions.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data sets 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. Data provided by a third party are listed in Acknowledgment.

Nomenclature

AUT = Alternate Uses Task, where participants are asked to generate as many uses as possible for common objects.

WRT = Wind-turbine-blade Repurposing Task, where participants are asked to generate concepts to repurpose wind-turbine blades that are preemptively retired.

Appendix A: Wind-Turbine-Blade Concept-Generation-Activity Instructions

In this next task, you will be asked to generate many alternate uses for different wind-turbine-blade sections.

According to the Global Wind Energy Council, as of the end of 2019, there are over 650,000 wind-turbine installations globally. As wind turbines age and retire, their disposal must be considered. Wind-turbine blades are made of materials such as glass-fiber-reinforced polyester to increase lightweight, stability, and corrosion resistance.

Such composites are often challenging to recycle; therefore, we must find alternatives to disposal. However, this is also an opportunity to repurpose the used wind-turbine blades for other creative uses.

Please do NOT reuse such parts in wind-turbine, airplanes, or similar applications that risk safety.

You should maximize the amount of material reused for each part, which is made of fiber-reinforced composites and not meltable (high strength/strong, high stiffness/brittle, and low density/light).

You will have 10 min each to generate alternate uses for a total of two wind-turbine-blade sections.

Appendix B: Scale and Feasibility Concept Examples

Table 7 Examples of concepts categorized for scale

Category	Examples		
Shrunk	**Hand tools**	Use as **dumbbells**	Play as an **instrument**
To-scale	Cut into smaller pieces and used as **furniture**	**Bridge**	**Slide**
Enlarged	Use as a **house**	Cool concept for a **restaurant**	

Note: Bolded text corresponds to objects suggested for wind-turbine-blade repurposing.

Table 8 Examples of concepts categorized for feasibility

Category	Examples		
Not feasible	**Water filter pipe**	**Jars** to hold certain chemical b/c material is corrosion-resistant	**Axe**
Low feasibility	**Bench**	**Table**	**Tolls**
Medium feasibility	**Roof** for an outdoor patio	**Storage silo**	**Bathtub/pools** (multiple cuts)
High feasibility	**Water slide**	Can be used as **animal shelters**	Used in an **obstacle course** (for children or military)

Note: Bolded text corresponds to objects suggested for wind-turbine-blade repurposing.

Appendix C: Number of Wind-Turbine-Blade Repurposing Task (WRT) Concepts Assessed

Table 9 Number of WRT concepts assessed for fluency and flexibility

Measure	Characterization	Condition	Number of concepts
Fluency	Correctly scaled	Control	151
		Intervention	185
	Feasible	Control	131
		Intervention	155
Flexibility	Correctly scaled	Control	134
		Intervention	162
	Feasible	Control	119
		Intervention	138

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