



The Napkin Sketch Pilot Study: A minute-paper reflection in pictorial form

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ABSTRACT

This paper presents an evidence-based practice pilot study of the potential cognitive benefits of requiring students to create sketches that summarize course material in ways different than presented in class. This exercise is termed a “napkin sketch” to articulate to students the benefits of simple sketches to communicate ideas – as is often done by engineers in practice. The purpose of the study was to investigate how this napkin sketch activity addresses three concerns of engineering educators: creativity, visualization and communication, and knowledge retention. Specific objectives of the study were to generate conclusions regarding the activity’s ability to (1) provide an outlet for, and a means of encouraging creativity, (2) provide an opportunity for students to visualize and communicate what they have learned through drawings rather than equations or writing, and (3) encourage knowledge retention by providing a mechanism for students to think about and describe concepts learned in the classroom differently than for other requirements. The scope of this paper includes the generation, implementation, and analysis of the napkin sketch activity in three civil engineering courses across eight different class sections in the spring and fall of 2019 at the U.S. Military Academy, a small, public, undergraduate-only four-year college in the northeast United States. The motivation for the study stems from evidence-based practices of re-representation from educational psychology, minute papers from educational research, the growing shift to computer-aided design and away from hand drawing, and recent research suggesting our engineering programs may be degrading student creativity. A between-subjects quasi-experimental setup examined four activity implementations and 249 sketches were collected. Sketch creativity was assessed by three instructors using a creativity rubric adapted from literature. The sketch creativity scores, along with individual student academic and course performance data, were analyzed using standard least squares regression and machine learning techniques to investigate the effect of sketching on creativity and understanding of course material. An anonymous and optional survey was also provided to a total of 56 students, with 21 students responding (37.5%). The following key conclusions can be drawn from the study: (1) the activity does encourage students to think about the material differently, and provides a means for creative students to express lesson content creatively; however, assessment bias, selection bias, and the inherent difficulty in assessing creativity does not allow us to draw conclusions about the creativity of engineering students in any absolute sense from the collected data; (2) incorporating an emphasis on freehand sketching into the engineering curriculum could have positive effects toward developing creativity and pictorial communication skills; (3) there was evidence in the data suggesting that the sample populations examined in the study are experiencing degradation in creativity between sophomore and senior level coursework, which was an idea expressed in the literature; (4) the sketch creativity scores are higher when it is conducted after blocks of material and performed outside of class.

INTRODUCTION

This paper presents an evidence-based practice pilot study of the potential cognitive benefits of requiring students to create sketches that summarize course material in ways different than presented in class. This exercise is termed a “napkin sketch” to articulate to students the benefits of simple sketches to communicate ideas – as is often done by engineers in practice. The purpose of the study was to investigate how this napkin sketch activity addresses three concerns of engineering educators: creativity, visualization and communication, and knowledge retention. Specific objectives of the study were to generate conclusions regarding the activity’s ability to (1) provide an outlet for, and a means of encouraging creativity, (2) provide an opportunity for students to visualize and communicate what they have learned through drawings rather than equations or writing, and (3) encourage knowledge retention by providing a mechanism for students to think about and describe concepts learned in the classroom differently than for other requirements. Additional outcomes of the study included identifying the most appropriate pedagogical implementation of the exercise. The scope of this paper includes the generation, implementation, and analysis of the napkin sketch activity in three civil engineering courses across eight different class sections in the spring and fall of 2019. The motivation for the study stems from evidence-based practices of re-representation from educational psychology, minute papers from educational research, the growing shift to computer-aided design and away from hand drawing, and recent research suggesting our engineering programs may be degrading student creativity. It was hypothesized that the activity would pull students out of their regular academic mindset, encourage creative thinking, encourage visualization and the use of an international form of communication, and improve knowledge retention.

After summarizing current literature relative to the areas of concern that this activity was designed to address, this paper provides details about the implementation of the napkin sketch. Data gathered for this project included (1) a numerical assessment of the creativity demonstrated by each sketch generated by students using a rubric adapted from the literature, (2) academic performance on the term end exam (TEE) and overall course grade, (3) and incoming GPA, academic major, and class year. Comprehensive statistical analysis was completed to quantify the influence of the napkin sketch and other variables (such as incoming GPA) on academic performance as captured in TEE and overall course grades. Conclusions from this analysis are described, and ideas to improve the implementation of the napkin sketch in future semesters are summarized.

BACKGROUND

As described above, this project sought to understand how the napkin sketch addresses three concerns: (1) creativity, (2) visualization and communication, and (3) knowledge retention. This section is sub-divided to briefly summarize the current state of our profession’s understanding of these three areas.

The creativity problem

An engineer’s ability to innovate is critical to solving problems and “developing new or improved products and services [1].” To be *innovative*, a person must have a certain level of *creativity* and *imagination*. Robinson provides definitions for these three terms that differentiate them while describing how they are linked: “*imagination* is the ability to bring to mind events and ideas that are not present to our senses ... *creativity* is having original ideas that have value

... [and] *innovation* is putting original ideas into practice [2].” While broad, this definition for creativity will be used throughout this study for its simplicity and for the fact that organizations such as the National Academy of Engineering (NAE) and the American Society of Civil Engineers (ASCE) refer to, and use, the term *creativity* in a broad sense.

Both NAE and ASCE have noted the importance of developing creativity skills. NAE states that “creativity ... is an indispensable quality for engineering, and given the growing scope of the challenges ahead and complexity and diversity of the technologies of the 21st century, creativity will grow in importance [3].” More recently, ASCE “calls for civil engineers to be innovators and integrators of ideas and technology ... [therefore,] civil engineers must be creative, dependable, flexible, and curious about new ideas [4].”

While these professional bodies call for engineers to be creative, it is uncertain how these critical skills are being developed in undergraduate engineering curricula. Certainly, students are occasionally required to demonstrate creativity and innovation in projects, particularly capstone projects at the end of their undergraduate education. However, in many cases, these students are not adequately educated and equipped with the skills required to be creative and innovative. A recent study suggested that engineering students lose creative ability from freshman to senior year [5]. This may be due to naturally creative students leaving engineering programs to pursue other interests. However, it may also be due to the nature of engineering programs emphasizing analytical skills to the detriment of divergent thinking skills [6].

Because creativity is a topic often studied by psychologists and is more difficult to assess or measure than the focus of traditional engineering research, engineering educators may be hesitant to attempt to develop the necessary skills in their courses and curricula. However, it is essential to acknowledge that these skills can be taught in engineering courses [2], [7]–[12]. The challenge for engineering educators is to decide how best to include the development of these skills in their courses while still ensuring students master the vital engineering content. As suggested in Sunni Brown’s book “The Doodle Revolution,” one such method could be to simply *doodle*. Brown defines *doodling* as “making spontaneous marks to help yourself think,” and her book summarizes research indicating that those who doodle when exposed to verbal information retain 29% more information than non-doodlers, that *doodling* engages multiple learning modalities simultaneously, and that it may be crucial for creativity [13].

Once an educator has decided to integrate creativity and innovation skill development into the courses they teach, another critical challenge is to decide how to assess how well their students are developing these skills. Unlike most engineering topics, these skills cannot be accurately assessed using traditional assessment methods such as exams. They can, however, be assessed by other methods; validated techniques and rubrics to assess the creativity of people, processes, and products exist in the literature [14]–[17].

This pilot study followed a broad definition for creativity, built upon research demonstrating that creative skills can be developed, and that there is a potential connection between drawing and creativity. The study also utilized an assessment rubric adapted from the literature. Details of the technique and assessment method are described later in the paper.

The visualization & communication problem

Consider three potential scenarios involving engineering students, faculty, or practitioners:

1. Two engineers went out to lunch. The conversation meandered but naturally returned to the current design problem at work. One engineer had an idea, pulled out a pen while reaching for a napkin, and began to sketch.

2. An engineering student visited an instructor during office hours and asked a question. Pausing for a moment to decipher the question and determine a precise method of addressing it, the instructor instinctively turned to the chalkboard and began to draw a picture.

3. Members of an architectural and engineering firm were in the early stages of design. To generate and share ideas quickly, they relied on the most basic of drafting tools – paper and pencil – and generated dozens of simple sketches.

The commonality in these scenarios is the reliance on free-hand sketches to assist in visualization and communication. Sketching has been found to have “a positive impact on the quality of the designed solution and the individual experience of the design process [18].” The “self-made sketches [...] support the limited human memory capacity and mental processing for a detailed problem analysis [18].” Additionally, “since the design process is strongly influenced by feedback and dialogue, the communicative function of sketches is also of great importance in the daily design practice [18].”

Despite the acknowledged importance of sketching, “computer-aided-design classes have largely replaced those dealing with engineering drafting, resulting in an often-heard criticism of today’s faculty that engineering students are no longer able to express themselves using simple freehand drawings [19].” The napkin sketches employed in this study present a simple freehand sketching activity that encourages students to visualize and communicate lesson material in pictorial form.

The knowledge retention problem

Educators want their students to obtain deep and long-lasting understanding, and the first step in developing understanding is retaining the lesson material. Multiple sources indicate that active learning and reflection are useful strategies for retention and understanding [20], [21]. A recognized best practice for encouraging active learning and reflection is the “minute paper,” which “is typically assigned at the end of a class, and requires each student to briefly write down answers to two questions, generally: (1) What was the most important thing you learned in class today? and (2) What question is unanswered? As the name suggests, students are given a minute or two to complete the exercise. After collecting the papers, the lecturer reads the answers and ideally responds to them in the next class, or privately on an individual basis [22].”

While proven useful to instructors and students, the traditional minute paper is constrained to the expression of ideas in a medium used throughout all of academia – writing. As Fernandez et al. indicate in their 2018 research, self-generated sketches may be more effective. “Gains [in knowledge retention] are greater from drawings than from other known mnemonic techniques, such as semantic elaboration, visualization, writing, and even tracing to-be-remembered information [23].” Drawing potentially “improves memory by promoting the integration of elaborative, pictorial, and motor codes, facilitating the creation of a context-rich representation

[23].” Additionally, the person-action-object (PAO) system used by memory masters to rapidly memorize long strings of random numbers or randomly shuffled decks of cards relies on the conversion of numbers (or cards) into images, suggesting that images are easier to remember than the original string of numbers or cards [24]. With this in mind, the “napkin sketch” activity studied in this paper is similar to a “minute paper” but with the constraint of being in pictorial form.

EXPERIMENTAL METHODOLOGY

The “Napkin Sketch” Activity Design

Inspired by the available literature, the authors created the “napkin sketch” activity for students to complete. Originally, this activity was intended to be completed at the end of a class period as a way for students to summarize the main concepts from that lesson in a unique way. Students were encouraged to be creative – that is, to draw from experiences beyond the classroom to represent important concepts in a way that would be meaningful to them in the future. To provide a standardized form that reduced distraction from the intended activity, students were given a half-sheet of paper with specific instructions and space to create their sketch (see Figure 1). To not influence individual students’ creativity, no other details or examples were provided to students beyond the instructions on the sheet.

Name:
Lesson Title:
Sketch:
Written Description:
Directions: * Draw a creative sketch that helps you remember a key point from today's lesson. * No copying my in-class examples! * Minimal words & equations in the sketch. * The written description should explain the sketch (to help me interpret your creativity)

Figure 1: Napkin sketch student handout on a half-sheet of paper

Note: Directions at the bottom of the handout state: Draw a creative sketch that helps you remember a key point from today’s lesson; no copying my in-class examples! Minimal words & equations in the sketch; the written description should explain the sketch (to help me interpret your creativity)

This study was conducted at the U.S. Military Academy, a small, public, undergraduate-only four-year college in the northeast United States. The department in which it took place offers two

ABET-accredited engineering programs and graduates around 130 students between the two programs each year.

A between-subjects quasi-experimental setup was used, meaning students were not randomly assigned, and each student only completed the napkin sketch activity in one of four conditions: (1) an initial trial test where students completed the activity at the end of each lesson; (2) students completed the activity at the end of each lesson but were provided the opportunity to execute the activity at any time during the lesson; (3) students completed the activity outside of class after each lesson; and (4) students completed the activity outside of class after blocks of lessons. Results from condition (1) were used by the authors to inform subsequent iterations of employing this exercise in the other three conditions. For this reason, detailed assessment data from condition (1) was not included in this paper, and it is not included in Table 1, which displays the details of each treatment group.

Table 1: Treatment Group Test Matrix

Group ID	No. of students (<i>n</i> students)	No. of sketches (<i>n</i> sketches)	Course	Instructor	Activity location	Activity frequency	Grade value	Type of students
I-A	16	91	Engineering Mechanics	A	In class	Every class	None	Sophomore - Senior
II-B	32	53	Engineering Mechanics	B	Outside of class	Once per block of instruction	None	Sophomore - Senior
III-A	9	105	Advanced Geotechnical Engineering	A	Outside of class	Every class	None	Senior
Total	57	249						

Initial trial test

The initial trial test was conducted in a sophomore-level mechanics of materials class ($n=49$) in the spring of 2019. Similar to a minute paper, students were given five minutes at the end of class to conduct the ungraded activity and turn it in. This trial run suggested that the time allotted and instructions given for the activity would have a significant influence on its effectiveness; it was observed that students spent three to four of the five minutes trying to absorb the lesson and mentally convert it into a creative image, leaving the last minute of class to quickly scribble down a sketch. Anecdotal feedback from students and faculty suggested the exercise had value but was rushed. Based on these observations, it was hypothesized that more time for the reflection and creative processes to occur would influence the benefit to students from creating napkin sketches. This was examined in the fall of 2019 by incorporating the activity using three different test treatment groups with different implementation strategies.

Treatment group 1-A

Treatment group I-A consisted of one section of a sophomore-level introductory engineering mechanics course taught by instructor A. Students were given the napkin sketch paper (Figure 1) at the start of class, along with a verbal reminder to think about the activity and a reminder that it would be collected at the end of class. Any time remaining at the end of the lesson was given to the students to complete the activity. Initiating the activity at the start of class was intended to encourage students to generate ideas throughout the lesson and complete the activity at the

moment an idea came to them. This implementation of the activity remained true to the canonical minute-paper in that it was completed during class time and had no grade associated with it.

During each lesson in which new material was presented (i.e., not problem-solving, lab, or exam days), students were asked to fill in each portion of the napkin sketch (Figure 1). Directions were provided verbally and visually by the instructor during class and were also reiterated at the bottom of the half-sheet, as seen in Figure 1.

Treatment group II-B

Treatment group II-B consisted of two different sections of the same engineering mechanics course as for group I-A. These two sections were taught by instructor B and students were asked to conduct the activity outside of class on their own time. However, the activity was only conducted on entire blocks of material, typically consisting of five to seven lessons. Conducting the activity outside of class was intended to remove all time restrictions, and conducting the activity after each block of material provided multiple lessons worth of time and instruction to absorb and comprehend the material. This implementation of the activity moved away from the canonical minute-paper format in an attempt to examine the impacts of available time that seemed to negatively impact the spring 2019 trial run.

Treatment group III-A

The final treatment group, Group III-A, consisted of one section of a senior-level advanced geotechnical engineering course taught by instructor A. Students in Group III-A were asked to conduct the activity outside of class on their own time, but in this implementation, they conducted the activity after each lesson. Conducting the activity outside of class was intended to remove all time restrictions, and conducting the activity after each lesson was intended to generate a mental image for each lesson, similar to the PAO system described previously as a method of retaining long strings of information. This implementation again moved away from the canonical minute-paper format in an attempt to examine the impacts of available time that seemed to negatively impact the spring 2019 trial run.

Treatment groups I-A and II-B consisted of a variety of engineering majors and non-engineering majors ranging from sophomores to seniors who were required to take a three-course engineering sequence to meet graduation requirements. Treatment group III-A consisted entirely of civil engineering majors in their senior year.

Napkin Sketch Assessment and Feedback

Throughout the semester, instructors collected the sketches, scanned copies, and returned the originals to the students. Limited feedback was provided to students and the sketches were not graded for accuracy or creativity. A creativity rubric adapted from Brookhart (2013) was used to assess the creativity of the sketches for the purposes of the study (see Appendix A) [16]. This rubric assessed creativity within four areas: depth and quality of ideas, variety of sources, organization and combination of ideas, and originality of contribution. Each area was scored on a scale of 1 (Imitative) to 4 (Very Creative). The maximum creativity score possible was 16. Knowing that the definition we used for creativity was broad, the rubric provides additional detail about the expectation of creativity intended to be exhibited in the sketches produced by students. It describes that creativity involves drawing from a variety of contexts and sources and combining them in ways that are unique to achieve the intended purpose. This rubric was not

provided to students, so their understanding of what was expected by the instruction to “draw a creative sketch” was not standardized; nor were the results of the assessments provided to students. To improve understanding of expectations in future iterations, it is planned to provide the rubric to students at the start of the term and provide feedback to them as the term progresses.

Although assessment bias could not be eliminated from the sketch assessments, a deliberate effort was made to ensure all instructors were assessing the sketches according to the same standard. Three civil engineering instructors met to discuss the sketch assessment rubric and metrics to ensure there was a common understanding of how sketches should be assessed. The three instructors then independently assessed all sketches using the creativity rubric to generate a composite score for each sketch. Each student’s average earned creativity score was then computed across all three instructor assessments to balance the inherent assessment bias in analysis of the students’ sketch performance. Examples of student sketches and their associated creativity scores are included in Appendix B.

The sketch creativity scores, along with individual student academic and course performance data, were analyzed using standard least squares regression and machine learning techniques to investigate the effect of sketching on creativity and understanding of course material. At the end of the semester, students were provided an opportunity to complete an anonymous and optional survey regarding the activity. Finally, instructors A and B who conducted the napkin sketch activity in their courses recorded personal observations regarding the execution of the activity and its usefulness as a quick and informal assessment of student understanding.

RESULTS AND DISCUSSION

249 sketches across the three test treatment groups were collected. Data analysis of the creativity and academic and course performance parameters within each treatment group was conducted with a significance level (α) of 0.05, corresponding to a 95% confidence level for statistical testing procedures. The anonymous and optional survey was also provided to a total of 56 students, with 21 students responding (37.5%).

The analysis focused on several areas related to the three concerns described previously: (1) creativity, (2) visualization and communication, and (3) knowledge retention. First, data analysis helped identify factors that influenced the creativity demonstrated in the napkin sketches. Second, a quantitative assessment of the usefulness of the napkin sketch to demonstrate student understanding of the material by the visualization created was conducted and related to general communication abilities. Third, a variety of data analysis techniques were used to investigate the influence of the napkin sketch on student ability to retain knowledge gained in the course during the semester. Because of the data available, additional questions were able to be addressed: (i) what factors may influence how well creativity is demonstrated in the napkin sketches, (ii) the usefulness of the napkin sketch as an assessment tool, and (iii) the role that the various implementation methods played in the resulting quality of the napkin sketches. This section reports analysis results for the three primary areas of concern before beginning to answer the three additional questions described.

Napkin Sketch Creativity

Using the creativity rubric adapted from Brookhart (2013) (see Appendix A), the average creativity assessment score was 6.55 out of 16 for all 249 sketches. With the lowest possible score being 4.0, an average of 6.55 indicates that sketch creativity, as assessed by the rubric, was low for all treatment groups. Treatment group I-A had an average score of 6.40, treatment group II-B had an average score of 7.11, and treatment group III-A had an average score of 6.41. Figure 2 depicts the distribution of sketch creativity scores by treatment group. Despite the overall low scores, a few students consistently demonstrated higher creativity sketch scores, suggesting that the activity may provide an outlet for creativity if creative sketching ability is present to begin with.

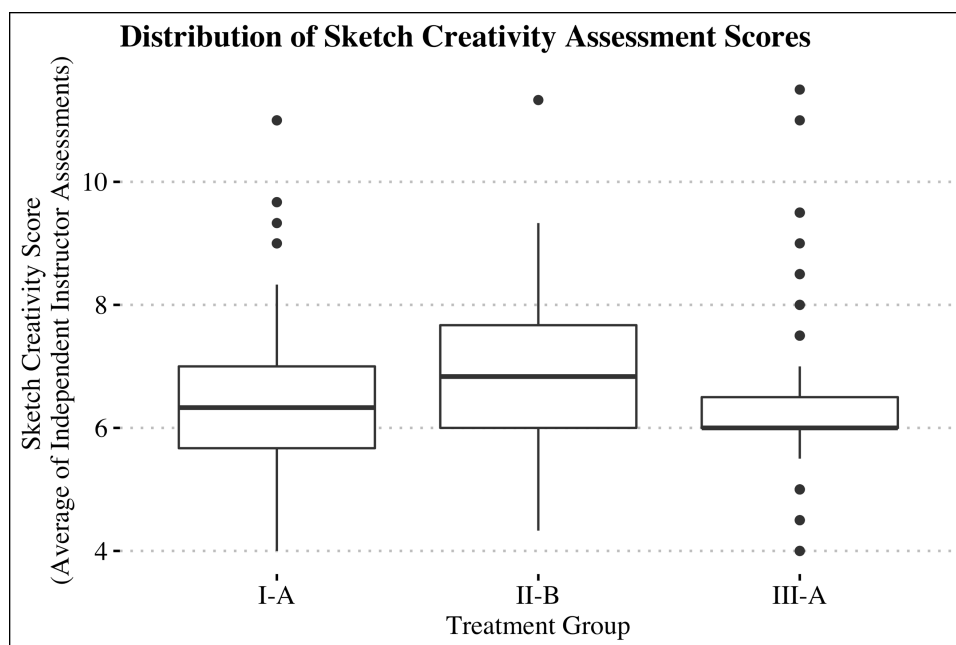


Figure 2: Sketch Creativity Assessment Scores by Treatment Group

While the creativity assessment suggested low creativity exhibited in the sketches, the survey responses (Table 2) indicate that the activity encouraged many students to think about the material differently. The distribution of each Likert response is generally normal, with a negative skew – distribution toward “agree.”

While not definitive, the few high creativity sketch scores, along with the survey results that tend toward “agree,” suggest that the napkin sketch activity provided an outlet for, and a means of, encouraging creativity, especially for those individuals who already had an inclination for creative drawing. Further studies should examine refining the creativity assessment rubric, and employ an experimental design that limits the number of variables and isolates the effects of confounding variables.

Table 2: Student Survey Questions

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Thinking of what to sketch encouraged me to think more deeply about the lesson material.	4.8%	33.3%	14.3%	38.1%	9.5%
The napkin sketch exercise helped me generate methods to remember the engineering concepts.	4.8%	23.8%	28.6%	38.1%	4.8%
The napkin sketch activity encouraged me to think about the lesson material in a different manner.	4.8%	14.3%	4.8%	61.9%	14.3%
Sketching ability is important to my career.	0.0%	14.3%	28.6%	52.4%	4.8%
The napkin sketch activity made me feel more confident in expressing my ideas through drawing.	9.5%	23.8%	23.8%	41.9%	0.0%
I'm a creative person	9.5%	14.3%	38.1%	33.3%	4.8%
I enjoyed the napkin sketch activity	9.5%	9.5%	33.3%	38.1%	9.5%

During tests, did you ever recall any of the pictures you drew during the napkin sketch activities?	7: Yes	4: No
Another common end-of-class reflective activity is the "minute paper," where students write a paragraph about what was taught in the lesson. Which do you feel is more beneficial to the student: a minute paper, or a napkin sketch?	16: Napkin Sketch	4: Minute Paper 1: "neither"

The Napkin Sketch and Visualization and Communication of Course Content

The second purpose of the napkin sketch activity was to provide an opportunity for students to visualize and communicate what they have learned through drawings rather than equations or writing. While some students did not follow the directions and ended up rewriting some equations for their sketch, most students completed the sketches as instructed. As indicated in the survey, the activity encouraged students to think about the material differently.

Within the context of each lesson, all sketches successfully communicated an aspect of the lesson, demonstrating that the students were able to visualize and communicate via drawing. However, the free responses of the survey indicated that students believe a drafting class may be more beneficial to developing pictorial communication skills. Since sketching skill was not a key outcome of the courses in which the activity was administered, time was not dedicated to teaching the skill. However, if a course intends to develop sketching as a skill, the napkin sketch activity provides an opportunity to generate more practice repetitions for the students.

The Napkin Sketch and Knowledge Retention

The third purpose of the napkin sketch activity was to encourage knowledge retention by providing a mechanism for students to think about and describe concepts learned in the classroom differently than for other requirements. The analysis required to address this was more detailed than for the previous areas being investigated. To understand the influence that napkin sketches may have had on knowledge retention, it was important to consider other variables that

influence retention, such as academic aptitude (as measured by incoming GPA) and academic maturity (as measured by year in school). Two methods were employed to conduct this analysis: (1) least-squares regression modeling and (2) random forest ensemble machine learning.

Predicting Exam Performance with Least Squares Regression Modeling

Major graded events like the term-end exam (TEE) are the best measures of knowledge retention for the course and are therefore the most logical starting point when investigating the impact of the napkin sketch activity. These exams typically are unchanged from semester to semester and are graded by a pool of faculty using the same cut-scale as in previous semesters. Each assessed sketch was related to the student that completed it, and a record was compiled for each participating student consisting of their incoming GPA, TEE score, academic major, the average of their sketch creativity scores, the maximum score earned on any of their sketches and a number of other factors. With the data cleaned and organized, it was apparent that only the engineering mechanics course produced normally distributed exam scores with consistent variance, and so the data was subsetting to focus on those records only. A least-squares regression model was fit to the data with TEE score as the response variable, and incoming GPA, academic major, average sketch creativity score, and total sketch creativity scores by student as the independent variables.

Regression modeling indicates statistically significant results and suggests a positive relationship between sketching and TEE scores. All four predictor variables had p -values less than 0.05 (Table 3), indicating a statistically significant predictor at the 95% confidence ($1-\alpha$) level. While a p -value less than 0.05 indicates statistical significance, values less than 0.0001 provide compelling statistical significance.

Table 3: Regression Model Effects Summary

Source	Number of Parameters	Degrees of Freedom	Sum of Squares	F-Ratio	p -value (Prob > F)
Average Student Sketch Score	1	1	1225.05	8.99	0.0036
Total Student Sketch Score	1	1	687.75	5.05	0.0274
Major	12	12	86637.75	53.01	<0.0001
Incoming GPA	1	1	58635.75	430.51	<0.0001

Note: Table 3 reports a summary of the effects of the regression model and indicates the statistical significance of the effect of sketching on TEE performance. This analysis indicates some relationship between all predictor variables and TEE score.

Further interpretation of the regression model results is useful, as it provides insight into the relative effects of each of the predictor variables on the model for TEE performance. This analysis can inform future studies and help to better understand the effect of changing variable inputs. For example, analysis indicates that for each one-point increase in the average sketch score, a student's TEE performance increases by an average of seven percentage points. This indicates that students who produced more creative sketches tended to perform better on the TEE. Admittedly, the effect of sketching on TEE performance is confounded by the motivation of the student to complete a quality sketch with minimal incentive.

While this presents a shortcoming in the initial implementation and does not allow for the assignment of causality to the sketching exercises themselves, the early results provide sufficient

motivation for a designed investigation in future semesters. A future experiment would strive to separate the effects of motivation and the act of sketching, such that a judgment could be made regarding the effect of sketching on knowledge retention. The complete regression estimate output is shown in Table 4, which details the parameter estimates for each term in the regression model as they relate to their p -values for statistical significance. The estimate column reports the coefficient of each term in the model that predicts TEE score.

Table 4: Regression Output of Term-End Exam Performance Prediction

Term	Estimate	Std Error	t -Ratio	p -value (Prob> t)
Intercept	18.899	15.420	1.23	0.2240
Average Student Sketch Score	7.301	2.434	3.00	0.0036
Total Student Sketch Score	0.299	0.133	2.25	0.0274
Major [civil eng.]	-19.317	4.953	-3.90	0.0002
Major [english]	34.468	3.912	8.81	<0.0001
Major [engineering management]	1.399	12.712	0.11	0.9126
Major [chinese]	16.330	5.994	2.72	0.0079
Major [human geography]	-25.261	4.246	-5.95	<0.0001
Major [geospatial information systems]	9.907	5.051	1.96	0.0533
Major [US history]	-44.393	4.963	-8.95	<0.0001
Major [mechanical engineering]	30.288	6.592	4.59	<0.0001
Major [business management]	54.554	4.542	12.01	<0.0001
Major [international affairs]	-66.858	5.798	-11.53	<0.0001
Major [psychology]	53.563	11.166	4.80	<0.0001
Major [systems engineering]	-9.676	4.174	-2.32	0.0230
Incoming GPA	111.296	5.363	20.75	<0.0001

The execution of the sketching exercises varied with each implementation trial, and in all instances, the completion of quality sketches was not formally linked to course grade with points. Selection bias affects the data because students who voluntarily completed highly creative or quality work may also be intrinsically motivated to learn and do well. Therefore, student motivation is a confounding factor in the current data. Future experiments should eliminate this selection bias to better isolate the effects of the sketching exercises – regardless of the intrinsic motivation of the students. This could be accomplished by requiring sketch completion for a carefully selected quantity of course points.

In addition to assessing the effect of student sketch performance on knowledge retention, the impact of the sketching activity itself was examined. In the engineering mechanics course, the mid-term exams and TEE were identical to those given the previous year where sketches were not implemented, allowing for an analysis of the activity itself. The data was subsetted to isolate a single instructor in a single course across two different semesters. Data from student sections where the sketches were not implemented in the previous semester were compared with the sections in which the sketching exercises were implemented. Although this was not a designed experiment (sketching was not randomly implemented across sections and other variables controlled) and causality cannot be inferred from the results, it is possible to infer the effects of the sketching exercise and inform future experiments.

A model was fit to predict TEE score based on other variables collected in the study. When fitting a multiple linear regression model with class, major, GPA, and a binary variable that captured whether the napkin sketches were implemented for that student or not, the only

significant variable was incoming GPA. To improve the design of future experiments, understanding the relative variable importance is beneficial. For example, measuring relative variable importance would help indicate how important sketch performance was compared to the other variables captured in the data. Therefore, to infer relative variable importance, an algorithmic model building method like machine learning is preferred to a statistical method.

Predicting Exam Performance with Random Forest Ensemble Machine Learning

For data collected in the engineering mechanics course with the same instructor for semesters in which the napkin sketch was and was not employed, a random forest ensemble machine learning model was generated with TEE grade as the response variable and predictor variables of class year, major, GPA, sketch score, and a binary variable that showed whether the napkin sketches were implemented for that class section or not. The random forest model, with a residual standard error (RSE) of 5.14 TEE percentage points, was more accurate than the statistical model, which had an RSE of 9.18. In the random forest algorithm, one can determine relative variable importance by randomly permuting values of each attribute in the model and determining the effect on the model's prediction accuracy [25].

The model showed that GPA was by far the most important variable, followed by whether the sketches had been implemented or not. Additionally, the effect of the sketch exercise was approximately 20% as important as GPA when predicting TEE scores. This is not surprising; academic aptitude, as measured by GPA, is a better predictor of performance in current courses than one specific exercise. Other influencing factors of GPA, like work ethic, study habits, intelligence, and motivation, are likely the most important drivers of knowledge retention. Like the least squares regression model, this analysis does not allow for the assignment of causality to the sketching exercises themselves but does provide sufficient motivation for a designed investigation in future semesters. A future experiment would strive to separate the effects of motivation and the act of sketching.

Incoming and Outgoing Grades as Predictors of Sketch Performance

In considering whether student sketch performance had an effect on their course performance, the course grade was modeled as a function of sketch creativity score, while controlling for the effects of class year, course, instructor, and grade point average using ordinary least squares (OLS) regression. Sketch score was not a significant predictor of course grade, while grade point average and one instructor had a significant positive effect on course grades, and course (engineering mechanics) and the class year 2021 had a significant negative effect on course grades. Interpretation of this result could be that student and instructor motivation are the most significant predictors of course performance, while actual sketch performance does not directly impact performance in the course as a whole.

Student Graduating Class as Predictor of Sketch Performance

In considering which factors had a significant correlation with student creativity, the sketch creativity score was modeled as a function of course exam grades, class year, major, course, instructor, and grade point average using OLS regression. Graduating class (graduation year 2022), major (Systems Engineering), and one course exam had significant non-zero effects on sketch scores. The class of 2022 scored an average of 1.24 points higher on the sketches than students from the classes of 2020 and 2021. This result supports the literature that creativity may

decline over the course of the undergraduate engineering education [5]. However, at the U.S. Military Academy, it is typical that higher-performing and motivated sophomore students take the studied courses with junior or senior students, indicating that motivation may again be a confounding variable.

The 15 Systems Engineering majors scored an average of 1.23 points higher on the 16-point sketch assessment scale than Civil Engineers (sample size of 131). The Systems Engineering curriculum is known to include more coursework that pushes students to think critically and creatively about mapping complex system dynamics and analyzing complex adaptive systems, possibly attracting a different type of thinker than Civil Engineering. This result indicates that it is possible that certain majors may attract students that are more inclined to be creative, or that those majors develop creativity to a higher degree than other majors, or both.

Research suggests it is possible that foundational coursework in engineering education (i.e. statics, solid mechanics, dynamics, etc.), while integral to the development of young engineers, can stifle creativity. As students struggle with “what to think” in these fundamental courses, it is often at the expense of creativity. Additionally, these courses typically emphasize convergent thinking as students work toward a single correct answer. Creativity requires divergent thinking in which students explore a variety of potential answers in a much more circuitous manner. It has been suggested that the lack of opportunity to practice divergent thinking in engineering courses contributes to the observed degradation of creativity in senior engineering students when compared to freshmen. [5], [6] Therefore, it is paramount to incorporate opportunities for students to develop creative thinking skills in early engineering courses.

Pedagogical Assessment of the Napkin Sketch

While the primary purposes of the study were discussed above, there were two other areas worth investigating: (1) the usefulness of the activity as an assessment tool, and (2) the influence of different implementations of the activity.

The Napkin Sketch as an Assessment Tool

As an ungraded event, the napkin sketch was not an evaluation, but it did provide a mechanism for the instructors to assess student understanding. The authors found assessing the sketches was more enjoyable than reading minute papers, and seemed to provide a better reflection of student understanding (or lack of understanding) than writing about a particular topic. However, the authors also believe that the sketches did not necessarily provide a substantial assessment benefit compared to the already in place reading quizzes and in class questioning of students. In short, the napkin sketch activity is an assessment tool best used if time is available, otherwise the opportunity cost of not performing other activities most likely outweighs the activities benefits.

The Napkin Sketch Implementation

As described previously, the napkin sketch was implemented in three different ways. The distributions of sketch scores for each treatment group were shown in Figure 2. Treatment Group I-A, which was conducted in class with each sketch representing a single lesson, had an overall average creativity score of 6.41 out of 16. Because sketch implementation I-A was below the overall sketch creativity average score, it may not be the best strategy to pursue in the future. A combination of factors made implementation of I-A difficult. First, many students simply forgot

or chose not to participate in the activity. The sketch paper that was on their desks upon entering the class was quickly pushed to the side, sometimes even placed under seats and forgotten about. Second, many lessons were packed with instruction, leaving no time to squeeze the activity in at the end of class. During these lessons, only those students that were motivated to conduct the activity and actually performed it during class were able to submit sketches for the lesson. Finally, and perhaps most importantly, survey results indicated that students struggled with having enough time to absorb the lesson material, mentally convert it to a creative image, and then sketch their idea.

In Treatment Group II-B, which implemented sketches outside of class, time restrictions were effectively removed and each sketch covered a block of material rather than a single lesson. This implementation had the highest overall creativity score with an average of 7.11, which was a statistically greater mean score than both I-A and III-A (p-value of 0.05). This indicates that the II-B sketch implementation method is correlated with higher sketch creativity performance, suggesting that the additional time provided by this method allowed students to better absorb the material, reflect on it, and generate creative sketches. However, this treatment group also had a different instructor than the I-A and III-A treatment groups, so the effect of the instructor is confounded with the effect of the sketch implementation. This will be an important consideration for follow-on studies, ensuring that sketch implementation is not confounded with any other variables. Additionally, as suggested in the survey, it may be worthwhile to add points to the activity to encourage participation.

In Treatment Group III-A, students were also asked to conduct the activity outside of class on their own time, but after each lesson instead of blocks of material. This implementation had the lowest average assessment score of 6.40. While this low score, as indicated by the machine learning model, was influenced by the fact that the students were all seniors rather than sophomores, it is possible that this implementation may have been overdone. Approximately halfway through the semester the instructor began to observe students completing their sketches in the few minutes before the next class started, just before turning the sketches in. While pleased to see that activity was encouraging the students to recall the previous lesson that occurred at least 48 hours prior, the observation suggested the students may not be willing to put more than two minutes of effort toward the activity and ended up recreating images that had been shown to them in class and were recorded in their notes.

For future use of the napkin sketch activity, it is proposed that the best strategy is to conduct the activity after blocks of lessons and have the students complete it on their own time outside of class. It may also be beneficial to add points for completion of the exercise to encourage participation and recognize the time associated with the reflection activity. However, points associated with “grading” the creativity of the sketch is discouraged, as this can stifle creativity due to fear of earning a bad grade on subjective exercise [10].

CONCLUSIONS

This study presented methods and analysis to better understand the effect “napkin sketches” have on creativity, communication, knowledge retention, and the activity’s effectiveness as an assessment of student learning. The following key conclusions can be drawn from the study:

- 1) The activity encouraged students to think about the material differently and provided a means for creative students to express lesson content in a creative way; however,

assessment bias, selection bias, and the inherent difficulty in assessing creativity did not allow conclusions about creativity of engineering students in any absolute sense from the collected data.

- 2) Incorporating an emphasis on freehand sketching into the engineering curriculum could have positive effects toward developing creativity and pictorial communication skills.
- 3) There was evidence in the data suggesting that the sample populations examined in the study experienced degradation in creativity between sophomore and senior level coursework, an observation expressed elsewhere in the literature. This should be examined more deliberately in a follow-on study that assesses creativity over time.
- 4) Sketch creativity scores increased when the activity was conducted after blocks of material and performed outside of class. It may also be beneficial to allocate course points to completion of the exercise to encourage participation and recognize the time associated with the reflection activity.

PLANNED FUTURE STUDY CONSIDERATIONS

The authors intend to design a future experiment in which confounding effects are isolated, such that causality can more confidently be assigned to the sketch exercises in terms of the effect on creativity and knowledge retention. Planning is underway for a future study in which selection bias will be avoided by requiring sketch completion from all students in the experimental group. Secondly, to isolate the effects of different course material and different instructors, data collection by two or more instructors across two or more courses is necessary. Each instructor, in each of two different courses, will teach a section in which the sketch activity is not conducted (a control group) and a section in which the activity is conducted. This is intended to isolate the effect of different course material and the effect of different instructors from the effect of the sketching exercises. Further, it is planned that sketches will be conducted after blocks of lessons and outside of class to allow for more material to be depicted in each sketch and to remove time constraints that can hinder creativity. However, a more thorough examination of the neuroscience literature will be conducted to better understand potential cognitive benefits of integrating the sketching activity into the lesson rather than tacking it on at the end. The future study will collect the student's major graded event performance and sketch creativity score. As in this current study, each sketch will be assessed by a team of instructors in the study to reduce potential effects of instructor grading biases. Other ideas requiring further research include requiring students to meet a minimum creativity score on their sketches for it to receive a grade, and if sketching is included in the grading, it may be beneficial to also include a sketching challenge on the term end exam.

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APPENDIX A - ANALYTIC RUBRIC FOR CREATIVITY OF NAPKIN SKETCH*

Name of person who created the napkin sketch: _____

Name of person conducting the assessment: _____

INSTRUCTIONS: Assess the napkin sketch in each of the four areas below by recording the number associated with the statement that most accurately reflects your observation. Sum the scores for a total score (maximum score of 16; minimum of 4). Each sketch will be independently assessed by at least three individuals and the average rating will be used as the final assessment.

	Very Creative (4)	Creative (3)	Ordinary (2)	Imitative (1)	SCORE
Depth and Quality of Ideas	Startling variety of important concepts from different contexts	Important concepts form different contexts	Important concepts from similar contexts	Unimportant concepts	
Variety of Sources	Wide-ranging variety of sources including texts, media, people, or experience	Variety of sources including texts, media, people, or experience	Limited set of sources	Single or inappropriate/non-trustworthy sources	
Organization and Combination of Ideas	Combined in original and surprising ways	Combined in original ways	Combined in ways that are derived from the thinking of others	Copied or restated from the source consulted	
Originality of Contribution	Interesting, new, or helpful contribution for a previously unknown problem, issue, or purpose	Interesting, new, or helpful contribution for its intended purpose	Serves its intended purpose	Does not serve its intended purpose	
TOTAL:					

*This rubric is adapted from Brookhart, Susan M. *How to Create and Use Rubrics for Formative Assessment and Grading*, Association for Supervision & Curriculum Development, 2013

APPENDIX B – EXAMPLES OF STUDENT SKETCHES

Lesson Title: LSN 5 Field Testing, Trenches, Instrument

Sketch:

AGE 0
DON'T EAT DIRT!

AGE 3
DON'T EAT DIRT!

AGE 9
DON'T EVEN TOUCH DIRT!

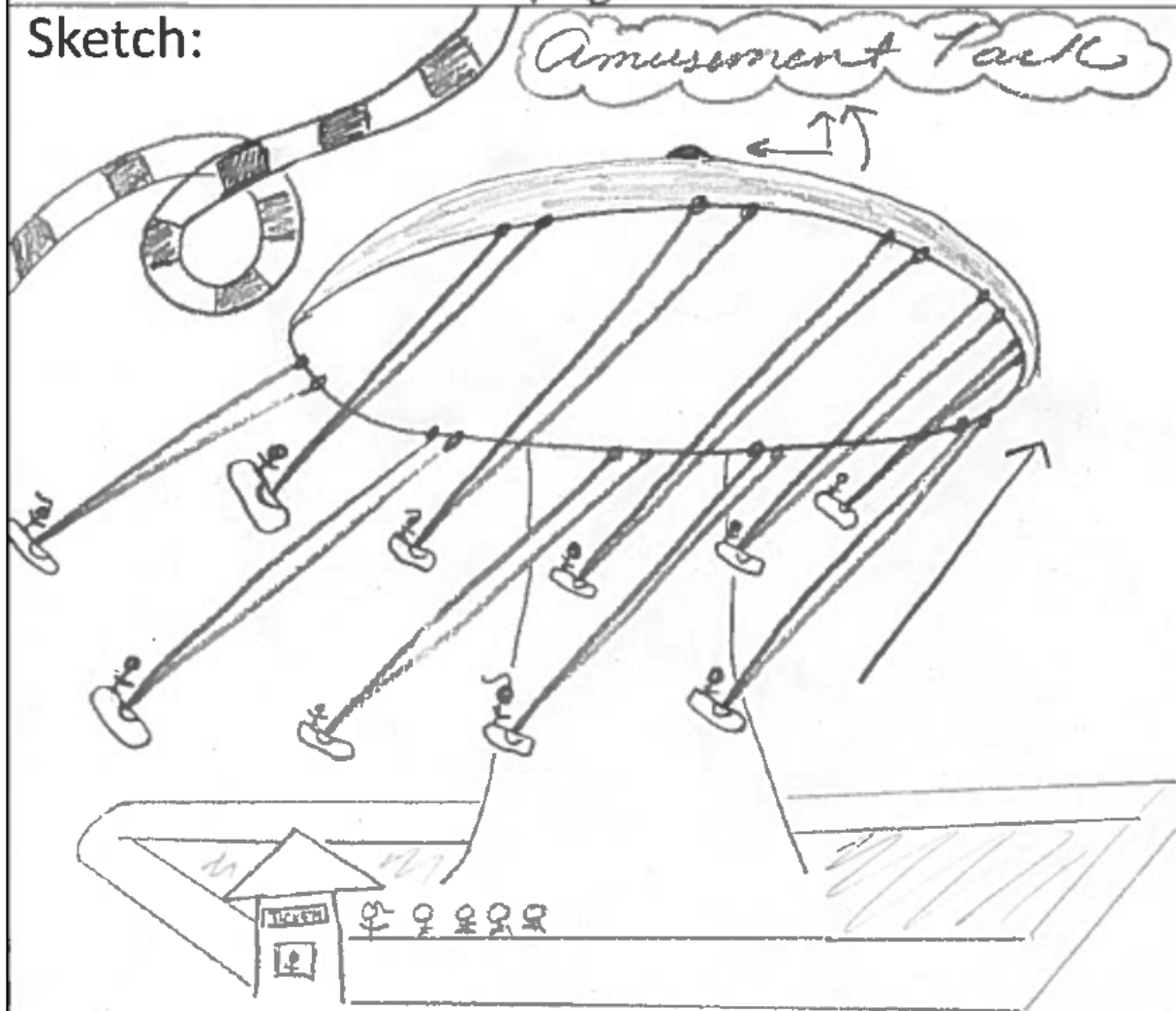
AGE 21
IT'S NOT DIRT IT'S SOIL - TASTE IT!

Written Description: Testing soil is one tool in determining its properties- which I find funny.

Creativity Score: 11.5 of 16

Lessons Covered: 1-5

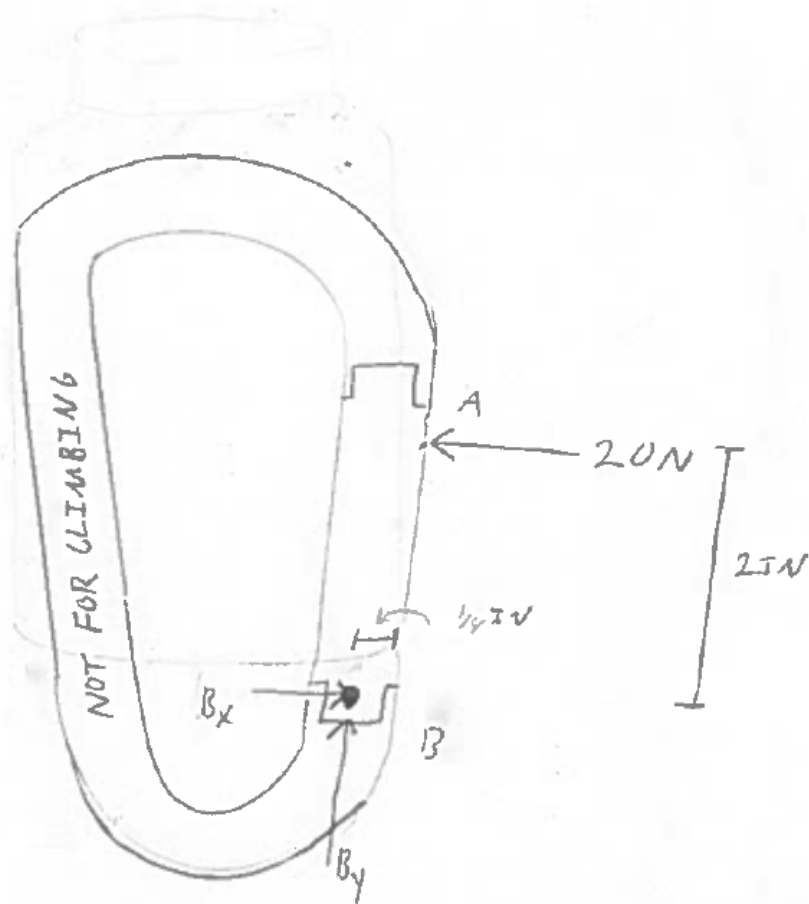
Sketch:



Written Description:

This is an amusement park ride that demonstrates both a fixed and a cable support. The swing system is rotating around a point, and the cables have tension which allows the swings to fly.

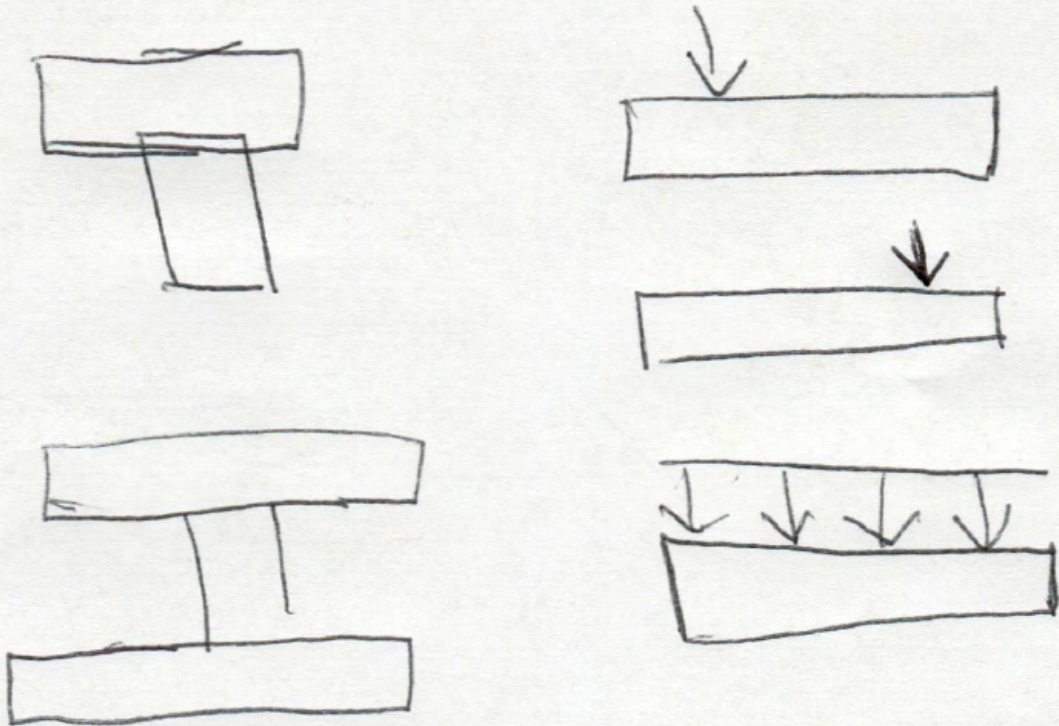
Sketch:



Written Description: This is a common carabiner with a $20N$ force applied at point A. The point is to find the reaction forces at point B.

Equations: $\sum F_x = 0$ $\sum F_y = 0$ $\sum M_B = 0$

Sketch:



Written Description:

Creativity score: 4 of 16 (lowest possible score)