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ART MEETS ENGINEERING DESIGN: AN APPROACH FOR REDUCING SKETCH INHIBITION IN ENGINEERS DURING THE DESIGN PROCESS

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ABSTRACT

While much prior work has been done regarding sketching and its impact on design and a few on how to train engineers to sketch, there have been no prior studies in engineering to reduce inhibition to frequent sketching. This paper describes a sketching intervention developed from art teaching aimed at reducing inhibition to sketching and a study to evaluate its effectiveness. In the study, students (n = 55) were tested with pre-mid-post assessments consisting of a mechanical, organic, and design-oriented sketching task and a TLX survey measuring the level of difficulty. The study found that the students overwhelmingly reported their inhibition was lowered, but the short-term TLX data suggested inhibition was higher. However, the TLX data showed a longterm decrease in inhibition-related measures, perhaps suggesting that long-term encouragement to sketch is effective in reducing inhibition to sketch. These results tentatively suggest that sketch inhibition is reduced by actively promoting creativity and sketching, some use of the activities presented here, and by deemphasizing the importance of higher-level skills such as perspective drawing.

1 INTRODUCTION

Sketching in engineering is well established as an important process for communication [1] and visual thinking [2]. Several studies have explored how sketching influences creativity in design [1], concept generation [3], and thinking in general [2]. A few studies have explored the effect of sketch training [4–6].

Based on our previous studies [7] and the work done in our classroom environments [8] we explored how to train students in sketching to help them use visual thinking more freely. While our studies found some improvement in the quality and mechanics of the sketches, we still found that many engineering students are reluctant to sketch or otherwise draw in a meaningful way. A few have noted that engineers are reluctant to sketch [9], and some have proposed technological or practice based interventions to reduce inhibition [10]. There are limited studies in other design fields, including interior design, but the majority of literature regarding reducing inhibition is in the arts.

This study brings art techniques for reducing inhibition into an engineering course lecture. To enhance our art background, we recruited a local artist who is also an art lecturer at a Purdue University. Among other classes, this artist teaches art classes oriented toward "rehabilitating" engineers back into an artistic frame of mind. In this study, we explore the effect of various interventions commonly employed in art on engineering students through a lecture and three homework assignments over the length of the semester. To do this, we compare survey responses from the lecture with data from the NASA TLX survey completed with the homework assignments. The TLX survey measures task difficulty commonly used in human factors research (see Section 3.1.1). Our goals were to improve the frequency of sketching and reduce the inhibition to sketch.

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2 MOTIVATION AND BACKGROUND

Sketching is an important skill for engineering, particularly because it improves communication and visual thinking. Sketching has been consistently shown to improve the quality and novelty of ideas [11], the quantity of ideas [12], and the overall quality of final designs [13]. The total volume of sketches and the number of 3D sketches is positively associated with good design outcomes [13]. Furthermore, sketching on paper is far more flexible for ideation than CAD drawing, but is inadequate for further articulating design ideas [14]. The creative process is often inhibited when a designer uses CAD before a detailed design phase [15, 16]. Therefore, sketching serves the role of delaying CAD drawing and modeling until concepts are better explored and can be considered more carefully. This role is important since design creativity is associated with longer time spent in the problem definition phase [17]. Furthermore, creativity is enhanced when decisions are delayed to the latest possible time. Therefore, sketching is of vital importance to engineering design since it helps designers explore ideas, solve problems, generate new ideas, and delay decision making; all of which contribute to creativity.

Sketch training has been implemented in several programs with varying emphases, such as product sketching [4], free-hand technical drawing [5], and visual thinking [6]. It has also been found that sketching is most effective when paired with other forms of communication, such as annotations, verbal communication, or hand gestures [13, 18, 19]. Some programs have found that by fostering the confidence of students, sketching skills are acquired at a much faster rate [4]. One study found that pre-sketching activities, such as sketching a dream house in Alaska, helped prime designers for effective ideation and increased the novelty of generated concepts [9].

While many prior studies have observed the reluctance to sketch, to the best of our knowledge work in this field has been limited. Worinkeng et al. [9] attempted a directed intervention to specifically reduce sketching inhibition. Schmidt et al. also discuss intellectual and environmental factors that contribute to sketching behavior, and summarize other efforts to encourage sketching [10]. They describe technological interventions and educational interventions including assignments and lectures to encourage freehand sketching. However, the efforts described in this literature review do not attempt directed activities designed to reduce inhibition.

2.1 Types of Inhibition

To define inhibition, we turn to prior literature and make our own additions. Our overall hypothesis is that the reluctance to sketch may be due to any combination of several types of inhibition. This study only explores skill-set and personal inhibition and purposely removes social and other forms of inhibition. We define several types of inhibition, derived from prior research as well as our own analysis.

- Personal inhibition is characterized by trying to make the sketch too perfect on the first try. In other industries, this type of inhibition is called "gold plating". It happens when sketchers become preoccupied with the mechanics of sketching or drawing [20].
- Intellectual inhibition is due to the belief that sketching is not relevant to engineering or design [10]. This type of inhibition may be due to not understanding the value of sketching, believing sketching is not an "engineering" task, or not valuing the problem-definition and ideation phases of design.
- Skill-set inhibition is due to the awareness of an actual or perceived deficiency in skills, independent of external comparison. This type of inhibition may be seen as an awareness for a need for improvement or feeling unqualified, and may be a form of humility or lack of confidence pertaining directly to a particular skill-set. Many artists implicitly understand that a lack in skills inherently causes inhibition, and training a few basic drawing skills can reduce inhibition (ex. Richards [21]).
- Social inhibition is due to the fear of being unfavorably considered by others [22]. With sketching, it is analogous to the fear of public speaking [23], wherein these two fears differ only by medium. This type of inhibition is frequently seen in students or teachers when drawing on a chalkboard or in a meeting among peers. Situations where this is seen include when the teacher apologizes profusely for not being able to sketch, or the students refuse to volunteer until someone with at least some confidence in sketching finally tires of the wait. This is also seen in meetings, where people do not sketch because others are watching.
- Comparative inhibition is when a potential sketcher judges him/herself to be inferior in skills to someone else. This type of inhibition is particularly evident when someone is asked to sketch or draw immediately after seeing an impressive work of art or being present with a person regarded to be good at art. This type of inhibition is closely related to social inhibition, but may also occur when an individual is alone.
- Social loafing and matching are inhibitions seen when group participants try to minimize their contribution to the group [22]. These are not cognitive inhibitions, though, and are more closely related to motivational deficiencies, and sometimes a lack of feeling responsible.
- Situational inhibition is when a designer is not in the proper state of mind to allow the "flow of consciousness" that is required for creativity when sketching. This state of mind requires that sketches are deliberately vague, without sacrificing the "feeling" of the sketch [24]. This often means that sketches can be mere squiggles which do nothing more than vaguely express an emotion.

A recent interior design study found that the outcomes of inhibited sketching are drawings that are timid in line quality, overworked in style, and slow in production [20].

2.2 Activities Used in the Arts to Reduce Inhibition

While many prior studies have observed the reluctance to sketch, to the best of our knowledge, Worinkeng et al. are the only engineers that have attempted any directed intervention [9]. Of the available prior literature in engineering and design research, none appear to draw on similar interventions common in the field of art, except Song et al., who used timed perspective exercises to force interior design students to focus on quick sketching [13]. Art instructors have long observed reluctance to sketch or draw, and many suggested activities are available. For example, Betty Edwards, in the book Drawing on the Right Side of the Brain [25], suggests activities such as copying drawings upside-down and restricting verbal or written communication while sketching. These activities force students to focus on lines, rather than overall shapes, and allowing the brain full access to creative centers, which are described as being in the right hemisphere. The results of her work are dramatic. Students who use these exercises are much better drawers and show significant improvement over a short amount of time and continue to maintain that improvement in the long-term. Other sketching resources such as McKim [26] also suggest similar exercises to reduce sketching inhibition, in addition to other exercises to enhance various aspects of visual thinking.

3 METHODOLOGY

Due to the large amount of art literature, we worked with Scott Frankenberger at Purdue University, to identify relevant exercises. Scott selected the activites, as well as the length of them, based on his experience with using them in his art classes. The methods are common in art to “loosen up” and prepare for a creative session. The activites are detailed in table 1.

In order to test the efficacy of these methods in reducing inhibition, we introduced them as an in-class lecture in a toy design class. The inhibition reducing exercises were blended into the existing course framework and structure prior to a sketch training module. The purpose of introducing the inhibition reducing activities prior to the sketch training is to encourage the students to use the training module more effectively. An initial pilot study was conducted to determine the overall value of the exercises. The pilot sought to answer the following questions:

- Do the exercises help reduce student inhibition to sketching?
- What activities should we include in the future?
- What activities should we not include in the future?

Following the pilot study, the main study took these same questions and added a couple additional questions:

TABLE 2. Research activities used in the pilot and main studies

Research Activity	Pilot	Main
Pre-test (Set 1) / TLX (Week 1)		X
Sketch Inhibition Lecture / Survey (Week 4)	X	X
Sketching Skills Lecture (Week 5)	X	X
Mid-test (Set 2) / TLX (Week 5)		X
Post-test (Set 1 & 2) / TLX (Week 16)		X

- Does the students’ sketching behavior match the self-reported drop in inhibition?

3.1 Design of Experiment

The two portions of the study used a similar set of research activities. The pilot study relied exclusively on surveys, whereas the main study used surveys, TLX task load indices, and sketching tasks administered before, immediately after, and long after the inhibition reducing lecture (see table 2). These sketching tasks are referred to as the pre-test, mid-test, and post-test. Each sketching test consisted of at least three sketching tasks, with three tasks comprising a set. The post-test uses both the sets used in the pre and mid tests.

3.1.1 TLX Surveys In order to measure inhibition, we used the NASA TLX survey. This survey is commonly used in human factors research to determine the difficulty of a task, and the task load [27]. Since the survey relies on self-reported measures, some bias is to be expected. The survey consists of six questions which are answered by marking a scale from -10 to +10. The questions ask about how high the mental, physical, and temporal demands were. It also asks how well the participant believes they completed the task, how much effort they felt it took, and how much frustration they felt.

The TLX survey was chosen to measure inhibition because other measures of load are limited to uninformative metrics [28], including task-time measurements (such as time to shift attention [29]), highly intrusive metrics (such as EEG [30]), or laboratory specific measures (such as qualitative observations [31]). None of the alternative metrics would have functioned well in such an ecological study. Additionally, the TLX measures are comparable to various causes of inhibition. Personal, intellectual, or skill-set inhibition are likely to be reflected in the measures, but not easily distinguished. For example, if frustration and mental demand are both high, this may be due to personal or skill-set inhibition. If temporal demand is high, this is likely due to skill-set. If frustration is high and effort is low, this may indicate intellectual inhibition. The physical and temporal demands are in the TLX questions are not as relevant for this study.

TABLE 1. Exercises used in the sketching inhibition-reducing activity, all times approximate

	Exercise	Media	Purpose	Time
1	Draw an animal with eyes closed	Sharpies	Introduce an uncomfortable task	60 s
2	Draw a flower with opposite hand	Pencils	Brain hemisphere reversal	60 s
3	Draw a self-portrait holding partner's hand	Pencils	Break social inhibition, foster self-awareness	150 s
4	In groups of 4, each member draws part of a house and passes to left without talking	Markers	Sharing ideas with others	200 s
5	Draw a bicycle	Crayons	Introduce non-technical, imprecise tools	45 s
6	Draw a monster with finger paints	Finger-paints	Playful thinking, unexpected materials	60 s
7	Draw mountains upside down	Finger-paints	Disorientation, hemisphere reversal, unexpected materials	90 s
8	Draw a "sound"	Finger-paints	Visualizing abstract concepts	60 s
–	—- Clean hands —-	—–	Clean up time, and breathing space	300 s
9	Draw the person diagonally across from you 3 times - quickly/fast/faster	Sharpie	Reduce concern about details, emphasize quick sketching	100 s
10	Draw same thing (cat) 3 times using different media each time	Pencils, Sharpies, Crayons	Revisit the same problem with different resources	90 s
11	Draw a house using a continuous line (never lift pencil)	Pencil	Dealing with limitations and strategizing	90 s
12	Fill the page from the edges to the middle with a vehicle for transportation	Markers	Maximizing all your resources, and emphasizing the "whole" picture	45 s
13	Draw a "sad" flower	Crayons	Applying abstract concepts to unrelated things	45 s
14	Scribble with Sharpie, then find & outline a face within the scribbles with crayons	Sharpie, Crayons	Pattern recognition	90 s

3.1.2 Main Lecture and Post Surveys The core of both portions of the study is the inhibition-reducing exercises developed jointly with the artist. In each iteration, these sketching exercises were administered during an in-class lecture for the toy design class. Sketching supplies were provided to the students (n=45 for the pilot, n=60 for the main study) and they were guided through the exercises by the artist or the main author of this paper. The students were only given approximately between 30 and 240 seconds each exercise. This was done to help students give up the need for perfection and to emphasize the need for rapid sketching. The time was controlled by the lecturer. No talking was permitted during a sketching activity, but talking was permitted between activities. The lecture began with an introductory set of exercises, followed by several activities that required fingerpaint, and finished with a final set of non-painting exercises. All the fingerpainting exercises were clustered to facilitate clean-up afterward. Immediately following the exercises, the students filled out a four-question, open-ended survey. The questions were:

- What did you like/dislike about the session today? Be as complete as possible.
- What activity did you enjoy the most?
- What activity did you dislike the most?
- Have you had any experiences like this before?

3.1.3 Homework Assignments and Pre-Mid-Post TLX In order to test the reluctance to sketch, and the change in behavior over time, we gave students sketching homework assignments in the first, fourth, and last weeks of the semester. The first sketching task set was administered in the first weeks of the semester, prior to any sketch training. The second set of tasks

TABLE 3. Sketching tasks used in the pre-mid-post tests

Task	Set 1 (Pre/Post Tests)	Set 2 (Mid/Post Tests)
Mech.	Crane lifting a heavy bar	Forklift
Organic	Bird on a shoe	Hand holding a celery stalk
Design	Device that folds clothes and organizes closets	Automatic device that removes leaves from yards

was administered just two weeks after. The final set was administered during the last week of classes and during finals week. In each set of tasks, students were instructed to spend no more than five minutes per sketch. This was to encourage rapid sketching, rather than drawing or illustrating. The sketching tasks were given as take-home tests, so adherence to the five minute limit is assumed. Due to the large number of assignments due in the last week of classes, students were given a week and a half to return the completed tasks, so they could finish their finals first. The time limits were given to improve participation. The students were informed that participation was voluntary, but the results would be used to improve the course.

Each set of tasks consisted of three sketching tasks (see table 3). The sketching exercises were chosen to test different types of sketching, including mechanical, organic, and design sketching. This grouping of tasks is very similar to that used by Yang and Cham [1], except part of the organic drawing task requires memory sketching too. In set 1, the students were asked to draw a crane lifting a heavy bar, a bird on a shoe, and a device to fold and put away laundry. In set 2, they were asked to draw a forklift, a hand holding a carrot or celery stalk, and a device to automatically collect leaves from the yard.

By using different types of sketching tasks, we can explore what happens when they use different sketching skills. The crane and forklift are both mechanical objects, and it is reasonable to assume virtually all the students are familiar with what these look like. Mechanical objects usually incorporate many straight lines or primitive shape combinations, and are easily adapted into scenes that use perspective. The bird on a shoe and hand holding a carrot tasks were designed to give students an organic shape that they could sketch from a reference (the hand and shoe) and from memory (the bird and carrot or celery). These tasks are difficult to do with only basic skills in perspective, and in most cases forced students to use a 2D sketch or use a model for the perspective. It also uses much curvier lines. Finally, the clothing and leaf devices were designed to force the students to generate concepts in order to sketch them, since neither device is a real device. It would also strongly encourage annotation, indicating motion, and giving contextual clues in the sketch.

This variety of sketching exercises allows us to differentiate between different types of sketching and see if there was more inhibition for one type more than another. Although the organic drawings are generally not of interest to engineers (although that is debatable), they remove the ability to use simple perspective techniques, require more curves than straight lines, and do not include explicit functionality. This makes them a convenient comparison, since they require skills beyond what we explicitly teach, thus revealing a more accurate idea of the individuals' native sketching ability.

3.2 Population

The students in both portions of the study were recruited from the toy design class ME 444 [8]. The students in this course were seniors in mechanical engineering, and had a prior CAD and graphics course as freshman and a design course as sophomores. Some were concurrently enrolled in a senior design course. Some had also participated in internship and co-op programs. None of the students had been exposed to freestyle sketching, visual thinking, and using sketching for ideation in any prior courses.

No compensation was offered as a part of the study, and all activities were incorporated as homework assignments or lectures. Students were informed that the surveys were voluntary, and would be used to improve the course. In the pilot study, 45 students responded, and in the main study 63 students responded. Due to missing data, only 55 of the results from the main study could be used.

4 PILOT STUDY RESULTS

Students had various reactions to the pilot lecture (see figure 1). A large majority discussed feeling freed or relaxed as a part of the lecture, or mentioned an improved understanding of design principles. Many of the miscellaneous comments were along the lines of "happy" or "it was fun", and indicated some positive benefit of the lecture. A few examples of sketches from various students are shown in figure 2. For some, the sketching activities inspired the students to learn to sketch better. "It made me wish that I could learn to sketch my ideas well."

There was some indication that the intellectual inhibition was also lowered, by drawing a connection between engineering and playful thinking. One student reported, "I felt that it was different than anything I've encountered in engineering. It brought out my creativity and allow for 'thinking outside the box"'.

Many students felt that the lecture was relaxing, which presumably lowered the inhibition to sketch. Students that reported this in the comments often mentioned feeling more connected with their creative side. If we take these comments to be an indication of inhibition, it appears that this lecture has been successful at reducing the inhibition in some way.

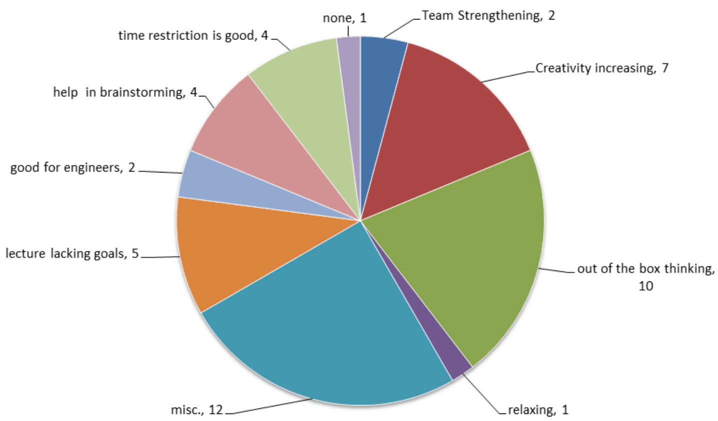

FIGURE 1. Types of comments to the question "What did you think of today's activity?"

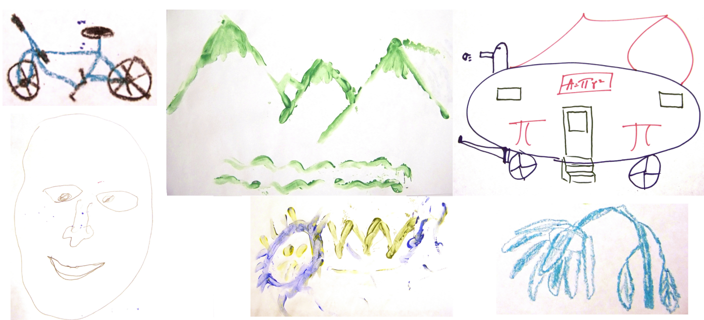

FIGURE 2. Examples of sketches from various students. From left to right: Top - A bicycle drawn in crayon (5), mountains painted upside-down (7), a house drawn by a team (4); Bottom - a self-portrait drawn with a partners hand (3), a monster using finger-paints (6), and a sad flower (14).

- "The session made me feel relaxed, because it was really easy. Just to let loose and be able to let your mind run free."
- "besides being very fun and surprising, the session was actually insightful. Being present with rapid and varying objectives was great at showing the importance of getting your ideas down on a paper quickly. Having to use various techniques and materials for drawing should the need to be able to adapt quickly."
- "I enjoyed the session. It took a few exercises to feel like I was comfortable with what was going on but once I relaxed some it was easier to be creative."
- "I felt like it was a fun way to explore creativity without worrying too much about technicalities. It felt free, easy, and enjoyable."

Around 11% of respondents indicated that they felt the lecture was pointless. This result is not completely unexpected. In order to not bias the responses from the students, we purposely withheld the intent of the exercises. In the future, we plan to inform the students as to why we do the exercises. Additionally, the effects of this lecture would probably be enhanced if we told them the purpose of it.

We also asked the students which activities they liked the most and which they liked the least (see figure 3). The three most popular activities were finger painting in general, scribbling and drawing the face, and drawing with the eyes closed. The least popular activities were finger-painting and using a partners hand for a self-portrait. Notably, around 40% of the participants did not have any least favorite activities.

We suspect that the dislike for finger-paint was due to the messiness. One student said they disliked "fingerpainting because it was messy". Another student said their least favorite activity was "fingerpainting, [because we] spend more time messing with getting enough paint and spreading it than being able to draw anything."

The majority of students reported not having experiences like this lecture whereas a few said they had some experience with activities like these. This seems to simply indicate that this experience is novel for the majority of participants (see figure 4).

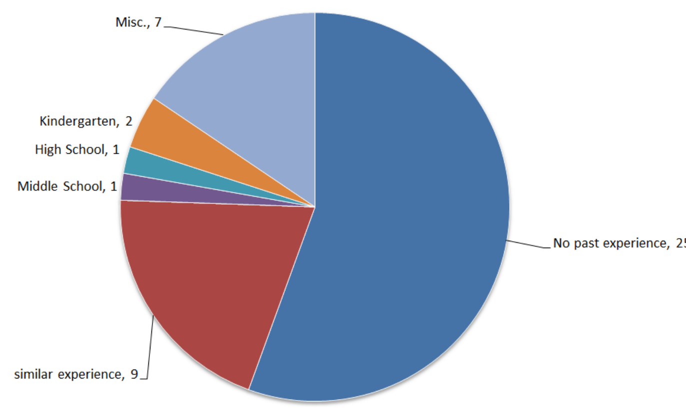

FIGURE 4. Responses to "Have you experienced an activity like this before?"

All in all, the comments were overwhelmingly positive, which led us to the main study. They seem to suggest that the inhibition to sketching is reduced through these exercises. The comments also suggest that the reduction in inhibition is due to getting them to do unorthodox activities during an engineering class. On the other hand, the success of this exercise is tempered by the lack of explanation of the activities.

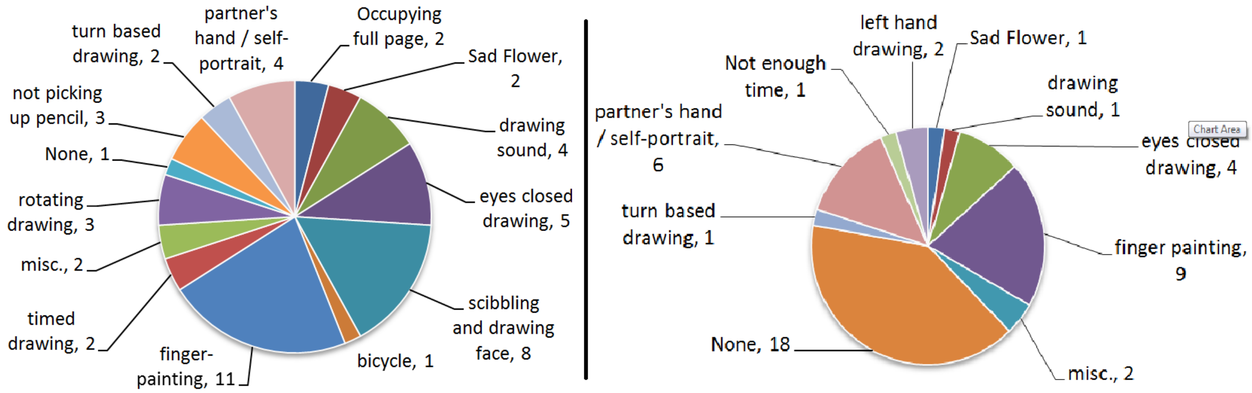

FIGURE 3. Responses to “Which activity did you like the most?” (left) and “Which activity did you like the least?” (right)

5 SURVEY RESULTS FROM THE MAIN STUDY

The comments we gained from the main study were similar to the comments in the pilot study, but some things showed up more frequently (see figure 5). Many more talked about how the inhibition-reducing exercises seemed to be great methods for improving the relationship among team members. Again, most of the comments were positive.

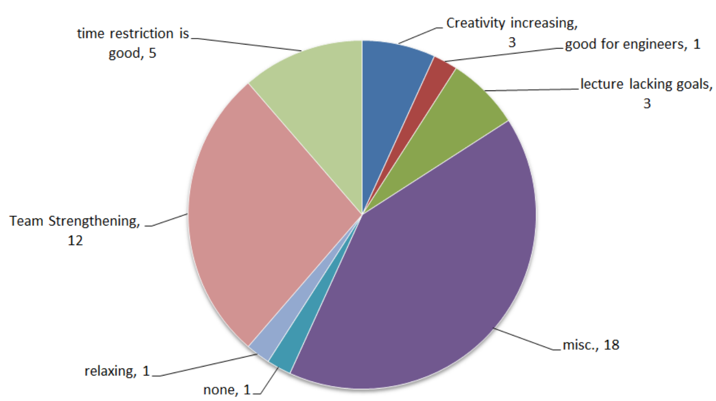

FIGURE 5. Main study responses to “What did you think about today’s activity?”

Again, the students were asked, “What did you like most about this activity?”

- “Was a fun way to bond with new teammates and learn about each other.”
- “I thought that the activities were a good teambuilding icebreaker but I felt it was too Time-consuming”
- “I had fun and since we had just met our teammates it was a great way to break the ice and get a positive initial tam dynamic. It put us all on the same skill level + playing field.”
- “It was an interesting to meet the group, good icebreaker it got us to enjoy class and just because be comfortable”
- “it was fun, got to see the artistic clarity of my teammates and was impressed by how the were able to draw what they did on their time constraints”
- “I felt today’s session was fun. The interaction with teammates was fun.”

Some respondent felt the exercises were not meaningful or took too much time.

- “I thought that the activities were a good teambuilding icebreaker but I felt it was too Time-consuming”
- “I had a great time but at the same time I don’t see why we are actually doing this. I felt like it was kind of pointless.”
- “With proper explanation, I believe the activity could be more well justified as a good use of time for this particular course.”
- “it was fun but seemed bizarre. Do not see why this is effective for design (Other than maybe trying to kickstart creativity)”

Many students reported that they felt more relaxed and free to think creatively.

- “I loved it. It was finally a chance to relax and think freely and be creative. There really should be more activities that inspire like that in engineering.”
- “It was a lot of fun, in the beginning it was harder to give in fully to the activity but half way through I stopped caring about getting right and just having fun. I enjoyed it, something outside the daily routine.”
- “It was silly but encouraged me to be creative (artwise) which (never) happens in engineering”
- “I like drawing and today’s session was very fun and I enjoyed it a lot. Drawing in a short amount of time pushed me to think of an idea quickly which resulted in some unexpected but interesting idea[s]”

- "I also enjoyed the quick pase [sic] of drawing fast and also that it doesn't matter if our art is good just that we finished."

As in the pilot study, many students felt challenged by the constraints of the activities.

- "It was surprisingly difficult to complete the taks [sic] in the given amount of the time and achieved the desired amount of detail."
- "I think it was a very interesting approach to thinking about design. The time constraints and having to use your group members really changed my way of thinking."

It is clear that the attitudes of at least some of the students changed as a result of the exercises. "[It was] awesome. I have never taught drawing could be like this" For others, they felt like they were opened up to a new set of possibilities. "[It was] exciting and insightful, I can see what I was capable of in short time or under other constraints"

Reactions to the various exercises were similar to the pilot (see figure 6). Again, the most popular activities were finger-painting and drawing with the eyes closed. Also popular this time was turn based drawing. However, the least liked activities included finger painting and drawing a sound. These seemed to be because the students did not like the mess as well as the lack of control over the medium or did not like the abstract nature of the exercise. For example, one student said that they did not like "finger Paint, just [because] it's messies [sic] and I have less control over it." Another student said they did not like drawing the sound because "The one drawing [where we drew a] sound wave [was] too abstract."

As with the pilot study, the majority of students reported not having a similar experience to these activities before (see figure 7). While it is highly likely these students have done finger painting, drawing with crayons, and pencils; it is clear that they view this activity as fundamentally different. It is not clear if this is because of the design environment of the class, or if the exercises are fundamentally different from elementary school art because of the directed nature of them.

We also asked each student to fill out a TLX survey for the entire set of exercises. The purpose of this was to determine the difficulty of the exercises for them. Table 4 shows the averages for each of the categories. For the most part, the TLX surveys showed that the difficulty of the exercises is low or average. Since this is self-reported data, there may be some bias in these results; however, this seems to confirm the conclusion from the comments that the activity was well received. Since no comparison is made here, no conclusions can be made regarding inhibition for this activity alone.

Although the surveys seemed to indicate that these activities were successful, some responses from both the pilot and main studies suggest that the length of the lecture is too long. In the future, we would remove some activities and pair them with a related topic, such as idea generation techniques. One activity to remove, in particular, would be fingerpainting, since it is time consuming and messy.

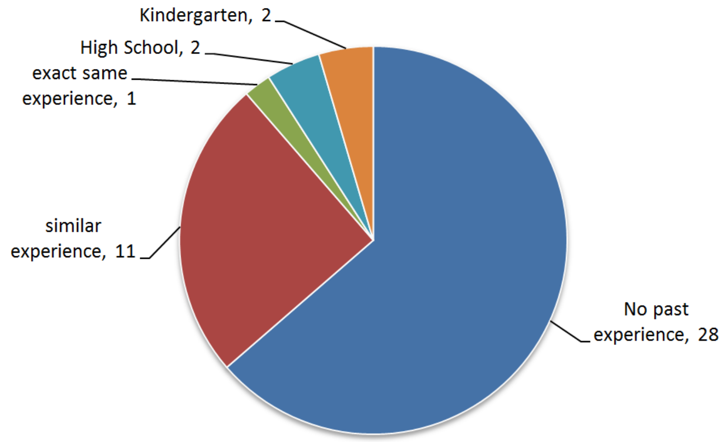

FIGURE 7. Main study responses to "Have you experienced this kind of study before?" (right)

TABLE 4. TLX results measuring the difficulty of the inhibition-reducing exercises. Scores range from -10 to +10. MD = mental demand, PD = physical demand, TD = temporal demand, PF = performance, EF = effort, FR = frustration

	MD	PD	TD	PF	EF	FR
Avg Score	-1.64	-3.93	-5.05	-0.16	1.60	-4.37
Interp.	Avg	Low	Low	Avg	Avg	Low

6 PRE-MID-POST TLX RESULTS

6.1 Pre-Analysis of TLX Data

Since the pre-test and mid-test were so close in time, learning effects were a potential problem. To mitigate this problem, two different sets of sketching tasks were used for the first two tests, and combined for the last set (see table 3). For ease, we abbreviate each group of data by its set number and its chronological order.

- Pretest (Set 1) = 1A
- Midtest (Set 2) = 2A
- Posttest (Set 1) = 1B
- Posttest (Set 2) = 2B

To validate if we can compare the two sets directly, we first confirm that the differences between the two task sets are negligible. To do this, we compare the difference between the two

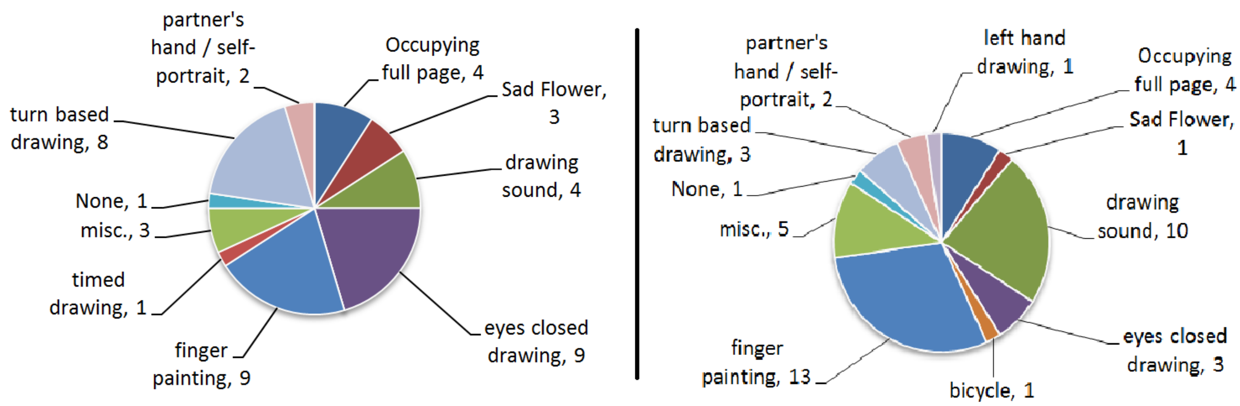

FIGURE 6. Main study responses to "What did you like most about this activity?" (left) and "What did you like the least?" (right)

sets used in the post test (Eqn. 1). We could also compare the pre test set with both post sets and the mid test set with both post test sets, but this is mathematically equivalent by the associative property (Eqns. 2 and 3).

$$1B - 2B \approx 0 \tag{1}$$
$$1A - 1B \approx 1A - 2B \tag{2}$$
$$2A - 1B \approx 2A - 2B \tag{3}$$

The differences between each set are reasonably close (on a 20 point scale, see table 5 for specific values). The greatest differences between the sets do not exceed 10% error (dividing 2 by 20). While this is not ideal, it is sufficient to get a rough idea of the inhibitory effects. Therefore, we treat comparisons between the sets as valid.

6.2 Analysis of TLX Data

Given an approximate equivalence between sets 1 and 2, we use a general linear model in MiniTab to determine if these changes are statistically significant. Only students who submitted a complete set of TLX surveys are considered (n = 26, 29 submissions ignored) The student and the type of task (mechanical, organic, design) were used as blocking factors. All necessary assumptions were met for all response variables, including homogeneity of variance and normality.

The test found that mental demand ($p < 0.0001$), physical demand ($p = 0.007$), and effort ($p < 0.0001$) were significant between the pre, mid, and post tests (see Table 6). The task was also significant for the mental demand, suggesting that certain tasks were harder than others. To determine which averages were significantly different, we performed a post-hoc Bonferroni analysis. This analysis shows that the pre-test was significantly different from the post test and that the mid test was generally different, but that the pre-test and mid-test were not significantly different (see table 7).

TABLE 7. Bonferroni groupings for significant factors. MD = mental demand, PD = physical demand, EF = effort

Test	MD		PD		EF	
Mid	A		A		A	
Pre	A		A	B	A	
Post		B		B		B

We also compare the average values of the pre/mid/post tests. The overall inhibition seems increases in the short term (due to the mechanical and organic sketches), but decreases at the length of the semester (see figure 8). The one exception to this is perceived performance, which returns to the baseline value. While the short term increase is not statistically significant, we still take it into consideration.

6.3 Interpretation of TLX Results

With the statistics and average values together, it appears that inhibition may have risen shortly after the initial lecture, but dropped over the length of the semester. While this could be due to the inhibition-reducing exercises, it is more likely due to the sketching skills lecture, which was held shortly before the mid-test was administered.

We also noticed that the quality of sketches seemed to decrease dramatically from the initial pre-test to the post-test. We also noticed that the post-sketch sketches included many more construction lines and many more participants attempted to use perspective. Interestingly, some students who effectively used perspective in the pre-test were much less effective in the post-test. Although this aspect of the sketches was not formally studied, perspective drawing seemed to be a key inhibiting factor for

TABLE 5. Evaluation of data to determine if a comparison between set 1 and set 2 is valid. MD = mental demand, PD = physical demand, TD = temporal demand, PF = performance, EF = effort, FR = frustration

	Set 1	Set 2	MD	PD	TD	PF	EF	FR	Avg Err	Harder Task
Mech.	Crane	Forklift	2.00	0.80	2.00	-0.40	0.30	2.00	5.58%	Forklift
Organic	Shoe	Carrot	1.45	1.25	0.80	1.35	0.20	1.55	5.50%	Carrot
Design	Clothes	Leaf	-1.75	-0.60	-1.45	-1.10	-0.30	-0.85	-5.04%	Leaf Machine

TABLE 6. Statistical results from the general linear model with pre-mid-post test as main factor and mechanical, organic, design as blocking factor. MD = mental demand, PD = physical demand, TD = temporal demand, PF = performance, EF = effort, FR = frustration

	MD		PD		TD		PF		EF		FR	
	F	p	F	p	F	p	F	p	F	p	F	p
Test	14.39	< 0.001	5.16	0.007	0.96	0.385	0.93	0.398	17.98	< 0.001	1.49	0.229
Task	9.10	< 0.001	0.38	0.687	1.6	0.204	0.50	0.605	0.95	0.389	2.99	0.053

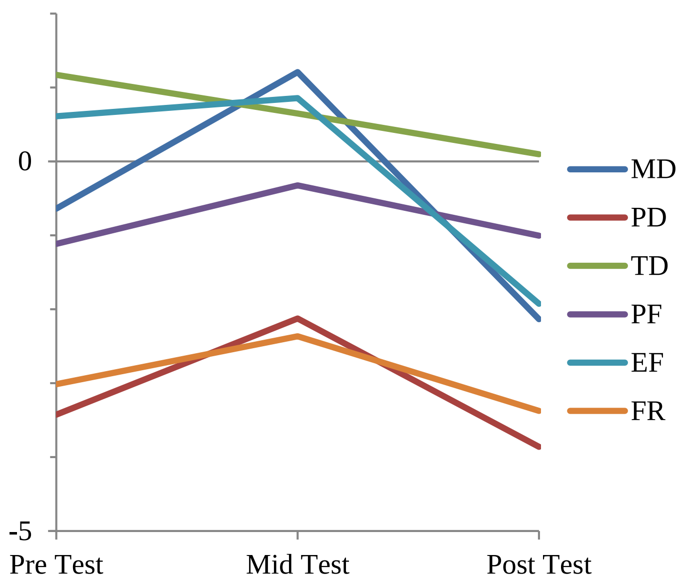

FIGURE 8. Overall change in TLX indices from pre to mid to post tests. Increases in indices are marked in red, and decreases in green. Only significant changes are shown.

many students.

This is probably because students learned perspective drawing and other unfamiliar skills in the sketching skills lecture and were encouraged to do more perspective drawing. The high cognitive load of these new skills probably contributed both to an increase in skill-set and personal inhibition and a decrease in skill [32, 33]. In the long-run, however, these same measures seem to have decreased, suggesting that the sustained efforts to encourage sketching over the semester were successful in both encouraging quick sketching and reducing inhibition.

6.4 Other Observations Made at the Length of the Study

We did not make a count of notebook sketches since this metric is meaningless without a comparison group to see if the sketches increased or not. However, we did glance through nearly half the notebooks for the class, and we saw that the majority of the notebooks only included sketches from the sketch skills training lecture. A few students had 4-6 sketches beyond this, some of which appeared to be individual idea generation, but the majority had 0-1 additional sketches. Idea generation for the toy course was conducted on sheets outside the notebooks, so these sketches are not recorded here, meaning the notebook would only contain personal work outside the idea generation sessions.

7 IMPLICATIONS AND CONCLUSIONS

The results suggest some interesting possibilities, including partial success and some room for improvement. The survey results show that the students enjoyed the sketching activities and felt less inhibited as a result of the process. Many students also described a boost in creativity. On the other hand, though, the TLX indices do not support their report. Most students reported a short-term increase in mental demand and effort. This probably means that teaching sketching skills shortly after these exercises caused students to focus too much on these skills [32,33], and not on fluid sketching. Over the long-run, TLX measures showed decreases in personal or skill-set inhibition, but it is not clear if this is due to sustained emphasis on sketching by the instructors or due to practice effects (which are desirable in this case).

These results imply that some aspect of formal sketch training may be inhibiting students from sketching frequently and often. This result has been seen in other studies where exposure to new skills also increased inhibition, until those skills were mastered in which case inhibition was lowered [20]. This also corresponds with learning theory, which states that cognitive loads are higher immediately after learning a new skill [33]. From what we saw in the sketches between the pre and post tests, it appears that perspective drawing is a significant source of inhibition for most of the students.

The results also imply that a sustained emphasis on sketching over the course of the semester may have a significant impact on the inhibition students feel toward sketching. The sketching inhibition exercises may serve their purpose by simply creating an open environment, and not have any real long-term effect. If this is true, this means that inhibition may be best reduced by frequent emphasis on creativity, openness, and quick sketching.

7.1 Recommendations and Future Work

Based on the comments from the students and implications from the TLX surveys, future inhibition lectures should be shorter (around 30 minutes), include novel and unexpected mediums such as finger-paint or crayons, and be coupled with an environment where all levels of sketching are encouraged unconditionally. Furthermore, sketching training should focus less on complex skills such as perspective drawing and other skills that require extensive practice. Sketch inhibition and sketch training exercises should focus on reducing the perceived and actual need for higher-level sketching skills. Sketch training should focus on skills that add the most value for the least cost or effort, such as annotating sketches [17, 18].

Future work in this area should focus on better metrics for inhibition and closely examine what exercises or environments best reduce inhibition. Future studies should also include comparison groups, but continue to test participants at the length of a semester or longer. Additionally, more direct interventions are needed to emphasize the need for rapid sketching to students. These results tentatively suggest that sketch inhibition is reduced by actively promoting creativity and sketching, and by deemphasizing the importance of higher-level skills such as perspective drawing. Future studies may also explore correlations between PSVT scores and sketch inhibition metrics, as there are some cognitive similarities between the two activities.

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