Uncovering Generative Design Rationale in the Undergraduate Classroom

Molly H. Goldstein
Industrial & Systems Engineering
University of Illinois
Urbana-Champaign, USA
mhg3@illinois.edu

James Sommer
Industrial & Enterprise Systems Engineering
University of Illinois
Urbana-Champaign, USA

Natascha Trellinger Buswell
Mechanical & Aerospace Engineering
University of California, Irvine
Irvine, USA

Xingang Li
Walker Dept. of Mechanical Engineering
University of Texas at Austin
Austin, USA

Zhenghui Sha
Walker Dept. of Mechanical Engineering
University of Texas at Austin
Austin, USA

H. Onan Demirel
Mechanical, Industrial & Manufacturing Engineering
Oregon State Universityline
Corvallis, USA

***Abstract*—This work-in-progress, set in the context of an introductory design and graphics course, explores student reasoning when tasked with choosing a "best" option among solutions developed from a CAD-based generative design solution space. Students tend to cite rationalistic reasoning in design decision-making, rather than relying on intuition or on empathy for users. Future work will explore the relationship between traditional undergraduate engineering design task decision-making and generative design decision-making.**

Keywords—engineering design, design cognition, design rationale, generative design

I. Introduction

We are now at the advent of a new era of design thinking, revolutionized by the introduction of generative design. Generative design allows designers to work from the objective space back to the parameter space while utilizing machine learning and artificial intelligence (e.g., genetic algorithms) to automate and consequently expedite the divergent thinking process. In addition to saving time, platforms with generative design capabilities are often able to produce more diverse results, rather than allowing design fixation to which many undergraduate students fall victim [1]. While generative design is able to produce impressive outcomes, this change in the design process also requires a designer to possess a different skillset and mindset.

The objective of this study was to understand the thought process of undergraduate students in the context of generative design. Generative design simulations often produce numerous viable outcomes along the Pareto frontier, or optimal solutions set, which may require complex reasoning behind student decisions. This reasoning was analyzed using the framework set by Sadler & Zeidler [2] in hopes of better understanding this evolving facet of engineering design. We hope the data from this study will serve to update and improve how engineering design is taught in a classroom.

II. Background

A. Generative Design

Generative design aims at creating new design processes that produce spatially novel yet efficient and buildable designs through exploitation of current computing and manufacturing capabilities [3]. Generative design is the process of using algorithms to help explore the variants of a design beyond what is currently possible using the traditional design process [4]. Industry is embracing the potential for generative design capabilities. For example, airplane manufacturer Airbus used generative design to create an alternative to their current interior partition for their A320 aircraft, coming up with an intricate design that reduced the weight of the part by 45% [4]. This weight reduction resulted in a substantial reduction of jet fuel consumption and, as a result, a reduction in hazardous air pollutants. In general, companies investing in generative design technology see a promise to "reduce component mass, improve the performance of their designs, minimize manufacturing process time and help them create new products that are suited to the next generation of customer who's concerned more than every with customization and uniqueness" [4].

B. Design Rationality

Designers have a bounded rationality [5]. Bounded rationality refers to the intrinsic inability of human beings to accurately choose "rational" options prescribed by decision models such as expected utility.

With generative design engine as an AI assistant, the design space can be much further explored and more information can be provided for designers' decision-making. Therefore, it is expected that designers would make more rational decisions with the presence of generative design.

III. Theoretical Framework

Previous work has investigated design rationale of students in classroom settings [6] and analyzed engineering decision-making [7] [8] [9] [10]. In this study, we explore design rationale in the context of generative design while utilizing the framework for assessing patterns of informal reasoning set by Sadler & Zeidler [2].

In this framework, open-ended responses are broken down into three categories: rationalistic, emotive, and intuitive, as well as accounting for the overlap of the three as depicted in Fig. 1. This framework was developed to understand emergent patterns of integrated reasoning regarding socio-scientific issues in undergraduate students.

We employed this framework to understand students' reasoning because design decisions, much like socio-scientific decisions, are multifaceted and lack a single correct answer.

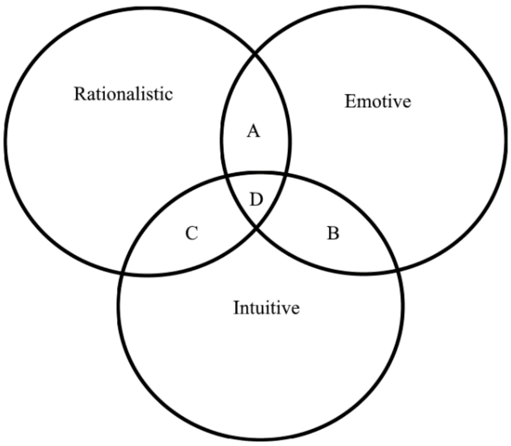

Fig 1. Emergent patterns of integrated informal reasoning with overlapping patterns [2]

IV. Methods

A. Participants and Design Task

This work-in-progress study took place in an introductory design and graphics course at a large, land-grant university in the Midwest United States and is a required course for agricultural and biological, industrial, and systems engineering students. This course aims to introduce students to the design process, including communicating design ideas generated through hand-sketches and produced in the CAD platform, Fusion360. Students engage in the human-centered design process in a semester-long team design project.

As part of the course, students complete nine individual modeling assignments (MAs) in order to learn Fusion360. The final assignment, MA9, served as an introduction to generative design and stress analysis and was a required assignment. MA10, an extra credit assignment, investigated students' generative design thinking through how they approached an open-ended engineering scenario. Nineteen students of the total 80 students in the course opted to complete the extra credit assignment during the Spring 2021 semester.

B. Data sources & Collection

Our research and pedagogical approach consist of tasking students to employ generative design thinking in a product design scenario. As part of this assignment (MA10), students review a set of generative design solutions and make their recommendation regarding which solution within the set is "best" (The Generative Design Rationale Task). In Part 1 of this extra credit assignment (MA10), students acted as design engineers working to create a lightweight bracket with which a consumer would mount a bicycle to a wall (see Fig. 2).

Fig 2. Context for MA10, generative design extra credit assignment

They were given the critical parts of the wall-mount bicycle bracket (See Fig. 3-4) and asked to hand-sketch the structure that would connect these four features. The bike bracket was chosen as it is a simple and easily recognizable product with nonplanar features that would encourage unique and novel solutions from each student. These sketches served to depict a standard baseline engineering approach to product design.

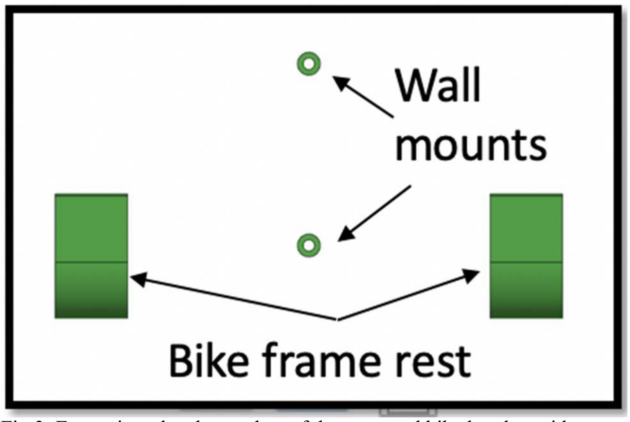

Fig 3. Front view sketch template of the proposed bike bracket with preserve geometry (green)

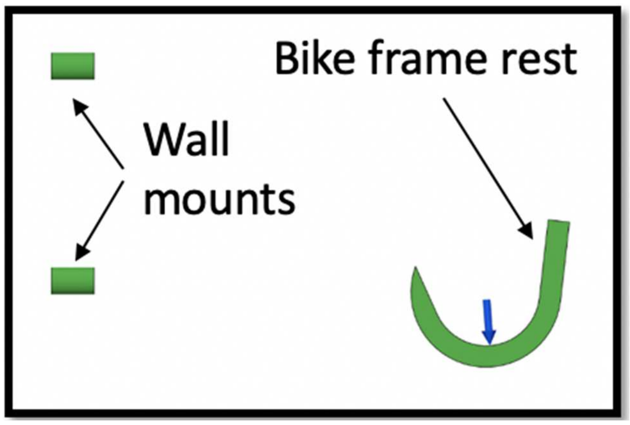

Fig 4. Side view sketch template of the proposed bike bracket with critical features (green) and applied force (blue)

Next, in Part 2 of MA10, the students were presented with five generative design solutions of various materials (ABS Plastic, Aluminum, and Stainless Steel) created in Fusion360 based on the critical features used in Fig. 2 and Fig. 3. Renderings of the five outcomes were presented alongside a table (see Appendix) of the respective properties, including material, median piece part cost, volume, mass, max von Mises stress, minimum factor of safety, and maximum global displacement. The students were then asked the following questions in order to assess their generative design solution trade-off rationale:

> *Q1: Imagine you ran this scenario through the Generative Design feature of Fusion 360 to find a starting place for your design process and the following designs were produced* (see Appendix). *Based on the figures and table above, which design do you think is the best starting place?*
>
> *Q2: Rank the seven outcome characteristics from most (1) to least (7) important (keeping in mind*

that these designs are a starting place, not a finished product) and explain:

Q3: How did your design from Part 1(hand sketch) compare to the computer-generated design? (What did the generated designs do well, and what could they improve on?)

C. Data analysis

A research assistant collected all student responses from the course learning platform, compiling them into one spreadsheet, with all responses numbered and anonymized. We took a qualitative approach to thematically analyze all student response to the open-ended Generative Design Rationale Task, using Sadler & Zeidler's informal reasoning framework [2] This descriptive coding technique [Creswell, 2014] allowed us to categorize each student response as rationalistic, intuitive, emotive, or a combination of these categories. Rationalistic responses used logic to justify their decision, sometimes describing the pros and cons of an option. Intuitive responses were "gut-feeling" responses and often focused on one feature of the design such as aesthetics (e.g., "It looks better.). Emotive responses reflect students considering others and either included a reference to users or phrases such as "I feel…"

Two authors coded all of the students' responses to establish inter-rater reliability. The reliability [Miles & Huberman, 1994] or agreement for Q1 was 18 out of 19 (95%), and for Q3 was 17 out of 19 (89%). The two researchers discussed the disagreements before reaching a consensus.

V. Results & Discussion

A. Selection & Description of "best" option

Results from Q1 *"Based on the figures and table above, which design do you think is the best starting place*?" shows that design #5 was the most commonly cited answer, accounting for 42% of the responses and design #1 and design #4 accounting for 5% each (or one response each). Fig. 4 shows a pie chart representing student responses. (Please see the appendix for a visual of the five designs as well as the performance metrics table.)

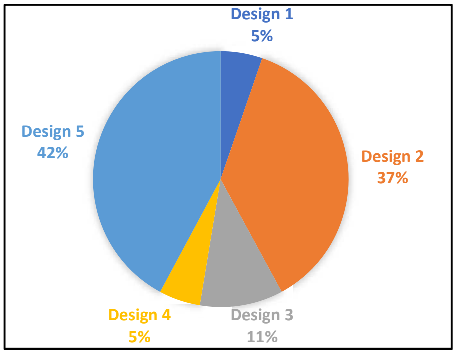

Fig 4. Student response to "best" design solution

Results from coding the open-ended rationale for students' selection were predominantly rational (18 of 19 responses) with one response rational and emotive). One student displayed emotive thinking. This participant described one design "caught [their] eye" and described how they "feel having such a high factor of safety" was valuable.

Participant SP21B_028 - Rational and Emotive:

"When looking at the table I notice that there are a wide variety of factors that can influence the decision of which design to pick for the best "starting place". When I think of a "starting place", I think of a design that is only in the early stages of development and has a long way to go until it reaches the shelves and eventually the hands of the consumer. This means that in order for a design to be a good "starting place" it must have lots of potential for positive growth. After glancing at the minimum factor of safety column I see a wide array of different values for each design which was rather surprising to me at first since the designs looked oddly similar. ***One design that caught my eye in particular was design number 5 with the highest safety rating by far with 102 almost doubling stainless steel the closest competitor. I feel having such a high safety rating will allow for design number 5 to have lots of potential if it ends up undergoing further product analysis and design. Its median piece part cost is only in the middle of the five designs which is also promising if this design is meant to be mass produced."***

Most design problems have multiple solutions that require trade-offs [11]. The generative design scenario presented to students did not have an obvious solution, and students cited reasons to select each of the five options. In addition, open-ended student responses were predominantly rational (rather than intuitive or emotional). This might make sense because the 100-level students are beginning designers [12] and might not have much intuition or heuristics [13] to lean on. However, in weighing both the pros and cons of the various designs, students are exhibiting growing informed design behaviors [12].

B. Outcome characteristics ranking

Students cited various rankings in how important each criterion was in making the selection of the "best" design alternative (Q3), as shown in Fig. 5. As shown in the table, students cited safety factor as most important (9/19 responses).

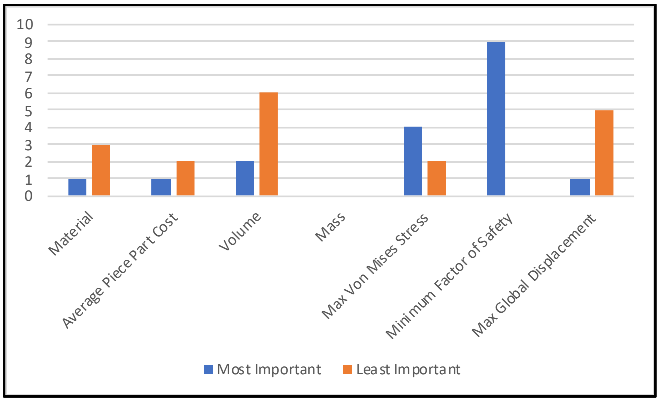

Fig 5. Student rationale category ranking

Most responses to Q2 were rational with a couple responses including elements of emotive or intuitive thinking. The emotive response considered how safety is an important factor in order to ensure that no one gets hurt. The intuitive response described again relying on "feelings" when describing their decisions.

Students cited the safety factor as the most important characteristic in selecting their top design option. In the context of a generative design assignment, it is particularly interesting that students were not apt rank volume or price as both of these characteristics, as the desire to minimize volume and price have been driving the development of generative design technologies [4].

C. Student comparison of sketches to generative design

Results from Q3 “How did your design from Part 1 compare to the computer-generated design? (What did the generated designs do well and what could they improve on?)” showed that all students cited rational responses with six students discussing intuitive reasons in addition to rational and one student citing emotive reasons in addition to rational. While the responses to Q3 again were mostly rational, they included the most elements of intuitive thinking of all the questions. Participant 28 even acknowledges the difference between the computer and themselves as a designer is that the human is able to rely on intuition “without any sort of calculations or tests." The second example response from participant 30 emphasizes how humans and computers can work together in order to find the best solution.

Participant SP21B_028 - Rational and Intuitive:

"My design was somewhat similar to the computer generated designs that were shown above. One key similarity that I'm pretty sure designs 1 through 5 and my design all had in common was a singular or multiple supports between the top and the bottom points. This means that the two points that would in theory connect to the wall have some sort of support connection between the two of them for increased stability. Besides that, ***one key difference is that the computer generated designs were much more complex and had a higher number of different support beams going from the vertical points to the hooks that connect to the bike frame. I'm guessing this is because the computer is doing a pretty intense analyzation of the situation while I'm just coming up with something that I "think" will work without any sort of calculations or tests."***

Participant SP21B_030 - Rational and Intuitive:

"My design from part 1 was fairly similar to the computer generated design. The computer generated designs are a very interesting tool. I believe that the greatest value added by the designs that the computer generated was that they bring an entirely new perspective through which to look at solving the problem. Not only does the computer present something that helps guide the user towards what the most viable solution might look like, but more importantly the generated designs can help the human mind to look at a problem from a completely different perspective. This sort of fresh perspective being presented can often spark novel ideas as to what components the design should incorporate, and how the design should look completely. Additionally, the ability of the computer to optimize the volume of the design provides valuable insight into what the solution can look like and function like at an optimal level. I think that where the computer-generated design is lacking is that it is unable to incorporate the logic and objective perspective that the human mind can bring to evaluating a design solution. ***Often times in engineering we want a solution to be clean, simple, and straightforward in its appearance and its function. The computer-generated models are not able to bring solutions with this sort of logic and often the things that the computer makes are impractical in their own complex way and strange aways. That is why it is important for the use of the generation to go hand in hand with human aided design. The generation can inform your design, but the designer must also have a critical perspective when evaluating which components of the generation should be incorporated, altered, or deleted altogether."***

In discussing their own designs as compared the computer-generated solutions, students still were rational but also relied on other intuition and feeling (empathy). This finding should be further investigated to understand the degree to which student involvement in the design process influences their engagement with decision-making processes.

VI. LIMITATIONS

While generative design education, such as in this study, holds promise to advance engineering student knowledge, there are some limitation for future consideration. The bike bracket is approachable, but might not lend itself to emotive responses. In addition, since this was an extra credit assignment we need to consider self-selection bias. It is feasible that the type of student who would do extra credit might also be more likely to be a rational thinker.

VII. CONCLUSIONS & FUTURE WORK

This work-in-progress suggests that students are likely to cite rational reasoning in design decision-making between generative design solutions. When comparing their own sketches to the computer-generated solutions, students are still rational in their responses but might engage in intuitive and emotive thinking. Future work will explore the relationship between traditional undergraduate engineering design task decision-making and generative design decision-making. Perhaps the concept of design trade-offs or the elusive concept of the Pareto frontier might be effectively taught using generative design solutions and their visualizations?

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Appendix

MA10, Part 2

Imagine you ran this scenario through the Generative Design feature of Fusion 360 to find a starting place for your design process and the following designs were produced:

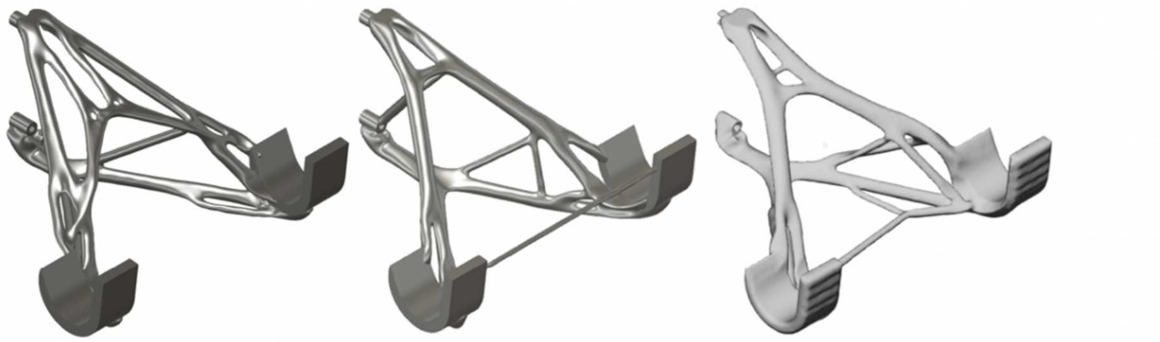

Figure 5a: Design 1, Stainless Steel *Figure 5b: Design 2, Aluminum* *Figure 5c: Design 3, ABS Plastic*

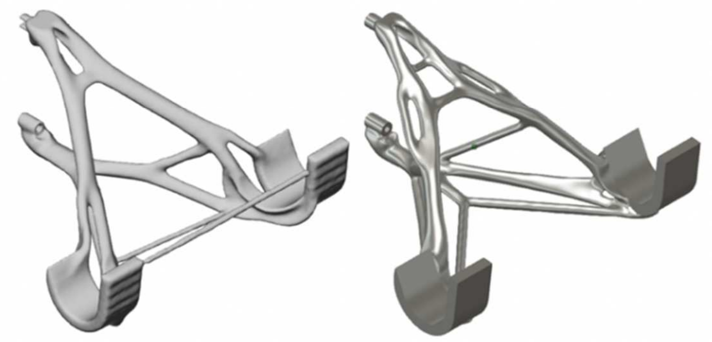

Figure 5d: Design 4, ABS Plastic *Figure 5e: Design 5, Aluminum*

Table 1: Describes each of the five designs suggested through generative design

Design Number	Material	Median Piece Part Cost*	Volume (cm^3)	Mass (kg)	Max von Mises Stress (MPa)	Minimum factor of safety	Maximum global displacement (mm)
1	Stainless Steel	6.60x	556	4.5	3.2	67.5	.02
2	Aluminum	3.14x	552	1.5	5.5	43.5	.03
3	ABS Plastic	1.01x	563	.6	2.5	8	1.38
4	ABS Plastic	x	564	.6	5.7	3.5	1.25
5	Aluminum	2.6x	559	1.5	2.4	102	.05

*scaled to show relative median piece part cost

Based on the figures and table above, which design do you think is the best starting place (minimum 200 words)?