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Building Confidence and Embracing Failure Through Sketching Practice*

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There is a growing movement in engineering for students and practitioners to learn to embrace failure and develop resilience. The design process is inherently full of iteration and failures that can be leveraged as learning opportunities for students. This paper presents a preliminary study that introduces a sketching practice intended to provide students with opportunities to experience low-stakes failure and space to build their confidence in sketching. The study analyzes the resulting sketches for attributes such as line smoothness, accuracy/proportion, and understandability to identify potential links with sketch confidence and student perspectives on failure. 47% of students reported finding the sketching activity to be effective in making them feel more comfortable with failure. The study found that students' sketch smoothness showed signs of improvement during the course of the class and students' confidence in sketching increased. Additionally, the study found that women were initially more confident in sketching but men experienced greater growth in confidence over the course of the class and bridged that confidence gap. This gender difference persisted in sketching performance as well, as women scored higher in sketch smoothness and proportion/accuracy.

Keywords: sketching; design education; engineering confidence

1. Introduction

Sketching is a key tool for representing, exploring, and sharing a designer's thinking. This paper investigates how the way a designer sketches might capture or reflect the mindset of the designer. The central focus of this study is to understand how changes in physical aspects of a sketch due to repeated practice can offer insights into a student's confidence in sketching as well as their openness to failure.

Sketching is an essential tool that designers and engineers use to represent design ideas, think through these ideas and share them with others [1]. The quantity and timing of sketching in early stage design has been shown to be linked with design outcomes [2–5]. Engineering students are often well prepared in high school in subjects such as math but may feel more hesitant about sketching and drawing [6, 7].

Many undergraduate engineering students have been conditioned to value success and avoid failure [8]. Often, high achieving students experience their first real failures at the college level, realizing their hardest efforts may not be enough to match the academic performance they had in high school, or discovering a class project isn't working as planned. Especially troubling is that girls tend to have a greater fear of failure, a gap that widens among top-performing students [9]. Literature shows that experiences with failure are associated with guilt and shame [10, 11], quitting [12], and lower expectancies of future success [10]. However, learning to embrace failure is imperative for personal growth. Traditional approaches towards failure often target student self-confidence or beliefs about their intelligence, but several studies recommend instead allowing students to experience failure firsthand in the context of their learning environments [13]. Learning from failure is essential in tackling new problems, especially the problems engineering students hope to solve at the cutting edge of industry practice and academic research.

One key component of undergraduate engineering curriculum, as outlined by ABET accreditation criteria, is to give students experience with the design process [14]. Iterating on ideas through sketching and prototyping is an essential part of the design process [15, 16]. In order to iterate on concepts, however, designers must acknowledge that there is room for improvement in their ideas.

Prior research considers how students respond to failure in engineering design settings [8]. Fear of failure has been correlated with low engineering design self-efficacy [17]. Students as young as elementary and middle school struggle with receiving feedback and may perceive it as a sign of failure [18]. However, experiences with design at an early age have been successful in transforming student attitudes towards embracing failure [13, 18].

This preliminary study seeks to better understand the links between regular practice with sketching and sketch confidence and perceptions of personal or professional failure. In particular, we hypothesize that repeated practice with sketching builds confidence in sketching, which in turn may make students more comfortable with failure. The study

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outcomes measured include physical attributes and quality of sketches as well as student enjoyment and self-confidence in sketching and design.

The aim of this study is to determine the impact of opportunities for failure that are embedded into the instruction of design skills. The study investigates how repeated practice with sketching might be linked with sketch quality and student confidence as measured by self-reported measures and by changes to their sketching styles, particularly in the line smoothness of sketches. Colloquially, smooth lines in sketching are often also described as "confident." However, this link between sketch confidence and sketch smoothness is not well documented in the literature. Research from the field of industrial design shows initial results that a bold industrial design sketching style is perceived as being more confident, whereas the fine art "feathering" style of sketching is seen as less confident and more hesitant [19]. Even though both styles of sketches are high in proportion/accuracy and are high in quality, the smooth, bold lines are associated with high confidence. That study also examined the role of gender in sketching and found a significant difference in this sketching style and confidence – women were more likely to use the "feathering" style and have sketches perceived as less confident, whereas men were more likely to have sketches that were perceived as more confident with smooth, bold strokes [19].

This study presents a novel sketching exercise that is designed to provide students experience with repeated low-stakes failure through the introduction of a sketching exercise. In this exercise, students sketch the same object in 5 seconds, 30 seconds, and 2 minutes. Students quickly learn that no one's 5-second sketches look good, so they are freed from some of their initial inhibitions when attempting that sketch. Furthermore, this exercise is repeated during every class in order to ritualize the experience of sketching.

This intervention was presented as one of a series of interventions in an introductory design course [8]. The other failure-related interventions included a "failure seminar" speaker series of guest speakers from the university who shared experiences of personal or professional failure and a "mistake museum" where students exhibited failed prototypes.

1.1 Research Questions

RQ 1: What physical elements of sketches change due to regular practice with sketching?

A variety of descriptors may be commonly used to characterize a line drawing, including accuracy/proportionality of the sketch, smoothness of lines, and ease of understandability [20]. The goal of this research question is to understand which, if any, of these physical elements shift due to regular practice with sketching. In this context, participants are not told that these elements are things to strive for-instead this question aims to determine which of these physical attributes changes naturally with more practice. In particular, we are interested in any changes in line smoothness as it is a seemingly less intuitive physical element of sketching but has been linked to perceptions of sketching skill and confidence [19].

RQ 2: Does regular practice with sketching correlate with changes in confidence in sketching, perceptions of failure, and sketch quality?

The goal of any kind of training or practice in a new skill is to build expertise and confidence in the skill. The goal of this research question is to determine if consistent practice with sketching for a short time period each time is enough to impact students' sketching skill and confidence in sketching. In addition, it aims to see whether regular experience with low-stakes failure through the sketching exercise impacts students' perceptions of failure overall. This question investigates whether experiences with failure in sketching permeate to students' mindsets beyond just the sketching exercise.

RQ 3: Are there gender differences in sketching confidence and performance in engineering design?

Work from an adjacent field, Industrial Design, indicates that there may be gender differences in sketching confidence and performance [19]. The goal of this research question is to determine whether these differences persist in engineering design as well. If there are significant gender differences in these metrics, it may have implications for engineering design training and instruction.

We expect that sketchers who are not confident in their sketching abilities will be hesitant in their line strokes, which will result in lines that are more wavy. Conversely, the lines of confident sketchers will be bolder and straighter. As such, we posit that increased line smoothness in sketching correlates with comfort and confidence in sketching. We hypothesize that regular practice with sketching through the sketching exercise will help build, even in a small way, confidence in sketching and beyond. It is possible that the repeated experience of sketching may help sketchers be more open to failure because they know that the failure is low stakes (a short drawing exercise with no grade) and will happen regularly (every class). Regular practice with sketching may also improve students' sketching abilities, both in line smoothness and proportion/accuracy, which may in turn influence their sketch confidence. The study also discusses effective practices for sketching and tracking design activity in virtual classes.

1.2 Background

1.2.1 Role of Sketching in Design

Prior studies show that sketching is a key part of the engineering design process and used by novices and practitioners alike to explore and evaluate potential design directions [21]. Prior research on the ideation process indicates that there are correlations between quantity of ideas sketched and eventual design outcomes [3]. Sketches considered to be higher quality have also been shown to be perceived as more creative concepts [22]. As such, there is motivation for emphasizing and practicing sketching in design courses.

Traditionally, engineering design courses teach sketching with a focus on drawing in perspective, dimensioning, and spatial visualization [23, 24]. These are typically done as a form of instruction with a small amount of practice built into the course.

Sketches are a key part of early stage design and several aspects of sketches have been previously shown to be linked with design outcomes [3, 25, 26]. Researchers have made efforts to evaluate sketch quality, especially for more refined sketches at later stages of design [27–32]. However, early design drawings can be more challenging to assess. Sketches in this stage include informal "thinking" drawings that help designers clarify their own design concepts and "talking" drawings that help designers communicate their ideas, as defined by Ferguson [1]. These sketches' rough nature may make them more difficult to analyze when compared with formal graphical representations like CAD drawings [23]. Since sketches from these stages are often used as communication tools in the engineering design process, it is important to consider what formal characteristics make them more effective for communication. To address this, our prior work established a metric using three aspects of early stage sketches [20]. This includes their mechanical aspects, in this case, line quality [27, 28, 32], their overall proportionality/accuracy [27, 28, 32], and their ability to communicate and be understood by others [1]. The line smoothness and proportionality measures are combined to represent the overall quality of the drawing while understandability is used to evaluate the effectiveness of the sketch as a communication tool.

1.2.2 Context and Value of this Study

This study proposes a new sketching practice that can be used to help students gain confidence with sketching and provide a vehicle for repeated low-stakes failures. The study analyzes physical aspects of the sketches to evaluate trends in sketch quality and student sketch confidence over time.

2. Methods

The course studied was an introductory level half semester design class for Mechanical Engineering undergraduates at a northeastern US university. The course is a team-based, project-oriented, hands-on design-and-build course that was taught in an entirely remote setting due to the COVID-19 pandemic. Seven men and twelve women were enrolled in the course and the primary course instruction team was three women. This course is one of several introductory design offerings that students in a flexible Mechanical Engineering track are required to choose from. The course is geared towards sophomore level students but had enrollment from students of all class years. Several students in the class had non-Mechanical Engineering majors or were undecided in their major. There are approximately the same number of men and women enrolled in the flexible Mechanical Engineering track overall. The primary methods of data collection were sketching exercises and surveys.

Sketching exercises: We introduced a novel sketching ritual to normalize the experience of sketching as part of the students' regular class routine. This was started even before any formal sketching instruction in the course. The exercise gave students a common touchpoint of engagement in the course virtually and turned sketch practice into a habit. Each lecture, students drew a simple pre-selected object from a photo three times: first in 5 seconds, then again for 30 seconds, and finally for 2 minutes. Through this exercise, the students learned how to quickly "see" an object and break it down into its essential parts. In addition to this exercise, basic sketching techniques were taught through around 30 minutes of in-class activities including one, two, and three point perspective, cubes, simple shading, and contour line drawing. This represents the more standard sketch instruction at our institution for engineering design courses [23, 24]. All student sketches were done in a Rocketbook, a paper notebook that allows students to easily upload a digital version of their drawings to a Google folder shared with the teaching team. This exercise was done a total of nine times with the first and last objects being the same in order to make comparisons. The objects for each day are shown in Fig. 1 along with examples of a 2-minute drawing of each object from the same student. Note that most of these drawings represent the high end of the sketch quality scale.

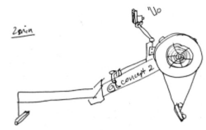
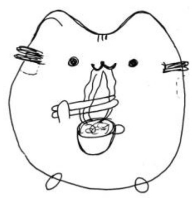
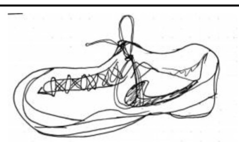
Lecture #	Object	Reference Image	Drawing
Lecture 1	Guitar		
Lecture 2	Kids' Alarm Clock		
Lecture 3	Hedgehog Stuffed Animal		
Lecture 4	Tea Kettle		
Lecture 5	Rowing Machine		
Lecture 6	"Pusheen" Stuffed Animal		
Lecture 7	Vertical Computer Mouse		
Lecture 8	Shoe		
Lecture 9	Guitar		

Fig. 1. Examples of 2-minute sketches from a high-scoring student from each day alongside the photograph the drawing was based on.

Table 1. Proposed sketching rubric showing the criteria and their definitions along with any relevant existing literature that contributed to the inclusion of the criterion to the rubric [20]. Example sketches of each criterion are shown in Fig. 1.

Sketching Criterion	Definition	Existing Literature
Line smoothness	How smoothly (lack of waviness) each line is drawn	[20, 27, 28, 32]
Proportion/ accuracy	How accurately each line is drawn relative to where it should be drawn	[20, 27, 28, 32]
Understandability	Can the rater easily understand what the sketcher tried to represent (without relying on words and descriptions)	[20]

Surveys: Students were given a pre-survey before the first class to collect demographic information and assess baseline attitudes, skill levels, and prior experience in design. A mid-course survey was used to assess attitudes and self-efficacy scores for sketching and design confidence. A survey at the end was used to assess overall changes throughout the duration of the class and answer specific questions about sketching activities in the class. Though the survey included many more questions, the relevant survey questions regarding their sketching skills and perceptions of failure are listed below.

In all surveys, students were asked the following:

- On a scale of 0–10, how confident do you feel in your sketching ability?
- How much do you enjoy drawing by hand? (5 options ranging from "Not at all" to "A great deal.")

In the end of course survey, students were asked about the failure related interventions (failure seminars, mistake museum, and sketching):

- How did [the Failure Seminars/Mistake Museum/Daily Sketch Practice] impact your attitude/perception of failure, if at all? (5 options ranging from "Made me much less comfortable with failure" to "Made me much more comfortable with failure")

To assess the quality of sketches from the in-class activity, a rubric was used with categories as shown in Table 1. The rubric was developed by the authors based on existing literature and a review of the characteristics of sketches generated by the students [20]. Sketches were assessed by three independent reviewers, including the authors and a graduate design student not working on this project. Each participant's sketches were rated on a scale of 1–5 where 5 was the highest score for line smoothness, proportion/accuracy, and understandability. The mode of reviewer responses for each sketch was calculated (or median, if there was no mode). Line smoothness and proportion/accuracy scores were taken to be representative of the "overall sketch quality." Examples of smooth and wavy lines are depicted visually in Fig. 2. An additional category of "understandability" was added to the sketching rubric to assess the ability of the sketch to serve as a communication tool. This category was not found in prior literature, but was added as a way of tracking the effectiveness of the sketch as a tool for communicating a concept. A total of 149 pages of sketches were rated for this study.

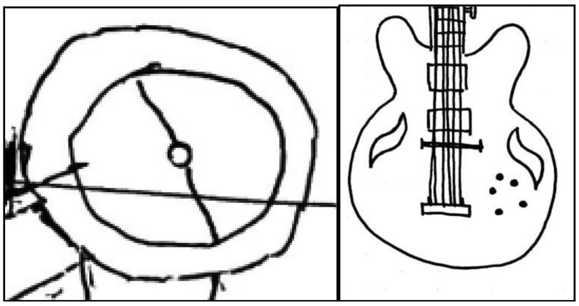


Fig. 2. Example of wavy (left) vs smooth (right) lines as defined by this study. The left sketch is a closeup of the flywheel of a rowing machine, and the right sketch is the body of a guitar.

Separately, the sketches from the beginning and end of class of the same object by the same student were anonymized and randomly ordered and evaluated by three independent raters to determine which sketch had smoother lines. The sketch for each student that was assessed as having higher smoothness by the majority of raters was noted.

The significance of changes in student confidence and sketching enjoyment scores were assessed using the Wilcoxon Signed Rank test due to the relatively small sample size and non-parametric nature of the paired student scores. Women and men's scores were compared using the Wilcoxon Rank Sum test.

3. Results and Discussion

Sketch quality was assessed on three metrics: line smoothness, proportion/accuracy, and understandability. Fig. 3 shows examples of 2-minute sketches that fit each rating level. Spearman's Rho was used to calculate correlations between attributes of sketches and overall outcomes due to the non-parametric nature of the data.

Sketches were assessed by three independent reviewers with a Krippendorff's alpha of 0.597. Krippendorff's alpha for inter-rater reliability was calculated using the open source tool ReCal [33, 34]. Landis and Koch's cut-offs can be used as a benchmarking guideline here to interpret that this alpha value signals moderate agreement between reviewers

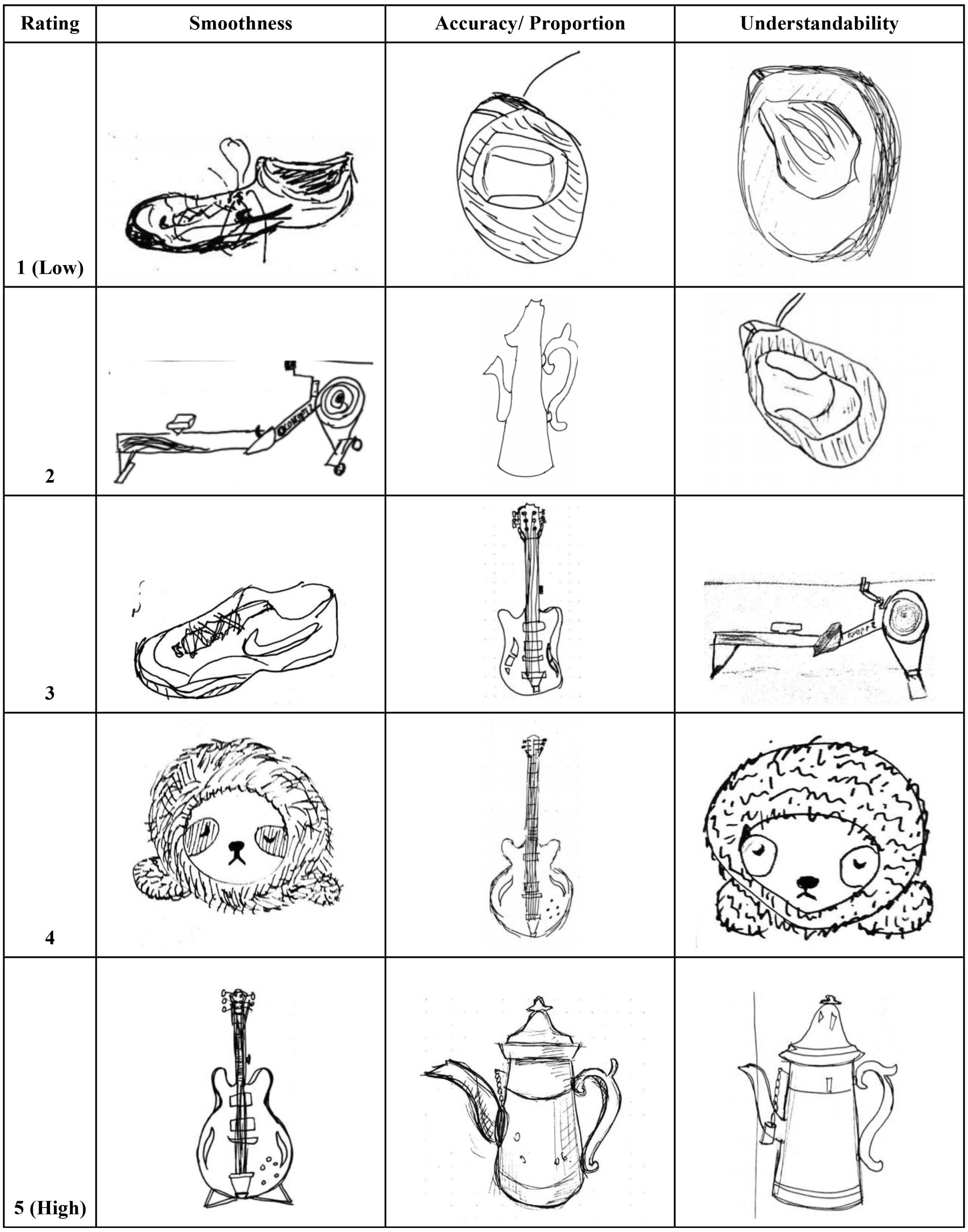


Fig. 3. Example 2-minute sketches that fit each scoring category. Ratings were on a scale of 1–5, where 5 is best.

[35]. As shown in Table 2, some objects, such as the vertical mouse, had inherently lower scores. This likely influenced the results as these more complicated objects tended to appear later in the term.

3.1 RQ1: What Physical Elements of Sketches Change due to Regular Practice with Sketching?

3.1.1 Changes in Sketching Over Time

Changes in sketch scores over time are challenging to quantify due to the differences in the objects that were sketched. The objects chosen for sketching later in the semester were assessed by the raters as being more challenging to draw. For instance, the vertical mouse (see Lecture 7 in Fig. 1) consistently received low understandability scores and had a median understandability of 2 as shown in Table 2. On the other hand, the guitar, alarm clock, and hedgehog stuffed animal were made up of simpler and more familiar forms and had median understandability scores of 4 and 5 as shown in Table 2.

The maximum understandability sketch score

Table 2. Median smoothness, proportion/accuracy, and understandability scores for each object

Object	Median Smoothness	Median Proportion/ Accuracy Score	Median Understandability Score
Guitar (First Lecture)	3	4	5
Kids' Alarm Clock	3	4	4
Hedgehog Stuffed Animal	3.5	4	4
Tea Kettle	4	4	5
Rowing Machine	3.5	3	3
"Pusheen" Stuffed Animal	4	4	4
Vertical Computer Mouse	3	3	2
Shoe	3	3	5
Guitar (Last Lecture)	3	4	5

could not be used for any correlation assessments as all students scored at least one 5 in that category. However, the number of sketches made by each student was negatively correlated with minimum understandability score ($r = -0.522$, $p = 0.02$). This means that students who drew less (had fewer sketches) tended to have lower minimum understandability scores (their least understandable sketches had lower scores). It is possible that an adjusted scoring system with greater granularity would reveal a similar trend at the maximum level. Prior work has linked sketch quantity to idea quality: these preliminary results indicate that sketch quantity may be linked with sketch understandability as well [3].

The sketches were split into two categories based on the midpoint of the course for further assessment. The first four sketches were grouped and the last five were grouped. Some student scores tended to decrease over time. Mean proportion/accuracy scores decreased from 3.72 to 3.41 with $p = 0.0012$. Mean understandability scores decreased from 4.49 to 4.28 with $p = 0.0061$. As discussed previously, this appears to be more of a factor of the objects than time. No strong correlations were found with smoothness scores using this rubric. Differences of smoothness for each student appear to be more granular than the intervals in the 5 point scale.

This is different from other studies that have found more profound differences in students' sketching abilities after sketching interventions in engineering design courses [24, 36]. However, our intervention did not involve additional sketching instruction, which is likely related to why we did not see marked improvements in sketching. Additionally, since the sketching tasks increased in difficulty over the term, it is possible that improvements in sketching skill are less visible as a result.

3.1.2 First and Last Sketch Direct Comparison

As reported above, there was no statistically significant change in sketch smoothness ratings on the 5-point scale over time, and sketch understandability and proportion/accuracy scores decreased slightly. In order to assess each student's change in sketching, side by side comparisons were made of each student's sketches of the same guitar from the beginning and end of class, an example of which is shown in Fig. 4. This comparison was made for every student who completed both guitar sketches, which was 11 of the 19 students.

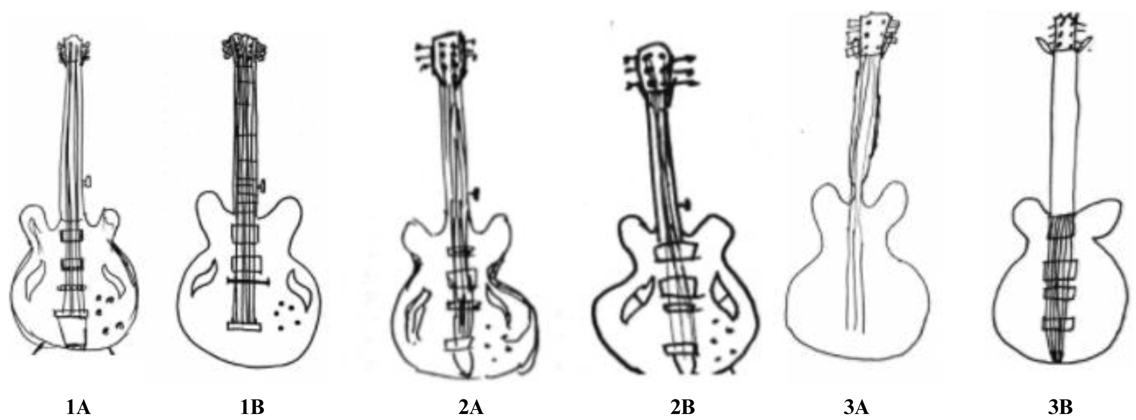


Fig. 4. Three students' (#1, #2, and #3) drawings of a guitar. A: Drawings from the beginning of class. B: Drawings from the same student at the end of class. Note that the line smoothness increases for all sets from A to B despite varied levels of demonstrated sketching proficiency.

Paired comparisons of student sketches of this same object from the first and last classes were conducted to determine what aspects of the sketches changed. Raters scored the sketches on a variety of metrics, including line fluidity, number of strokes, and level of detail in addition to the metrics used to assess sketch quality. None of these other metrics showed a consistent pattern and the proportion/accuracy and understandability of daily sketches also remained consistent. However, the smoothness of lines in sketching increased, even though line smoothness was not something explicitly taught or emphasized during the course. Each student's pair of first and last sketches was randomized for order and compared. Subsequently, the sketch assessed as having higher smoothness by the majority of raters was noted. These sketches were assessed by 3 independent raters with intermediate to good inter-rater reliability (Randolph's free-marginal Kappa score of 0.52). 91% (10 of the 11 sketches) assessed as having smoother lines were from the sketches at the end of the course. These results along with those described in Section 3.1.1 indicate that sketch smoothness increased slightly over time, but not to an extent that was perceptible in the ratings on the 5-point scale. It is possible that these incremental improvements would become more pronounced over a longer time period.

Comparing between the two guitar drawings for the students who completed both sketches, the average smoothness score (3.5) and median smoothness score (3) stayed the same. Average accuracy/proportion scores decreased slightly (from 3.7 to 3.6) but median accuracy/proportion scores stayed the same (4). All guitar sketches received scores of 5 in understandability, again appearing to be a feature of the object rather than the quality of the drawing.

These results are more in line with other studies that have seen improvements in students' sketching abilities after sketching interventions [24, 36, 37]. Indeed, some of these studies also had students sketch the same object at the beginning and end of the course in order to determine improvements in students' sketching skills, though we also find the limitation that the degree of improvement is difficult to quantify [37].

3.2 RQ 2: Does Regular Practice with Sketching Correlate with Changes in Confidence in Sketching, Perceptions of Failure, and Sketch Quality?

The average student confidence in sketching increased from 5.0 to 6.7 (on a scale of 0 to 10) over the duration of the class, with $p \leq 0.05$. This is in line with results from other studies that have found that emphasis and practice with sketching in engineering design courses leads to increased confidence in sketching [36]. This points to the importance of integrating sketch practice within design courses early in students' trajectory such that they become comfortable and confident with sketching and continue to use it throughout their engineering design experiences.

Students' pre-course sketching confidence scores correlated with their median proportion/accuracy scores ($r = 0.727$, $p = 0.0004$). This may indicate that initial sketch confidence could be linked with what is typically considered drawing skill (is the object proportional? does it look accurate?). Students' post-course sketching confidence scores correlate with both their median proportion/accuracy scores ($r = 0.553$, $p = 0.01$) and their median understandability scores ($r = 0.511$, $p = 0.025$) but not their smoothness scores. Changes in sketch smoothness are discussed further in section 3.1. Since sketch confidence increased between the beginning and end of the course, this could indicate that students' understanding of sketching skill grew to include understandability as a key component in addition to proportion/accuracy. This is promising as the role of sketching as a communication tool (rather than an artistic endeavor) was emphasized throughout the course.

Nearly half of students reported that their attitudes towards failure were influenced by the sketching activities. Around 47% of students self-reported that the daily sketching ritual made them more comfortable with failure. This encompasses both the 26% of students who self-reported that the daily sketching ritual made them "*much*" more comfortable with failure and the 21% of students who noted that the sketching ritual made them "*a little*" more comfortable with failure. In the survey at the end of the course, one student wrote, *"I think the [failure] seminars were helpful in the traditional sense of failure, which is hard to free yourself from those ideas, but confronting things head on with practice (sketching, prototyping, etc.) were also very helpful."* This indicates that students did see the connection between their daily sketching practice and the broader goal to help students embrace failure.

These results are in line with prior work in the K-12 world showing that engineering design experiences have the potential to shift students' attitudes towards failure [13, 18]. These results are especially interesting as they show that interventions even at the undergraduate level have the ability to shift student attitudes. Additionally, they indicate that interventions that are minimally time and resource intensive, such as the short sketching exercise, have the potential to influence attitudes towards failure.

3.3 RQ 3: Are there Gender Differences in Sketching Confidence and Performance?

Women started with a much higher confidence in sketching (5.9 for women, 3.4 for men with $p \leq 0.05$) and continued to have consistently higher confidence in sketching. This is surprising, as prior research indicates that women have had lower confidence in their sketching in an adjacent field [19].

However, the gender gap decreased over the course of the class: the initial 2.5 point difference decreased to 0.4 points, which was no longer a statistically significant difference.

Women and men's scores were again compared using the Wilcoxon Rank Sum test. Women had statistically significant higher average scores for smoothness (3.51 for women, 3.19 for men with a $p \leq 0.05$) and proportion/accuracy (3.72 for women, 3.19 for men with a $p \leq 0.05$). This indicates that the gender gap in sketching confidence is consistent with the gender gap in sketch quality. Again, these results are the opposite of prior work showing that women perform worse in sketching and tend to use the "feathering" style more than smooth lines [19]. Further study should investigate the source of these differences- it is possible that this is because of the differences in the Mechanical Engineering and Industrial Design fields, especially due to the differences in the gender breakdown in the departments at each institution. It is possible that these results could provide insights into how to circumvent the typical confidence gap.

There was no statistically significant difference between genders in understandability scores.

3.4 Limitations and Future Work

This was a small study with a limited number of participants during a relatively short time period, and was meant to be used as a first step for other studies. A limitation of this study is that not every student completed all of the sketches. 37% of students completed all 9 sketches, and 74% of students completed all but one sketch. 26% of students completed 7 or fewer sketches. Sketches from all students were included in the overall analysis, but for the guitar direct comparison, only sketches from the 11 students who completed both guitar drawings were included. Additionally, the objects being sketched were of varying levels of complexity throughout the course. The study was run in the context of an academic course, so it was not possible to have a control group for experiments and we cannot draw causal conclusions. Finally, there were only three raters for sketches, all of whom were part of the course teaching team and thus were familiar with most of the objects being sketched.

The findings regarding sketch smoothness and waviness suggest opportunities for new ways of assessing the progress of design and engineering students as they learn to sketch and work on projects. In particular, this study could be supported by a study that is run with objects that are pre-screened for being similar levels of difficulty. Additionally, the limited sample size and class setting made it challenging to draw causal conclusions in this context. There is indication that there may be a link between line smoothness and sketching confidence that should be further explored. However, this study should be run in a controlled setting to determine if the changes in line smoothness and sketching confidence are causally linked.

This study shows preliminary results that regular practice with a sketching ritual can help build confidence and skill in sketching and help students learn to embrace failure. There is much room to further validate the failure-related results from this initial work. Our results hinged on the responses to a single survey question, but it would be important to study the impact of the sketching ritual in a controlled setting to determine potential causal links. We also propose that this ritual be adopted by educators and practitioners as a simple and effective tool for sketching habit formation. This exercise has the potential to shift student mindsets around sketching and design while giving them the concrete skills to be successful designers. Of course, there is a long history of sketching curriculum in engineering design, industrial design, and related fields, and one path for potential future research would be to examine how other approaches for sketching instruction might be linked to confidence.

The gender difference uncovered in the results of this study both in sketching confidence and in sketch quality should also be further studied to determine if these trends persist at all experience levels. A follow-on study could determine if this gender difference is present in confidence and quality of other design activities such as prototyping and manufacturing.

3.5 Implications for Engineering Education

This work points to the value of regular, short practice with sketching in a low-stakes manner for engineering design students. Primarily, this sketching practice helped students build confidence in their sketching ability and showed promise for building sketching skills as well. Over the course of several weeks, students' line smoothness improved slightly so it is possible that a longer timeframe would show more marked improvements. Additionally, many students reported the sketching ritual to be helpful for them in becoming more comfortable with failure. This is a key result and it is possible that low-stakes skill building for skills such as sketching could help with shifting engineering design students' mindsets around sketching and failure in design.

The gender differences observed in this study are noteworthy and should be investigated further. In our context, there were more women in the course than men and all the teaching staff were women. In our case, the women outperformed the men in both sketch quality and sketching confidence. It would be important to note whether these patterns persist for more typical engineering environments where women are often outnumbered. Is there a correlation between representation in the classroom environment and confidence and skill in sketching? We encourage other researchers to investigate this in their courses to help determine whether or not the environment could be a contributing factor to confidence and skill in sketching.

4. Conclusions

The study found that the smoothness of lines in sketching increased along with student confidence in sketching. There were several interesting and surprising gender differences in the results: women were initially more confident in sketching but men experienced greater growth in confidence over the course of the class and bridged that confidence gap. This gendered difference persisted in the actual sketch scores as women had higher average smoothness and accuracy/proportion scores. Finally, student attitudes towards failure were closely linked to the sketching activity. The daily sketching ritual was initially introduced for the virtual setting of the course but would be useful for other design courses even in in-person settings. It helped students regularly practice sketching and making low-stakes mistakes in addition to fostering a sense of community within the globally distributed class.

RQ 1: What physical elements of sketches change due to regular practice with sketching?

Overall, changes in sketching scores over time appeared to be a factor of the objects chosen rather than students' sketching skill. However, paired comparison of student sketches of the same object from the beginning and end of the study shows that proportion/accuracy and understandability of sketches did not change but line smoothness of sketches increased perceptibly. This is a compelling result because line smoothness was not explicitly mentioned in the course as something to strive for. Additionally, smooth lines in sketches have been associated with confidence and skill in sketching, so it is possible that this change in sketch attributes is indicative of a change in sketching confidence as well.

RQ 2: Does regular practice with sketching correlate with changes in confidence in sketching, perceptions of failure, and sketch quality?

Regular practice with sketching was linked with increased confidence in sketching. Additionally, around 47% of students self-reported that the daily sketching ritual made them more comfortable with failure within the course of the class. This is in line with the goal of the activity in helping students embrace failure as part of their routine experience with design. Though this result was not consistent for the entire class, there is an initial positive trend and it is possible that a longer intervention would have an impact on a larger portion of the students.

Surprisingly, regular practice with sketching did not correlate with higher sketch quality. Instead, some sketch ratings decreased over time. However, this is attributed to the increased complexity of objects in the second half of the course rather than a conclusion about students' performance worsening over time.

RQ 3: Are there gender differences in sketching confidence and performance?

The study found that women began the course with higher sketch confidence scores. However, men experienced greater growth in confidence over the course of the class and bridged that confidence gap. A gender difference was observed in sketch quality as well with women scoring higher in average sketch smoothness and proportion/accuracy.

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