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Ideation Equation: Examining how mechanical engineering and industrial design capstone students generate ideas

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After graduation, he worked in industry for 11 years at Priority Designs working on consumer goods, sporting equipment, lawn care equipment, medical devices, UI/UX development and marketing. In that time, Wisniewski was able to work with industry leaders like Nike, TaylorMade and Scotts. He returned to Ohio State because he missed teaching students. From his experience in his teaching assistant days, Wisniewski had the itch to get back in the classroom and help the next generation of engineers. His teaching goal are to give engineers a better understanding of manufacturing, visual communication skills, entrepreneurial endeavors and how to bring their ideas to life.

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Abstract

This paper presents findings from a pedagogical experiment using the *Ideation Equation*, a short, in-class activity designed to surface patterns in early-stage idea generation. Conducted with senior capstone students in mechanical engineering (n=57) and industrial design (n=16), the activity prompted rapid sketch-based responses to a visual equation. Each student's output was analyzed for quantity, uniqueness, and derived metrics such as ideation breadth, depth, and impact. Results indicate that while industrial design students generated more unique and varied ideas on average, several engineering students demonstrated high ideation capacity, challenging assumptions about disciplinary creativity. Distinct strategies were also observed: engineering students often iterated within idea types, while design students explored a broader solution space. This work contributes to ongoing efforts to support creativity across STEM and design education by offering a lightweight, embedded method to compare ideation behaviors across disciplines and to make visible the cognitive diversity present within and between student cohorts.

Introduction

The disciplines of mechanical engineering and industrial design both contribute to the development of new products, services and systems. A crucial competency for both engineers and designers in a development effort is the ability to generate ideas, or to ideate. Thus, a critical goal of engineering and design education is to develop students' capacity to ideate. However, designers have a reputation for being "better" at ideation, and as educators who teach both design capstone courses and engineering capstone courses in four-year undergraduate programs, we have observed a lack of belief by engineering students in their own idea generation abilities. Does the ability to generate ideas fundamentally belong to design? We don't think so! However, we have – for years – informally observed ways in which our engineering and design students' ways of ideating differ from one another, and upon discussing ideation exercises we have employed to teach ideation, devised an experiment to reveal, uncover, and make plain such differences.

Therefore, this paper presents a novel instrument – a short ideation activity – and examines activity output from undergraduate capstone students in mechanical engineering and industrial design major areas for the purpose of characterizing students' ideation, highlighting emergent similarities and differences.

Background

Creativity and ideation are increasingly recognized as essential competencies in both engineering and design education, yet approaches to understanding them vary widely. In engineering, structured assessments like the Creative Engineering Design Assessment (CEDA) [1] and simplified TRIZ methods [2] aim to systematize creative thinking, while industrial design pedagogy embeds iterative idea generation into studio-based project cycles [3]. Research comparing STEM and arts students reveals that cognitive differences may be less pronounced than cultural narratives suggest; when measured in structured settings, both groups exhibit similar divergent thinking capacities [4,5]. Despite this, persistent assumptions about engineering students being less creative than design students [6,7] continue to shape educational experiences and student self-concept [8].

Existing studies focus on aggregate measures like fluency or novelty scores without examining the specific patterns or breadth of ideation across disciplines [9]. Scholars have called for broader frameworks that recognize and support diverse modes of ideation in technical fields [10], yet empirical comparisons across disciplines remain rare. There is a critical gap: little is known about how engineering and industrial design students ideate differently—or similarly. Addressing this need, we introduce *Ideation Equation*, a lightweight, embedded pedagogical instrument to surface and characterize ideation capacities across disciplinary lines, contributing to a more nuanced and equitable understanding of creativity in design and engineering education. Our research addresses two research questions: 1) how do student outputs from an ideation activity characterize their approaches to generating ideas, and 2) to what extent do engineering and design students' ideation outputs differ? We hypothesize that our analysis will show that both groups demonstrate a capacity to ideate, but may do so using different strategies.

Methodology

To better understand the idea-generation capacity of our students while also supporting their ongoing capstone efforts, the research team devised a mixed-methods approach comprising an in-class activity, and an analysis of collected activity outputs including thematic grouping and simple descriptive statistics.

Undergraduate capstone students (n=73) from mechanical engineering (n=57) and industrial design (n=16) major programs at The Ohio State University participated in the activity.

Research Method: Ideation Equation

Students were instructed to bring a full sheet of paper with their name on it and a writing utensil. Students were seated around a large conference room, each student with a chair and ample table space. Once seated, students were instructed that they would have 60 seconds to write down as many solutions as they could think of to an "equation" that would be written on a whiteboard. The equation was (circle) + (square) = "?" (e.g. Fig. 1).

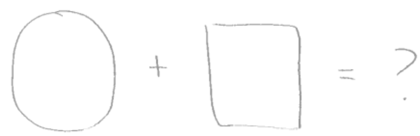


Fig. 1. Ideation equation prompt represented on a participant page.

Students were given a verbal half-way warning, and a 10-second warning, before being instructed to set down their writing utensils after 60 seconds had elapsed. Students' papers were collected.

Analysis Method

A unique student identification number was assigned to each student, linked with their major area and collected paper. For each collected paper, the total number of solutions to the (circle) + (square) = "?" equation was counted and logged into a spreadsheet. A "solution" was determined to be any written element (usually a small sketch), as perceived by the research team as being distinct from – but not necessarily different from – other solutions on a participant's page. Then, the researchers inductively categorized types and quantities of solutions, shared in Appendix A. Additional metrics were derived based on these categories to characterize the students' solutions, outlined in Table I, below.

TABLE I
DERIVED METRICS FOR IDEATION EQUATION SOLUTIONS

Metric	Calculation
Total solutions	= 1 for each solution on the page
Duplicate solution	= 1 for each solution that has been previously shown (note: first time shown is not a duplicate)
Unique solutions	= (total solutions) - (duplicate solutions)
Fluff	= (total solutions) - (unique solutions)
Depth	= (Count 1 for each solution beyond the 1st in a type) - (duplicate solutions)
Efficiency	= (unique solutions) / (total solutions)
Breadth	= 1 for each type of solution

Marginal ideation impact "bang for your buck"	= (breadth) / (total solutions)
Ideation impact	= (unique answers) * (breadth)

Note. Numbers calculated per participant.

To afford a direct comparison between solutions from engineering students (n=57) and design students (n=16), student numbers have been normalized (MINMAX) for each metric presented in the results.

Results

A total of 78 pages were collected (e.g. Fig. 2); 2 pages were excluded due to having no relevant content, the remaining pages (n=76) were assigned unique identification numbers linked to mechanical engineering students (n=57) and industrial design students (n=16); 3 pages contained relevant content, but could not be linked with a student, and were therefore omitted from major-specific results.

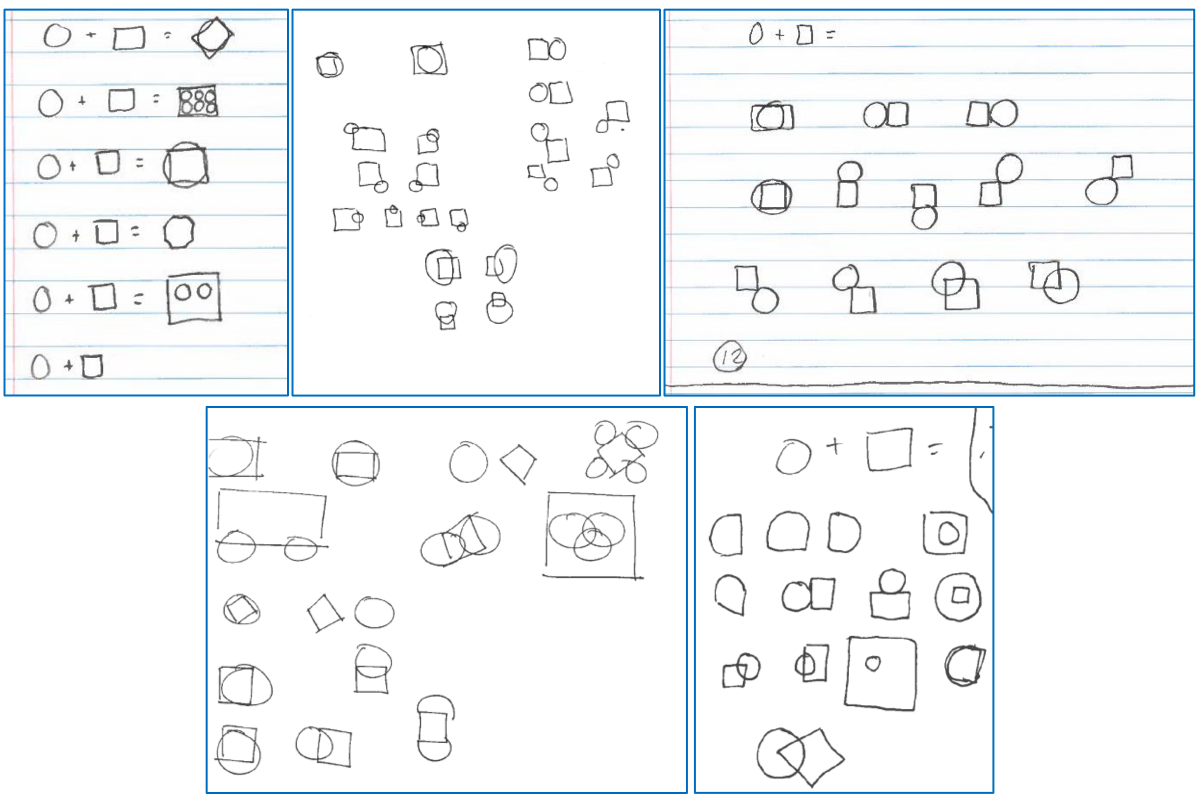
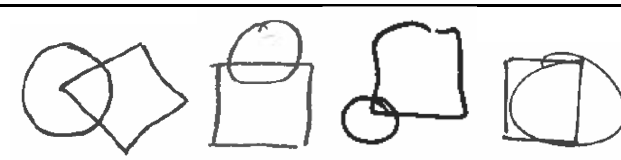
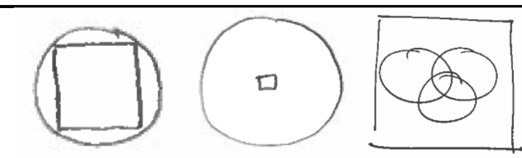
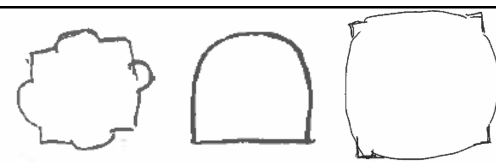
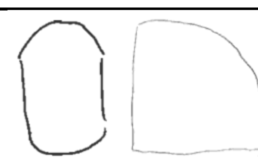
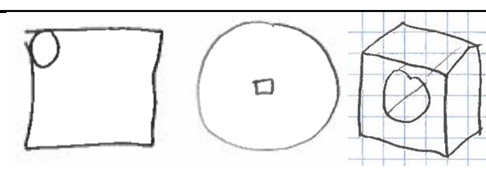
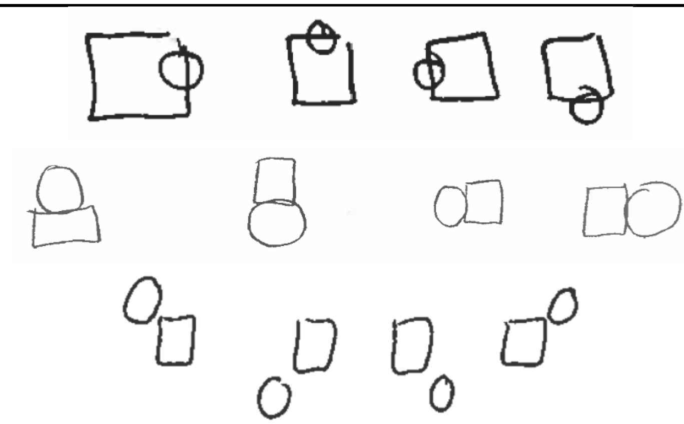
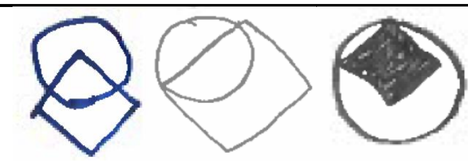
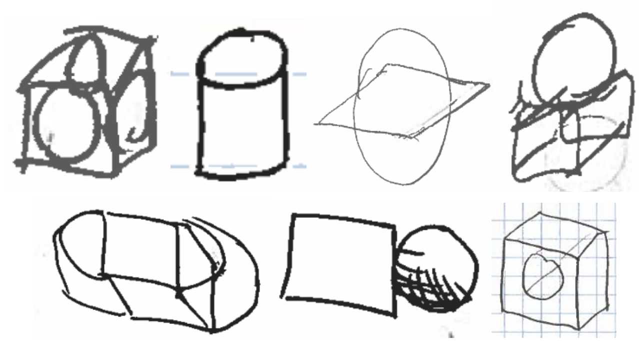
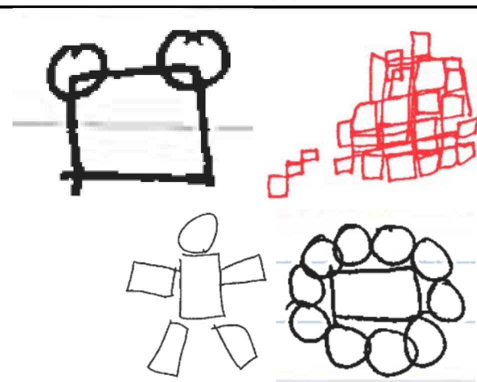


Fig. 2. Example pages containing students' solutions.

21 solution types, derived from all participant pages, are shared in Table II, comprising the total breadth of solution types across the data corpus. Note, any single solution might satisfy the inclusion criteria for more than one solution type.

TABLE II
IDEATION EQUATION SOLUTION TYPES, INCLUSION CRITERIA, AND EXAMPLES

Solution type and inclusion criteria	Example
only 1 square and 1 circle (3D shapes not included) (boolean add/sub not included)	
1 square and 1 circle INTERSECTING (overlap); boolean overlap? (not fully inside)	
1 square and 1 circle TOUCHING, not overlapped	
1 square and 1 circle NEAR each other (not touching, but clearly together as a solution)	
square or circle completely inside the other shape (including multiples)	
composite shape: boolean add (not like legos, no internal lines)	
composite shape: boolean subtract	(did not see an example in this dataset)
composite shape: boolean intersect (overlap shapes, get rid of area outside)	
# answers where SCALE of circle and square the DIFFERENT (3D included)	

rotated versions of other solutions (include the number of solutions that appear to be rotations of other solutions)	
a rotation of the square shape (different from how it was presented in the equation prompt)	
3D shape (could be planar or a volume)	
warped shape (context suggests intentional warping or skewing; excludes obviously 3D shapes that appear to be based on regular geometry)	
“squircle" (rounded square)	
more than 1 circle or more than 1 square (complete)	

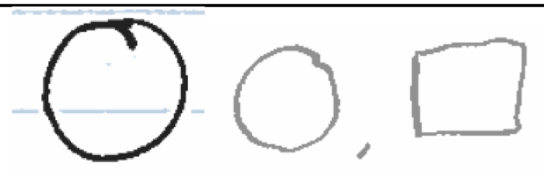
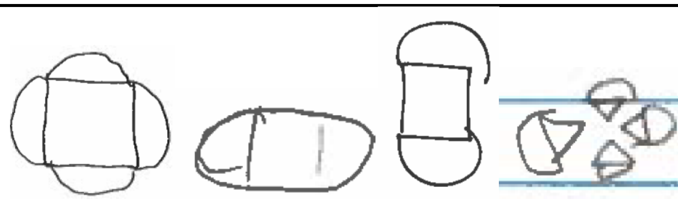
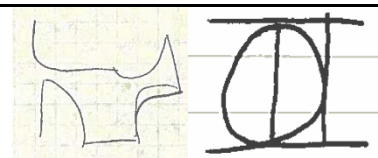
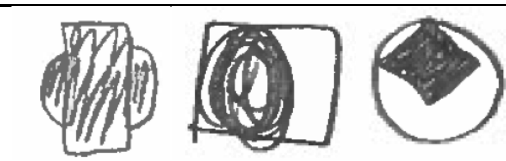
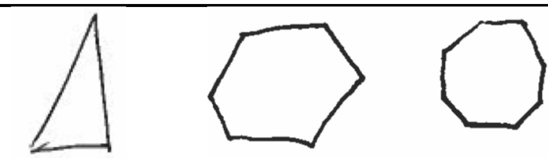
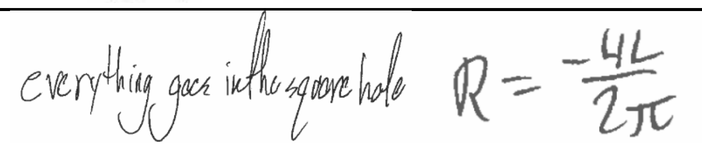
answer is ONLY a SINGLE circle or a single square (regular)	
shape built with CHOPPED shape(s) (different than boolean) (closed)	
PARTIAL shape(s) (different than boolean) (just lines, open)	
answers with colored-in (solid?) shape(s)	
other regular polygon (not an obvious boolean) (e.g., triangle, hexagon)	
text or math symbol answer	

Fig. 3 shows the normalized number of students producing a total number of solutions, separated by discipline. Notably, engineering students held the top two spots for having produced the highest total number of solutions (20 solutions, 16 solutions), as well as the lowest number of solutions (1 solution, 3 solutions).

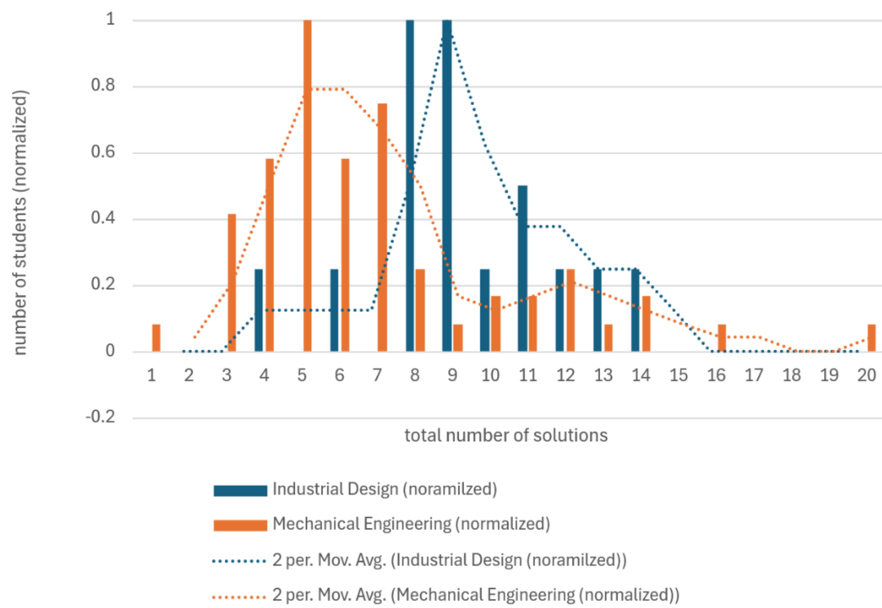


Fig. 3. Numbers of students with number of solutions, by discipline, normalized.

The distribution of numbers of solutions by discipline is shown in Fig. 4. For engineering students, the mean number of solutions was 6.96, with a standard deviation of 2.44. For industrial design students, the mean number of solutions was 9.31 with a standard deviation of 3.63.

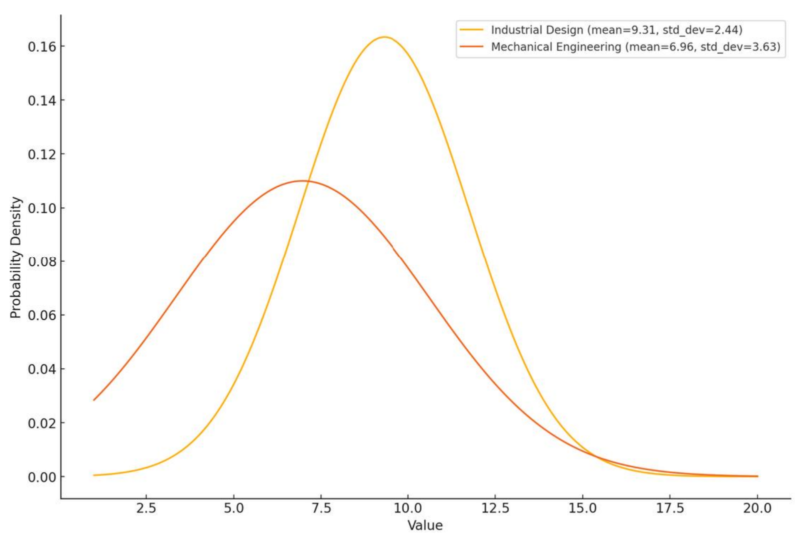


Fig. 4. Bell curve distribution of number of students with number of solutions, by discipline.

Fig. 5 shows the normalized number of students producing a total number of unique solutions, separated by discipline. Engineering students held the top spot for having produced the highest total number of unique solutions (11 unique solutions), as well as the lowest number of unique solutions (1 unique solution).

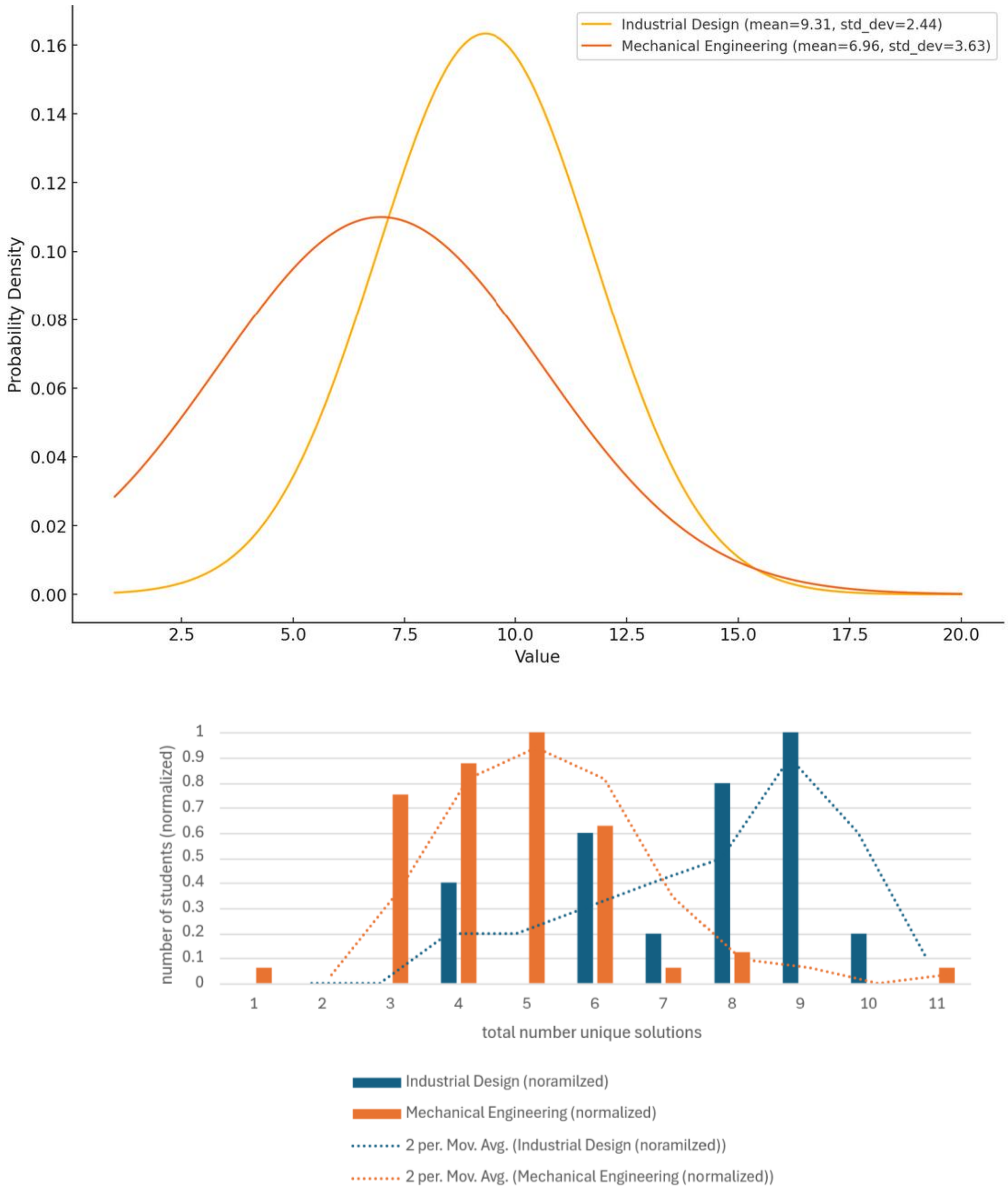
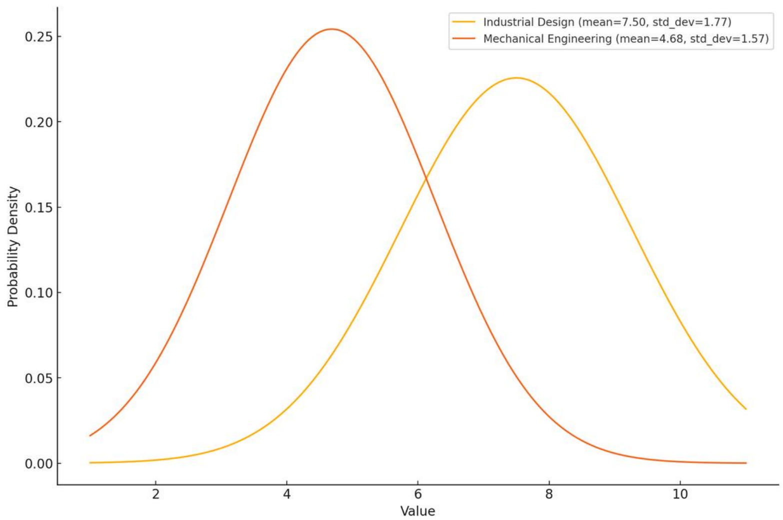


Fig. 5. Numbers of students with number of unique solutions, by discipline, normalized.

The distribution of numbers of unique solutions by discipline is shown in Fig. 6. For engineering students, the mean number of solutions was 4.68 with a standard deviation of 1.77. For industrial design students, the mean number of unique solutions was 7.50 with a standard deviation of 1.57.



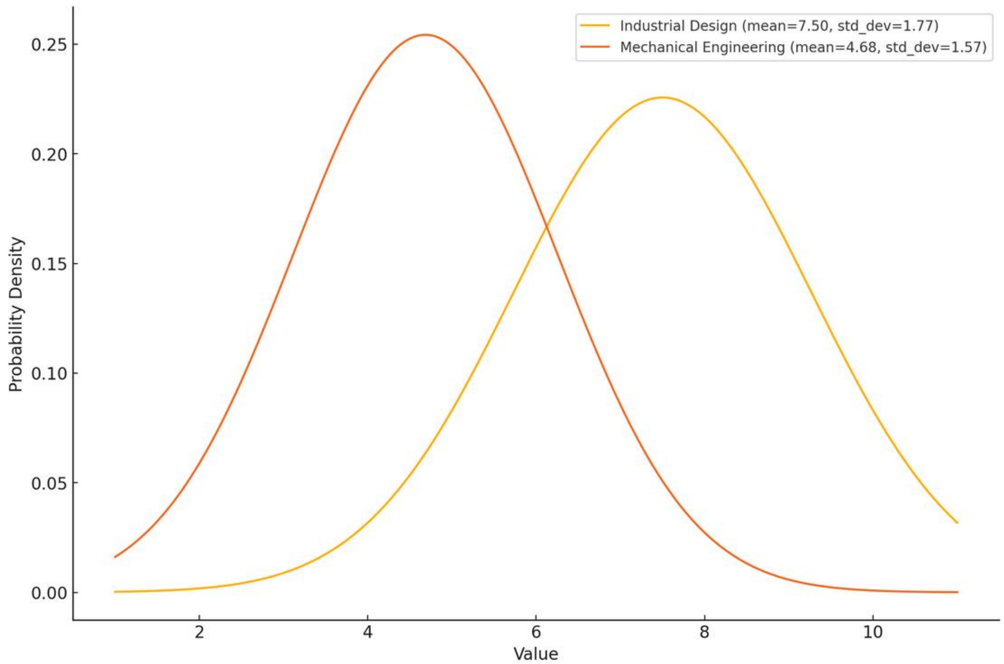


Fig. 7 shows the normalized number of students producing a particular solution breadth (equal to the number of solution types represented among all of their solutions), separated by discipline. Engineering students and design students held the top five spots for greatest solution breadth (breadths from 5 to 9). The lowest solution breadth for any design student was 5, while the lowest solution breadth for any engineering student was 1.

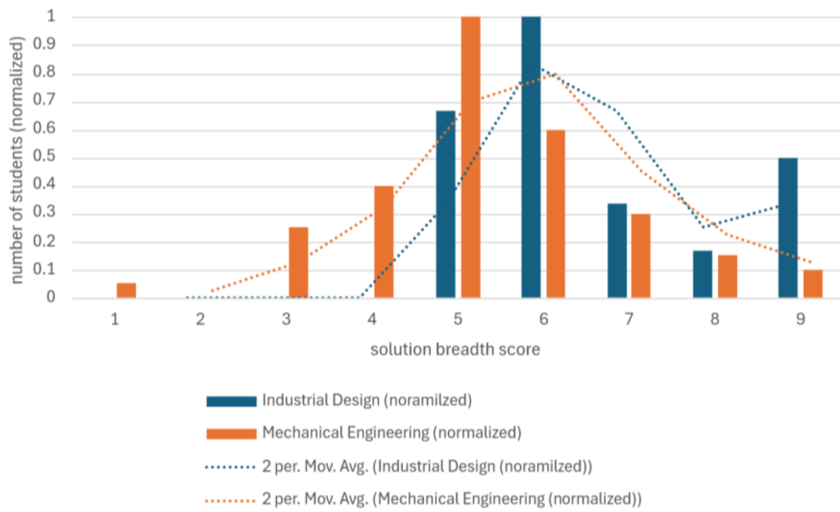


Fig. 7. Numbers of students with solution breadth values, by discipline, normalized.

The distribution of numbers of students with varying solution breadths by discipline is shown in Fig. 8. For engineering students, the mean solution breadth was 5.33 with a standard deviation of 1.53. For industrial design students, the mean solution breadth was 6.56 with a standard deviation of 1.41.

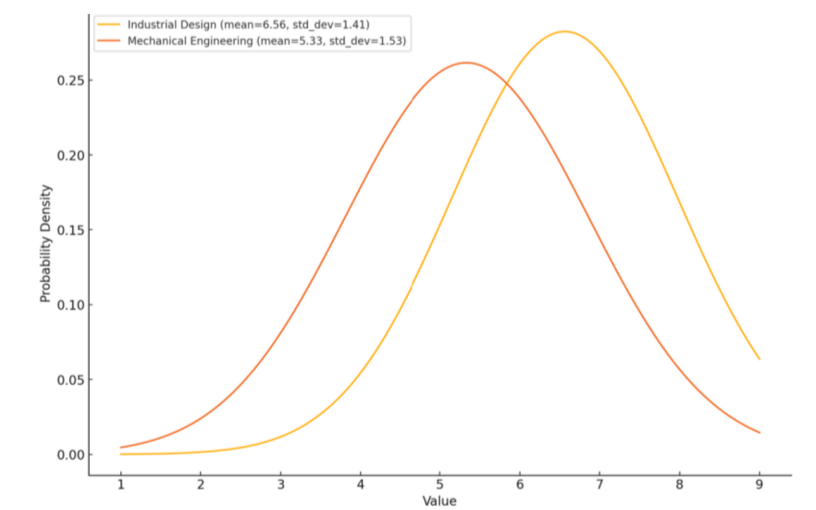


Fig. 8. Bell curve distribution of number of students with solution breadth, by discipline.

Fig. 9 shows the normalized number of students producing solution sets with a range of ideation impact values (equal to the number of unique answers multiplied by solution breadth) ranging from 1 to 81, separated by discipline.

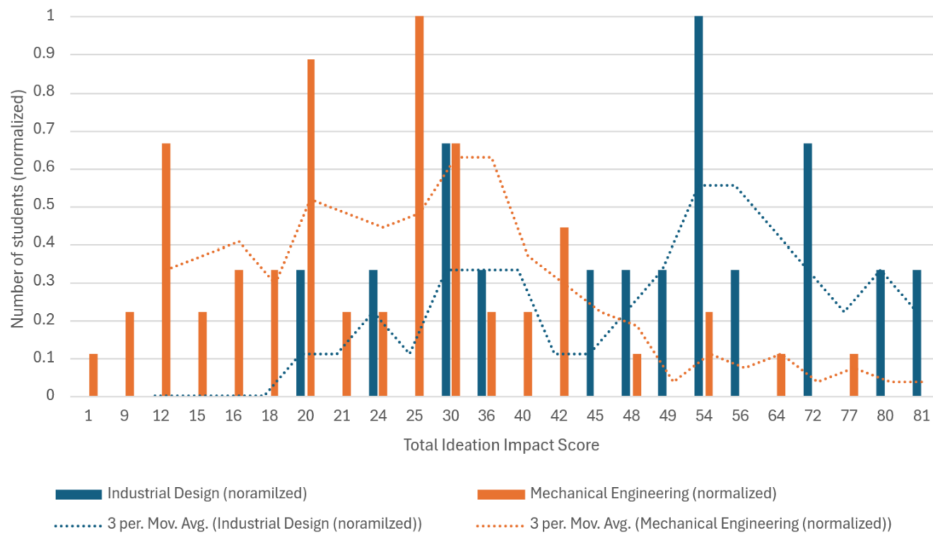
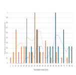


Fig. 9. Numbers of students with ideation impact values, by discipline, normalized.

The distribution of numbers of students with varying ideation impact values is shown in Fig. 10. For engineering students, the mean ideation impact value was 26.23 with a standard deviation of 14.06. For industrial design students, the mean ideation impact value was 50.31 with a standard deviation of 18.56.



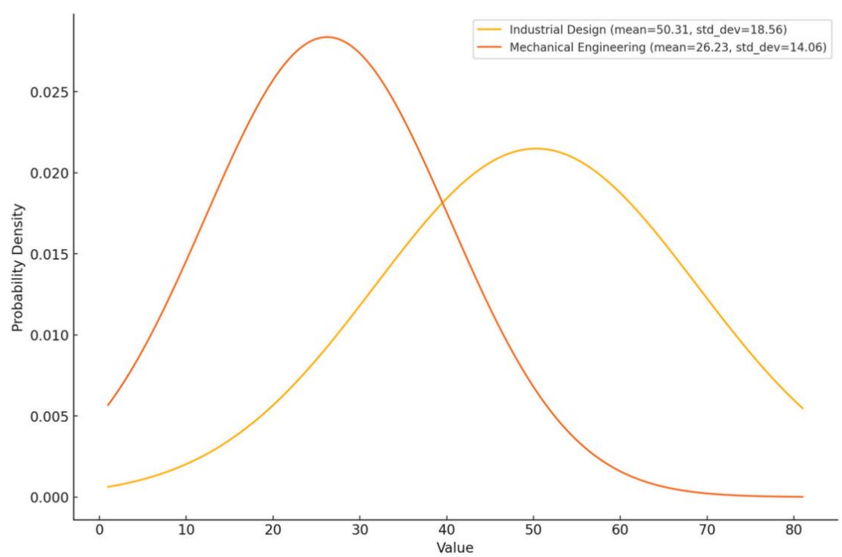


Fig. 10. Bell curve distribution of number of students with ideation impact values, by discipline.

These results reveal several notable patterns in how mechanical engineering and industrial design students approach ideation, addressing both of our research questions, which we explore in the following discussion.

Discussion and Conclusion

The *Ideation Equation* revealed both similarities and differences in how mechanical engineering and industrial design students approach idea generation. Several patterns emerge from the analysis that carry implications for characterizing and supporting creativity across disciplines.

First, both mechanical engineering and industrial design students demonstrated a capacity for divergent ideation. While the distribution of total and unique solutions was higher for industrial design students on average, some mechanical engineering students produced output comparable to or exceeding that of their industrial design peers. This finding challenges assumptions that engineering students are inherently less creative, aligning with prior work suggesting that creativity can be activated across technical and design disciplines when structured opportunities are provided [4,5]. The data supports a view that capacity for ideation exists across domains, though it may manifest differently.

Second, the character of ideation differed between groups. Mechanical engineering students more frequently produced rotated or minor variations of prior solutions, suggesting a depth-first approach that explores permutations within an idea space. Industrial design students, in contrast, tended to generate broader, more distinct solution types, consistent with breadth-first exploration strategies emphasized in design education [3]. These tendencies highlight different disciplinary mindsets toward idea generation: optimization and refinement versus expansion and exploration.

Third, the derived *Ideation Impact* metric—calculated as the product of unique ideas and solution breadth— potentially alongside *Marginal Ideation Impact*, provides a useful lens for understanding creative productivity. While industrial design students had higher average impact scores, the spread among mechanical engineering students indicates that individual variability is substantial. Future refinements of the activity could include weighting different types of solutions or tracking the progression of ideas over time, particularly identifying inflection points where ideation slows.

This study is an initial exploration with limitations, including small and uneven sample sizes between majors. Further validation is needed to assess the reliability of the *Ideation Equation* as an assessment instrument, including correlation with existing creativity measures such as CEDA [1]. Future work may also explore sequencing activities to capture both initial fluency and longer-term idea development, linking this short intervention with larger-scale brainstorming tasks and extending into project-based coursework, and possibly exploring its use as an assessment tool for forming interdisciplinary project teams.

Ultimately, the *Ideation Equation* offers a lightweight method for making idea generation visible, actionable, and comparable across disciplines. By characterizing how students from different fields generate ideas, educators can better tailor interventions that nurture diversecreative approaches in engineering and design education.

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