**Proceedings of IDETC/CIE 2005**
**ASME 2005 International Design Engineering Technical Conferences**
**& Computers and Information in Engineering Conference**
**September 24-28, 2005, Long Beach, California USA**

**DETC2005-85499**

# DOES SKETCHING SKILL RELATE TO GOOD DESIGN?

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## ABSTRACT

Sketching is an activity that takes place throughout the engineering design process, and is often linked to design cognition. This preliminary study identifies different skills that contribute to a designer's sketching ability and explores how those skills might be related to sketch fluency and design outcome. A positive correlation was found between the quantity of sketches produced and sketch skills that emphasize drawing facility, but a negative correlation was found between sketch quantity and a skill related to mechanism visualization. Sketching is sometimes considered a generic skill, but this study suggests that there are differences among the different types of sketching skills in the context of engineering design. No notable relationship was found between sketching ability and design outcome. Results also suggest that students provided with explicit instruction in sketching tended to draw more overall, although there are likely many other factors involved.

## INTRODUCTION

Sketching is an activity that takes place throughout the engineering design process. Sketches are used to capture and communicate ideas generated during design [1, 2], and have been closely linked with design thinking [3]. But to what extent does sketching activity actually reflect design thinking? What are the factors that lead designers to use sketches in the design process?

In this paper, we consider an often ignored aspect of conceptual design sketching: the designer's sketching ability. How is this ability linked to the design process, and what is its association with sketch fluency and design outcome? Does someone who can draw *well* also draw *more* while engaged in the engineering design process? Does better sketching also mean better design?

This preliminary study looks at sketching ability as assessed through sketch tasks that emphasize different aspects of drawing in the design process, including drawing facility, mechanical recall, and visualization of new objects. Issues explored include whether these different skills are independent of each other, whether they are correlated with the amount of sketching performed during the design process and whether they are linked to the quality of the final design product. The role of sketch instruction in engineering design education is also explored. Does the teaching of sketching skills correlate with better design? Many engineering undergraduates in the United States are provided with instruction in drafting and CAD, but it is less common to teach sketching. Understanding the role of sketching in design, and the factors that affect it, would provide insights for better design education and better interpretation of observable design activity in our quest to understand the cognitive processes during design thinking.

## RELATED WORK

### Sketching and design thinking

The link between designing and visually representing concepts through sketches and prototypes has been discussed in depth by many theorists, including McKim [4] and Schön and Wiggins [5]. Sketching has long been used by designers to represent their thinking [1]. In fact, Nagai and Noguchi [6] show that designers constantly translate non-visual textual specifications for a design into ones that are visual. Suwa and Tversky [3] suggest drawing is not simply an illustration of design cognition, but an important vehicle for the design thought process. They found that designers are able to understand the various aspects of a design only through sketching them. The work of several other researchers supports this idea that the act of sketching is the same as design thinking. Goel [7] states that sketches are inherent in the cognitive activities that facilitate concept generation, while McKim [4] maintains that the ability to "think visually" is a necessary skill for developing innovative solutions. Verstijnen, *et al* [2] conclude that combining and restructuring in sketching are inextricably linked to creativity. Cross [8] proposes that sketching is a "dialogue" with the designer in which his or her internal thinking interacts with external representation in the form of a sketch. Shah, *et al* [9] and Goldschmidt [10] describe the way sketches "talk back" to the designer. Purcell and Gero [11] suggest that the reinterpretation, or even iteration, of a sketch indicates the occurrence of new conceptual design knowledge. Indeed, Tovey, *et al* [12] refer to sketching as a "language for handling design ideas." They also describe the evolution of sketches that results over time as "interactive generation" and Goldschmidt [13] describes the way in which sketches are used both to represent ideas and to catalyze the generation of ideas.

Sketches can also serve as flexible idea repositories. Goel [7] argues that sketching is critical to capturing the ambiguity inherent in design activity. Kavakli, *et al* [14] refer to the ambiguity in conceptual design sketches as "partially envisioned entities." A sketch then becomes a way of preserving design freedom. Sketches also serve as a medium for communication. Verstijnen, *et al* [2] point out sketches may function as a presentation tool to share design information.

### Types of sketching activities

Sketching during design can take many different forms, depending on intent and the type of idea manipulation they represent. Several researchers [1, 15, 16] categorize sketches according to their purpose (thinking, prescriptive, talking and storing sketches). Goel [7] classifies sketches as representatives of lateral (incremental) or vertical (refining) idea transformations. Other work has labelled sketches by the physical elements of the sketch (shading, dimensions, annotation, etc.), which are typically independent of the content and meaning of the sketch itself [17, 18].

### Sketching and Design Outcome

Sketching activity has also been linked to design outcome. Schütze, *et al* [19] found that designers who were allowed to sketch while coming up with a design produced a higher quality solution than those who were deprived of the opportunity to sketch. Song and Agogino [20] make observations about the amount of 3-dimensional perspective sketching and design outcome. Yang [21] found that the quantity of dimensioned drawings created early in the design cycle is significantly linked with design outcome.

### Sketching ability and sketching activity

From these studies, it is clear that sketching serves a role in aiding cognition during the mechanical design process, and has the potential to impact the design outcome. It remains an open question, however, whether all designers utilize sketches in the same manner and to the same extent. What are factors that may account for individual differences in sketch utilization?

Sketching activity may provide a tool with which to observe design thinking. But to what extent does it really represent design thinking? What motivates a particular designer to use sketches in design?

## METHODS

This study looks at sketching ability and its relation to sketching activity. Our hypothesis is that while sketching activity *can* reflect design thinking, it is an activity affected by many factors, including the designer's facility with drawing and his or her ability to visualize concepts internally without the need for external representation through sketches. Thus sketching activity is seen as a behavioral consequence rather than a direct and necessary component of design thinking.

To explore this hypothesis, this preliminary study assessed the sketching ability of a small group of undergraduate novice designers (predominantly juniors) using a set of sketching tasks that take into consideration these different aspects of sketching ability. Performance on the sketching tasks was then correlated with design sketch activity, as captured by their design log books, and also correlated with design outcome in a three-week engineering design class project at the California Institute of Technology. We also explored the impact of teaching sketching skills on sketching activity by looking at differences in sketch fluency for a subset of the students that enrolled in a sketching and CAD course taught the same quarter.

### Survey of Sketching Ability

At the beginning of the quarter, students completed a survey to assess their drawing skill. The survey presented the students with two questions followed by three sketching tasks. The students were given approximately ten minutes to complete the survey. The five questions were:

1) Do you consider yourself good at drawing? (multiple choice answer: "nope"; "not really"; "kind of"; "yes" and "you betcha").
2) List previous experience with drawing/sketching (hobby, classes, etc.)
3) In three minutes, draw a bicycle with as much detail as possible.
4) Hold out the items given to you in your non-dominant hand (left-hand for right-handed persons). In three minutes, make a drawing of your hand and the items (items given were two small candy bars).
5) Visualize and draw the following in two minutes: A rectangular box that is open at the top. Inside the box is a rubber ball. The front of the box has a large button, and each side of the box has a large "X" painted on it.

These sketching tasks were designed to emphasize different hypothesized aspects of sketching ability. These aspects are:

- *Mechanical recall:* Sketching a bicycle from memory emphasizes the ability to recall and visualize non-simple functional mechanical structures and mechanisms (it was assumed that most, if not all, students had seen and likely ridden a bicycle, so it was familiar object).
- *Drawing facility.* Sketching an object from a live model emphasizes the ability to create clear, realistic,

well-composed drawings, as the task requires little imagination or ability to visualize.

- *Novel Visualization.* Sketching a three-dimensional object from a verbal description emphasizes the ability to visualize novel objects not previously seen that contain a specific set of features.

These proposed aspects of sketching ability seek to decouple the different skills necessary in translating and transforming ideas in mechanical design to visual representations. For example, *Mechanical Recall* is a skill that may be more related to a person's ability to grasp and manipulate spatial constructions, while *Drawing Facility* is hypothetically more related to a person's hand-eye coordination, sense of visual balance and practice in sketching.

The questions then arise of whether these activities are independent of each other, and whether performance on these tasks correlates to sketch fluency (amount of sketches) during the design process.

## Assessment of sketching skills

Sketching ability in the engineering design process is challenging to consider in part because of the subjectivity of what constitutes a "good" or a "bad" sketch. In this study, performance on the sketching tasks was assessed by first determining a clear scoring criterion for each task, and then binning each sketch into one of five levels of performance according to that criterion.

The bicycle recall task was graded on the basis of whether the sketch demonstrated a clear grasp of the concept, structure and operation of a bicycle ("Does this look like a bicycle and could it work mechanically?"). The live model task was graded on the basis of the sketch's accuracy on proportions of the hand and overall realism ("Does this look like a hand?"). The box visualization task was graded on the basis of correct proportion of the object, accuracy of 3-dimensional perspective and overall realism.

Sketches for each task were graded separately. Figure 1

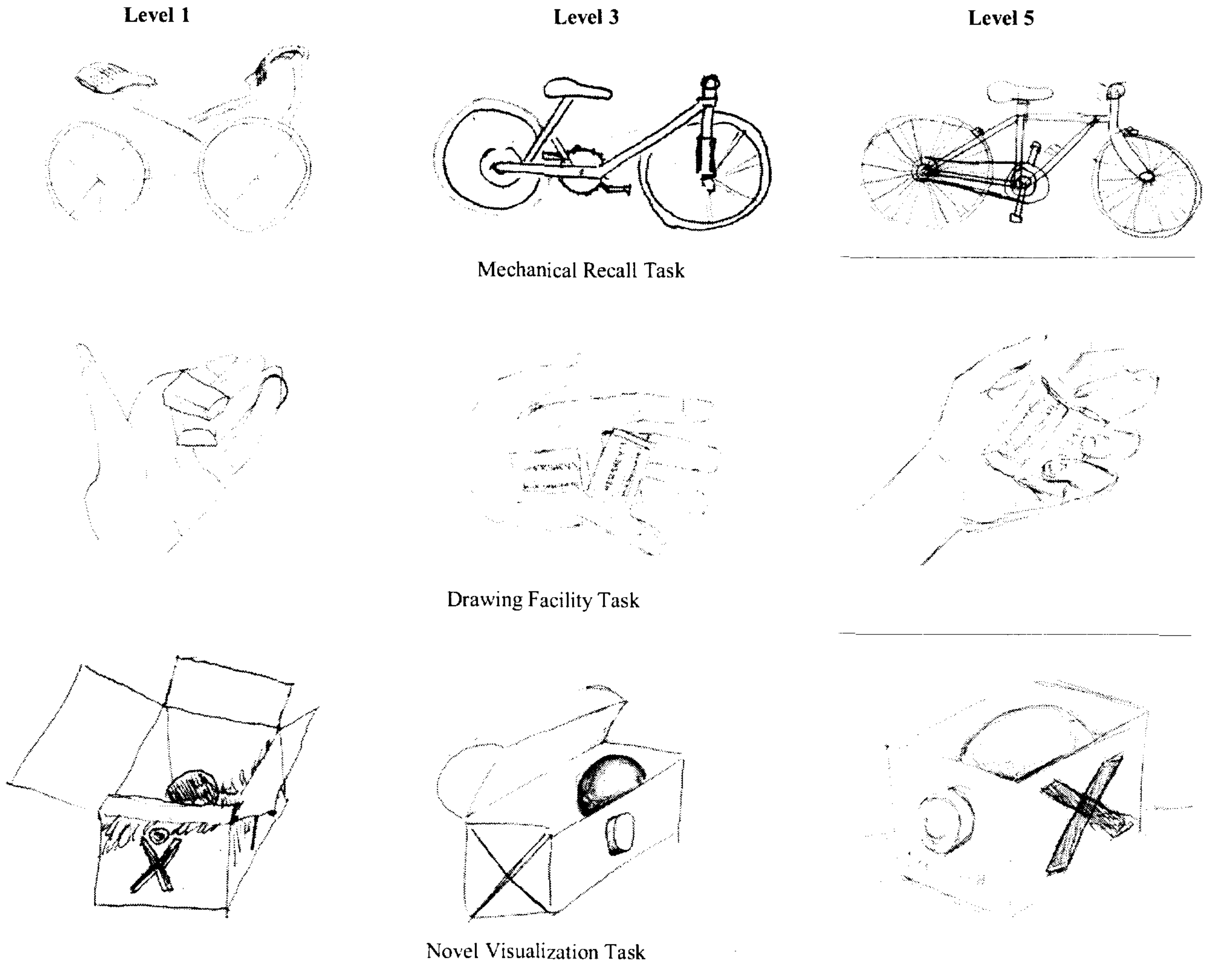


**Figure 1 Representative sketches by sketch level and sketch task**

shows representative examples of the sketches for each task.

## Understanding sketch fluency

There are a number of ways that ideas might be assessed in sketch, such as the range of sketches explored, and the innovativeness of a particular idea. This study focuses exclusively on the volume of ideas in part because it is a relatively objective yet informative measure. To understand the students' drawing fluency (that is, their quantity of drawing), this study examined the paper design logbooks each student kept for the course's final project. All students were given basic guidelines on the use of logbooks as a repository of ideas. Logbooks are unique in these courses because they are primarily an individual medium, rather than a collaborative platform. For the final project, each student worked individually or in teams of up to four people. Over 4 weeks, each team/individual selected a project from a pre-approved list of mechanical design projects (e.g., a can opener) or proposed their own project (e.g., a spice and condiment dispenser) subject to approval by the instructors, then designed and built their design in the machine shop. The instructors included a scaling factor for the grade based on their assessment of the project difficulty and scope, and the individual student or team's capabilities. During the final project, each individual was asked to maintain a logbook of their thoughts and ideas in text and sketches. Students were informed that use of the logbooks would constitute a small percentage of their overall grade. Each sketch included in the logbook was counted individually. In this preliminary study, the quality, type and content of the logbook sketches were not considered, only the raw number of drawings.

## Role of sketching instruction

To explore whether the explicit instruction of sketching skills can be linked to design activity, we analyzed differences between two subsets of the students involved in the study:

1. *Without sketch instruction*: 18 students enrolled in the introductory mechanical engineering design course previously described. Students learned design methodologies, basic machine shop skills, and were given three hands-on, open ended design projects over the quarter.
2. *With sketch instruction*: 14 students enrolled in the same above-mentioned mechanical engineering course, and *also* enrolled in a novel course that allowed students to practice their sketching skills and also taught them to use a Computer-Aided Design (CAD) software package. The course consisted of weekly in-class demonstrations of sketching techniques for perspective drawing of complex rectangular and curved objects, shading techniques, drawing of simple human figures, sketches to communicate the senses of action and emotion, storyboarding and techniques for illustrating mechanisms. During the second half of the quarter, the demonstrations were on basic CAD techniques for creating common 3D shapes, assemblies and engineering drawings. Weekly homeworks were assigned.

## Design outcome

Design outcome was assessed through final project grades and by two external design judges who are professional mechanical design engineers. Each judge individually examined the final project devices for their design, functionality, and level of craftsmanship, and then rank-ordered the projects. The final project grades were assessed by the instructor of the course (not the authors) and were computed independently of the judges' rankings.

## Correlation

The Spearman Ranking Correlation [22] for nonparametric populations was used to test for correlations between the different data variables. The Spearman correlation coefficient $R_s$ is computed in Equation 1:

$$R_s = 1 - \frac{6 \cdot \sum_{i=1}^{N} d_i^2}{N^3 - N} \qquad (1)$$

where N is the sample size and $d_i = X_i - Y_i$. X and Y are the ordinal ranks of the variables being correlated, in this case design data and design outcome. $R_s$ can take on a value between -1 and 1. If $-1 < R_s < 0$, there is a negative correlation between the two data sets. If $0 < R_s < 1$, there is a positive correlation. If the computed correlation coefficient $R_s >= 0.296$, the correlation is considered statistically significant for a significance level, or a probability of error, of $\alpha = 0.10$ (two-tailed) for a sample size of 32 students (N = 32).

# RESULTS & DISCUSSION

## Aspects of sketching ability

Table 1 shows the correlation coefficient between the performance scores in the three different sketching tasks ("Bike Task" refers to scores in the bicycle recall task, "Hand Task" refers to scores in the live model drawing task and "Box Task" refers to scores in the box visualization task).

| | Correlation coefficient, $R_s$ |
|---|---|
| Bike task and Hand task | 0.050 |
| Bike task and Box task | -0.032 |
| Hand task and Box task | 0.144 |

**Table 1 Correlation between sketch tasks**

The results show that there is virtually no correlation between scores in the bike recall task and either the hand drawing or box visualization sketching tasks. This suggests that doing well in one task does not correlate with doing well in the other tasks. In other words, it appears that the skills required for each task are independent. Independence between the different skills supports their selection as distinct aspects of sketching ability that are distributed differently among the surveyed participants.

## Sketching ability and sketch fluency

We now consider the relationship between the various individual sketching tasks and the quantity of sketches produced in each participant's design logbook.

| | Correlation coefficient, $R_s$ | |
|---|---|---|
| | Total number of hand-drawn sketches | Number of perspective hand-drawn sketches |
| Bike task | -0.06 | **-0.31** |
| Hand task | **0.30** | 0.29 |
| Box task | **0.33** | 0.08 |

**Table 2 Sketching tasks and sketch quantity**

Table 2 shows there is a distinct difference in correlation with sketch fluency between scores in the Bike task and scores in the Hand and Box task. Both Hand and Box tasks are significantly correlated ($\alpha$ = 0.10) with the total number of sketches. This implies that drawing well in a general sense correlates positively with total sketch output (the total amount of hand-drawn visual information recorded in their logbooks). In this case, it appears that performance in the bicycle recall task is uncorrelated with total sketch output.

Correlations with the number of perspective sketches show interesting results. Scores in the Hand task correlated positively (and nearly significantly) with total number of perspective sketches. However, scores in the Bike task correlated significantly *negatively* with total number of perspective sketches. In other words, participants who demonstrated capacity to accurately recall non-simple mechanical structures and mechanisms were less likely to draw three-dimensional perspective sketches.

Although these results are still preliminary, the differences in correlation between scores in the Bike and Hand task suggest the following observation: What designers choose to put down on paper seems to depend on an interplay between how well they can draw (high score on the Hand task), and how much they *need* to draw (low score on the Bike task). Having facility at drawing may make a designer more likely to use sketches in design, but only if they lack skill in recalling and visualizing complex mechanisms. Conversely, a designer with talent for mentally grasping mechanisms but with poor facility for drawing may be more likely to choose to work out the design in their head, and not utilize sketches at all.

## Sketching and Design Outcome

The above results indicate that there are distinct skills involved in sketching ability, and that these skills together may influence how likely a designer is to use sketches in their design thinking. The next question is whether these differences influence design outcome, as measured by the three metrics previously described.

| | Correlation coefficient, $R_s$ | | |
|---|---|---|---|
| | Project grade | Overall class grade | Avg. reviewer ranking |
| Total hand-drawn sketches | 0.24 | 0.18 | 0.16 |
| Perspective sketches only | 0.04 | 0.07 | 0.23 |
| Bike task | -0.031 | 0.068 | -0.03 |
| Hand task | -0.029 | 0.082 | -0.18 |
| Box task | 0.183 | 0.045 | 0.05 |

**Table 3 Sketches by type and task and design outcome**

Before we present these results, it is interesting to consider the consistency of the three metrics of design outcome, as measured by the correlation among the three metrics. The correlation between project grade and overall class grade was, not surprisingly, statistically significant ($R_s$ = 0.89). In addition, the rankings of the two outside design judges also correlated in a statistically significant way with each other ($R_s$ = 0.59). Interestingly, both judges' rankings correlated negatively with project grade ($R_s$ = -0.22), perhaps because project grades take into consideration the process involved in developing a project, while the reviewers rankings are solely based on responses to the final artifact itself.

Table 3 shows the correlations between sketch fluency and ability and design outcome as measured by the three different metrics previously explained. The first two rows show the correlations with the number of total and perspective sketches, while the last three rows show the correlations with performance in the three sketching tasks.

In terms of sketch fluency, there appear to be positive correlations between the total number of hand-drawn sketches and project grade, and between the number of perspective sketches and the ranking given by the independent judges. However, neither of these correlations is significant. In terms of sketching ability, scores in the sketching tasks seem largely uncorrelated with design outcome.

Overall, these results show there is no strong correlation between sketch fluency and design outcome, or between sketch ability and design outcome. In other words, the quality of the final design does not appear to depend significantly on the overall output of the designers' sketch activity, or their perceived facility with drawing or visualization.

These results lend further support to the possibility that sketching activity does not necessarily reflect design thinking. If sketching activity is more a result of the designer's *need* for external visual representation, then designers without that need will likely choose to carry out more of the design process internally. Thus, sketching activity in design appears to be a behavioral output, based the designer's preferences and cognitive abilities. The fact that design outcome appears to be uncorrelated to measures of sketching ability or quantity of sketching activity simply confirms that the design process depends on many skills and many factors, and not just on particular skills in visualization or sketching ability. Being a good or prolific sketcher (a "good artist") or having good mechanical sense (being a "gear head") does not mean that one is also a good designer.

## Role of sketch instruction

Is providing basic instruction in sketching somehow linked to how much an individual sketches? Or is it linked to how well s/he does on a project? Table 4 shows the average number of drawings found in student logbooks. The first column is of students who were *not* taking the concurrent class that included explicit sketching instruction. The second column is of students who were taking the sketching and CAD course.

In each case, the average number of drawings appears to be higher for the students who had taken the course with sketch instruction (though in none of the cases was the difference statistically significant). This was true whether the number of CAD drawings was taken into account or not. CAD drawings and hand sketches were considered separately because CAD drawings were often used more as a later stage communication tool rather than a thinking sketch and it was assumed that the students in the drawing course would be more facile with CAD tools because they had been exposed to CAD software tools. Perspective drawings, in particular, are of interest because they likely reflect some skill in sketching. Overall, it appears that the explicit instruction of sketching may result in higher sketching output, though this is not conclusive. This lack of significance in the difference is largely due to the large variance in the number of sketches produced, indicating again that sketch activity depends on many factors besides sketching skill.

It should also be noted that students who had sketching instruction started out with somewhat higher scores for the survey tasks, which may have also played a role in determining sketching fluency.

| | Without instruction | With instruction | % change |
|---|---|---|---|
| Avg. number of hand sketches + CAD drawings | 61.3 | 70.4 | 14.7% |
| Avg. number of hand sketches only | 47.0 | 53.4 | 13.7% |
| Avg. number of hand sketches drawn in perspective | 17.7 | 20.9 | 18.4% |
| Avg. bike task | 2.3 | 2.6 | 16.0% |
| Avg. hand task | 1.9 | 2.6 | 36.1% |
| Avg. box task | 2.2 | 2.1 | 7.4% |

**Table 4 Sketching instruction and sketch quantity**

## CONCLUSIONS

This preliminary study explored the link between various sketch tasks, sketch fluency and design outcome, as well as connections with sketch instruction. The results suggest the following conclusions:

- All sketches are not created equal. Often, sketching is thought of a generic skill, but in the context of engineering design, this study suggests that there are clear differences among different types of sketching skills. It was found that there was no correlation between the mechanical recall drawing task and the visualization and drawing facility sketch tasks. This implies that the individual tasks require different cognitive skills and that, in particular, mechanical recall is distinct from the other skills.
- It had been hypothesized that how much designers sketch may be partly determined by how well they draw, but it may also be based on how much they can work things out *without* drawing. It was true that those who did well on the hand and box tasks also tended to draw more in their logbooks overall. However, it was found that the mechanical recall task was negatively statistically significantly correlated with the quantity of perspective drawing. Perhaps those students with good mechanical recall ability are able to visualize designs in their heads (without committing to paper) and do not need to sketch well or often. In fact, a common complaint among some students is that they don't want to keep logbooks because their work is already "all in their head." In this study, logbooks were used as a tool for capturing design thinking through sketches and text. Thus, for those students who preferred this mode of "in my head" thinking, the logbook activity may not fully reflect their design thinking.
- Sketching is often linked to design cognition, and it was thought that the sketching ability might also correlate with engineering design performance. However, no notable relationship was found between performance on any of the sketch tasks and design outcome. "Good" sketchers did not necessarily do well on the project or vice versa. One likely explanation is that the engineering design process is complex and requires many different skills, and sketching is only one of these. For example, the engineering project that was examined in this study required not just engineering design skills but also the ability to produce a physical device using machine tools as well as to manage one's time on the project.
- It was hypothesized that providing students with sketch instruction would lead to them becoming more proficient, and possibly more motivated sketchers and engineers. It was found that, on average, students who received sketch instruction did do more sketching but with no effect on their grades or project rankings. However, this increase in sketching is subject to a good deal of variability which suggests that the increase could be due to any number of other factors, such as an individual's interest in sketching. Just because a student is given some instruction in sketching does not mean that they will actually be motivated to sketch.
- The chief measures used in this study were total sketch quantity and project grade. This study shows little

correlation between the total amount of drawing of any type and the grades received in the course.

These preliminary observations suggest that while sketching activity *can* reflect design thinking, it is an activity affected by many factors, including drawing and visualization ability, and should thus be seen as a behavioral consequence rather than a direct and necessary element of design thinking.

## FUTURE WORK

Design is a complex activity with many potential factors that can influence its outcome. In particular, it is difficult to tease out potentially confounding variables in the design process and in the nature of the designers themselves. In this study, we considered only the role of sketching ability in the design process. Future work should examine other potentially relevant factors that may affect sketching behavior, such as the effects working in a team versus working on a project individually, the role of an individual's motivation or personality, and the nature of a design task.

### Implications for engineering design education

Many engineering undergraduates in the United States are provided with instruction in drafting and CAD, but it is less common to teach sketching skills for concept generation and exploration. CAD tools are typically used in the later stages of the design process [23], when ideas are more solidified. In the initial stages of design, when flexibility is important, the designer's ability to quickly sketch and visualize ideas may play a more important role.

The general philosophy is that students need visualization skills in the same way they need math or verbal skills, and that emphasis should be placed on sketching and ideation techniques in engineering education. For example, Stanford University offers a mandatory course in "visual thinking" [4] for mechanical engineering undergraduates, and mechanical engineering students at Caltech are encouraged to take the visualization course described in this paper.

This work suggests that educators should be cognizant of the type of sketching that is being taught. Sketching in engineering design is not merely the ability to draw something accurately or realistically as in drafting, but the ability to represent and generate novel engineering solutions.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the support and guidance of the Prof. Joel Burdick and Prof. Erik Antonsson at the California Institute of Technology, and the commendable design efforts of the students that are the basis of this research. The authors would further like to thank Prof. Karl Gröte and Dr. Curtis Collins for their professional opinions.

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