Engineering Drawing for the Next Generation: Students Gaining Additional Skills in the Same Timeframe

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Abstract

Research has often found that engineering drawing is a vital tool for communication, idea-generation, problem solving, and developing key skills such as spatial visualization. However, many curricula have replaced the bulk of instruction in hand sketching with Computer-Aided Design programs despite these known benefits of drawing. In recent years, an introduction to engineering visualization course at Georgia Institute of Technology has modified the portion of the class dedicated to hand-sketching using pedagogy commonly used in industrial design courses to develop students' sketching ability and visualization skills. This modified curriculum involves instruction on techniques such as sketching in both isometric and perspective spaces, shading, and ray-tracing.

This paper observes the impacts of a modified curriculum in and engineering graphics course on students' ability to sketch, self-efficacy in engineering design, and spatial visualization skills. Impact was measured using pre- and post-course assessments and surveys. The pre-to-post comparisons of the groups of students taught using different methods showed equal improvements in the spatial visualization of the students. The improvements in sketching ability of the students in the modified perspective curricula were found to be significantly higher than the improvements experienced by students in the traditional curriculum. These findings suggest that the modified perspective sketching curriculum maintains critical spatial visualization skills, which are effectively taught with the traditional engineering curriculum, while also introducing an additional skill without requiring additional student time. These findings justify the need to continue improvement of the perspective-based curricula and to continue development of tools to aid in the instruction of these new skills.

Introduction

Free-hand sketching has long been upheld as a crucial skill for engineers. It is a useful tool in early stage idea generation, communicating ideas, and developing initial prototypes[1-3]. It has also been shown to be a highly effective way of improving spatial visualization skills[4,5]. A recent study by Kudrowitz, et. al,[6] showed that a better-drawn sketch is perceived as having a higher degree of creativity that a poorly drawn sketch of the same object, showing the importance of sketching in design communication. These reasons alone necessitate the need for engineering drawing to a priority of engineering education.

In response to the ever-advancing technology in Computer-Aided Design (CAD) software, the freshman-level course on engineering graphics at Georgia Tech has been updated several times in the past two decades[7,8]. When Georgia Tech converted from the quarter system to the semester system in 1999, the Engineering Graphics and Visualization course was co-listed between the Mechanical Engineering and Civil Engineering departments. At this point, the class was restructured using the backward design approach[7,9]. The curriculum was developed to include instruction on the interpretation and development of both hand drawing and the use of CAD programs. This included drawing in 2D, and Isometric (see Figure 1a) by hand using tools such as grid paper and straight edges. This coursework occupied the majority of the first five weeks of the course. The remainder of the course focused on computer-generated methods and included two projects requiring the use of a CAD program: one of a 2D schematic and one of a 3D model[7]. For the remainder of the paper, this version of the class will be referred to as the "Traditional" version, as it is built off of topics traditionally taught in engineering graphics and drafting courses.

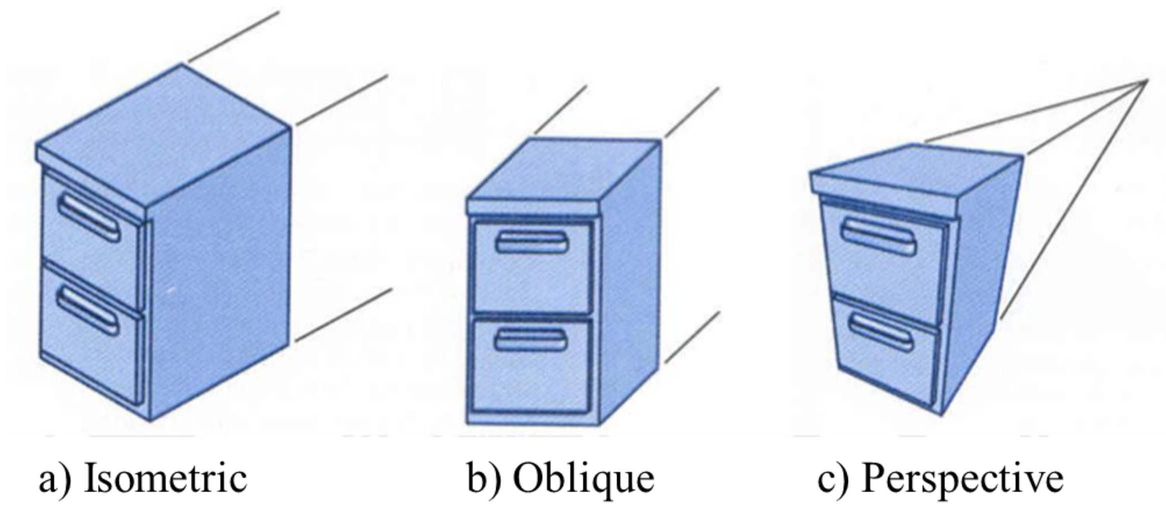

Figure 1. Examples of Isometric, Oblique, and Perspective Views[10]

More recently, the course has undergone another significant change. In the National Academy of Engineering's 2004 book *The Engineer of 2020: Visions of Engineering in the New Century*[11], one of the ways the engineering profession must progress is to "accommodate innovative developments from nonengineering fields". In this spirit, inspiration for a new version of teaching sketching to engineering students emerged from the methods by which professionals in Industrial Design professionals teach sketching in their curriculum[8]. With the help of Industrial Design professors, the new curriculum was modified to include instruction of more stylistic drawing techniques.

The first five weeks of the course were dedicated solely to free-hand drawing as in the Traditional method, but in addition to drawing in 2D, Isometric, and Oblique views, the students were also taught to draw in Perspective view (Figure 1 c). The students were also taught shading techniques through the use of different types and shades of markers to give their sketches the effects of proper lighting through shading techniques. The students would participate in a weekly critique session where they present their work to the class and their instructors and classmates would comment on the strong and week points of the students' sketch work. These assignments included, but were not limited to, sketches of basic shapes, combinations of basic shapes, and still-life depictions of objects found in a dorm room. There was also a final sketching assignment in which the students produced a perspective sketch of a concept product including staging, marker shading, branding, labeling of important features, and supplemental orthographic and sectional views of the concept. The remainder of the semester is, like the Traditional version of the course, dedicated to teaching the application of CAD programs including two projects, one individual assignment and one group assignment. For the remainder of this paper, this method of teaching sketching will be referred to as the "Perspective" version of the course.

Research Question

Several of the previous studies by the authors have revolved around the over-arching research question, "Does sketching matter in engineering design?" For this study, we set out to determine if the Perspective version adds value to the engineering curriculum by asking the question, "***Does teaching sketching based on Industrial Design pedagogy provide additional skills to engineering students in the same timeframe as more traditional engineering drawing curriculum?***"

In order to determine this, it needed to be shown that students in the Perspective version significantly increased in their sketching ability when compared to the students in the Traditional version. Also, it needs to be shown that the changes in the course do not have a negative impact on the skills that have been shown to be linked to learning engineering drawing more traditionally.

Data Collection

In order to compare the impacts of the Traditional and Perspective versions of teaching in the Engineering Graphics and Visualization course, different sections were taught the Traditional version or Perspective version of engineering drawing for one semester. A total of nine sections of the course were available, with four of them teaching the Traditional version by an instructor with decades of experience teaching the course and the other five teaching the Perspective version by three different instructors. Data was collected from all nine sections. The participants were asked to fill out surveys on their design self-efficacy, take quizzes to evaluate the spatial visualization skills, and take a paper-based sketching quiz. These tasks were completed during the first week of the semester and at the end of the semester so that pre-to-post within-subject data could be compared.

The design self-efficacy survey was based on Carberry's[12] work on measuring design self-efficacy by asking the participants to rate themselves in design tasks in regard to their *confidence* to complete the task, *motivation* to complete the task, *anxiety* caused by completing the task, and their expected chance of *success* in completing the task. To measure the participants' spatial visualization skills, two quizzes were used. The participants were given the Purdue Spatial Visualization Test: Rotation (PSVT:R)[13,14], which consists of 30 untimed problems, and the Mental Rotation Test (MRT)[15-17], which consists of 24 problems with a 12-minute time limit.

The participants also completed a sketching quiz designed to follow the pedagogy of sketching in which the level of difficulty progresses from simple to more complex[18]. Having this standardized quiz allows for a consistent sample from participants in both versions of the course. A portion of a completed sketching quiz can be seen in Figure 2.

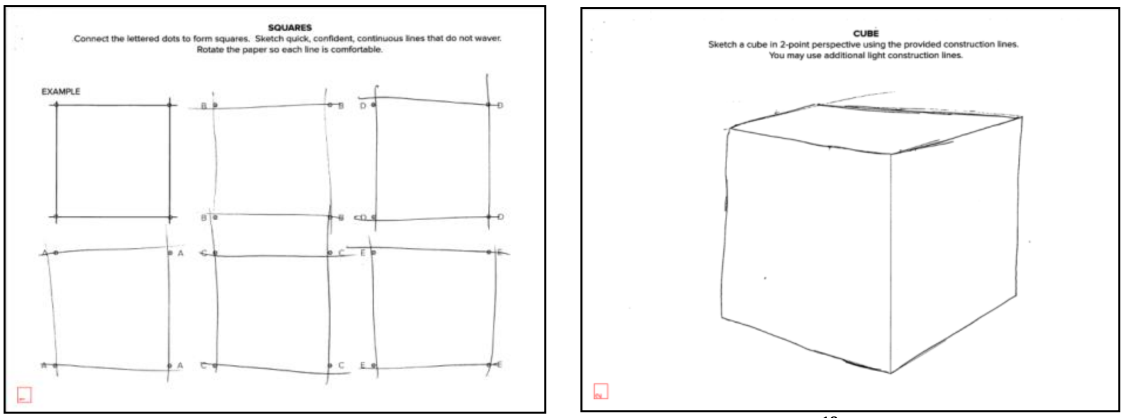

Figure 2. Portion of Completed Sketching Quiz[18]

Previous Work

In previous work, the results of the surveys and quizzes given to the participants pre- and post-course were looked at separately[8,19]. The first study compared the two versions of the course and how they impacted the spatial visualization skills and design self-efficacy of the participants[8]. As it is well-studied and determined that sketching in any form has a positive impact on these factors, the hypothesis of this study was for the impact on the students to be equivalent between the two versions of the course. The results of the spatial visualization quizzes for each group can be seen in Figure 3 and the full statistics can be seen in Table 1. All pairs were evaluated with a two-sample t-test and using Cohen's effect size (D)[20]. The statistics in Table 1 show that the p-values for all comparisons were above 0.05 and the effect size was less than 0.20. These statistical tests indicate that the difference between the two groups was not significant since the pre-course tests and remained insignificant during the post-course data collection. This indicates that the method by which sketching was taught did not have a significant impact on the participants' spatial visualization skills.

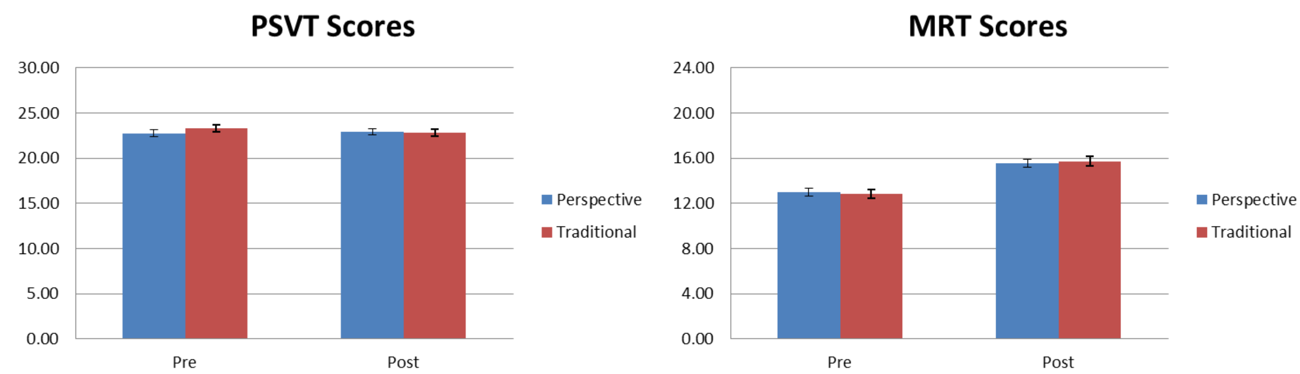

Figure 3. Spatial Visualization Scores

Table 1. Statistics for Spatial Visualization Tests

Test	PSVT:R				MRT			
	Pre		Post		Pre		Post	
Group	**Persp.**	**Trad.**	**Persp.**	**Trad.**	**Persp.**	**Trad.**	**Persp.**	**Trad.**
n	187	146	187	146	186	155	186	155
mean	22.74	23.29	22.9	22.8	13	12.83	15.52	15.75
StdDev	4.81	4.97	4.76	5.13	4.76	4.61	4.58	4.94
t-score	t= -1.02		t= 0.1878		t= 0.3301		t= -0.4508	
deg.free.	df= 331		df= 331		df= 339		df= 339	
p-value	p= 0.3083		p= 0.8512		p= 0.7415		p= 0.6524	
Effect Sz	D= 0.113		D= 0.021		D= 0.036		D= 0.049	

While it is important to establish that the Perspective method did not have a negative effect when compared to the Traditional method, it is also useful to see that the method does in fact improve students' visualization skills. This can be seen in the comparison of pre-to-post scores for the MRT as shown in Table 2 and Figure 4. A paired t-test and Cohen's effect size were used to evaluate each pair. The p-values from the t-test were found to be very small and the effect sizes were found to be over 0.5, which supports that both groups of students significantly improved in their spatial visualization skills over the course of the semester.

Table 2. MRT Pre-to-Post Statistics

Group	**Perspective**		**Traditional**	
Test	**Pre**	**Post**	**Pre**	**Post**
n	186		155	
mean	13	15.52	12.83	15.75
StdDev	4.7	4.58	4.61	4.94
t-score	t= -9.49		t= -10.19	
deg.free.	df= 185		df= 154	
p-value	p <0.001		p <0.001	
EffectSz	D= 0.543		D= 0.612	

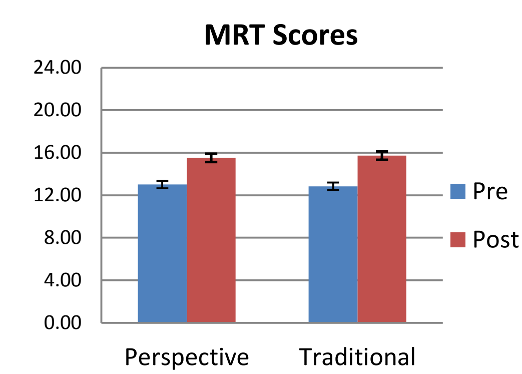

Figure 4. MRT Pre-to-Post Comparison

Another previous study focused on the improvements made in the participants' sketching skills[19]. This was achieved by viewing the pre- and post-course sketches completed as a part of the sketching quiz described in the Data Collection section. The final task of the quiz was to sketch a camera in 2-point perspective given three 2D views. The sketches generated by the participants were evaluated by a group of raters by comparing each participant's pre- and post-course sketch in a randomized survey. The pre- and post-course sketches were randomized in their presentation to the raters to avoid bias. The frequency of ratings is shown in Figure 5. To determine if the ratings between the two classes were significantly different, the ratings were given numerical values of -2, -1, 1, and 2 for "Much Worse", "Slightly Worse", "Slightly Better", and "Much Better", respectively. Figure 6 and Table 3 show the average results of this quantitative application and the statistical comparison of the two methods, respectively. A two-sample t-test ($p = 0.044$) found the difference between the two groups to be significant, and a medium effect size was found between the two groups ($D = 0.49$)[20]. These findings suggest that the Perspective Method is more effective at improving the participants' sketching ability.

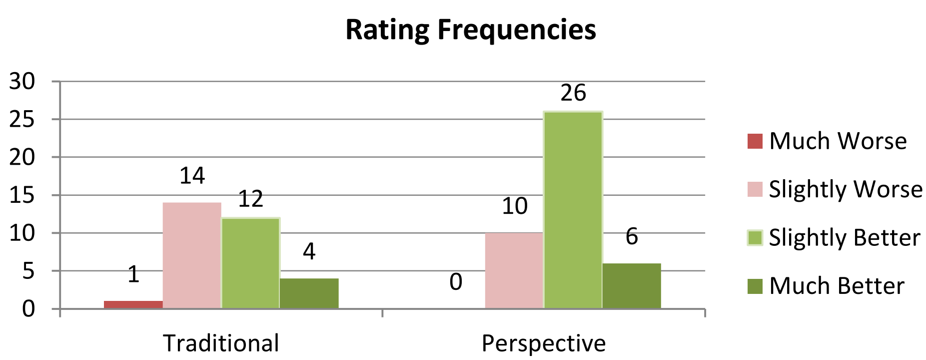

Figure 5. Frequency of ratings between pre and post sketches[19]

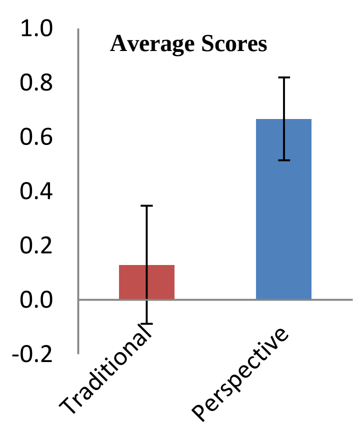

Figure 6. Average Scores of Method of teaching Sketching[19]

Table 3. Sketch Comparison Statistics[19]

	Perspective	Traditional
n	31	42
mean	0.13	0.67
SD	1.21	0.99
t-score	-2.05	
df	71	
p-value	0.049	
Effect Sz	0.49	

Summary of Results

While the findings of these previous two individual studies are powerful and important in the argument for the inclusion of the Perspective method of teaching drawing in engineering curriculum, it can be argued that by looking at both studies under one umbrella can bring about an even more powerful conclusion. The first study suggests that the new method does not hinder students from advancing or maintaining their spatial visualization skills when compared to the more traditional method of teaching engineering drawing. The second study suggests that the Perspective method is more successful than the Traditional method at advancing the students' sketching abilities. For this reason, it can be argued that observing both results suggests that ***a curricula for teaching free-hand sketching based on pedagogy from Industrial Design to engineering students allows for additional skills to be gained in the same timeframe***.

This finding encourages the continued development of teaching this form of sketching to engineering students. However, there are several obstacles present for implementing this sort of curriculum into engineering programs, and steps must be taken to help alleviate the hindrance these drawbacks present.

Drawbacks of the Perspective Version of the Course

The biggest drawback of implementing a curriculum based on pedagogy from Industrial design is the lack of instructors trained in presenting and evaluating this form of work. At Georgia Tech, this curriculum could not have been developed without instructors from the Industrial Design department, including developing lesson plans and teaching the engineering instructors the more detailed methods of free-hand sketching to a level that they could teach these skills to their students. Many engineering departments do not have this resource at their disposal, making it nearly impossible to prepare for teaching this method.

Another drawback is the difficulty and time it takes to properly evaluate student work produced using this method. There is currently no tool or rubric available to consistently evaluate sketches at a meaningful level and must rely heavily on the knowledge of the grader to recognize qualitative features. With the large class sizes present in many engineering programs today, this problem may cause the application of the method to be infeasible. Therefore, there are many steps that must be taken in future research to allow this method to be more accessible.

Future Work

One possible to solution to making the Perspective method presented in this paper more accessible to engineering instructors is to decrease the amount of instructor involvement needed for teaching perspective sketching. There is an Artificial Intelligence (AI) pen-and-tablet based sketching tutor called Sketchtivity developed by a the Sketch Recognition Lab (SRL) at Texas A&M University with assistance from subject-matter experts in teaching sketching and engineering education researchers[21,22]. This program has already begun to be implemented at

Georgia Tech in the Engineering Graphics and Visualization course in the mechanical engineering department and an introductory sketching and modeling course in the Industrial Design department. Sketchtivity is built around the same pedagogy of teaching free-hand sketching as the Perspective method. This program aims to lessen the needed instructor interaction by providing sketching activities with built-in human-like feedback, including immediate feedback of line accuracy such as that seen in Figure 7.

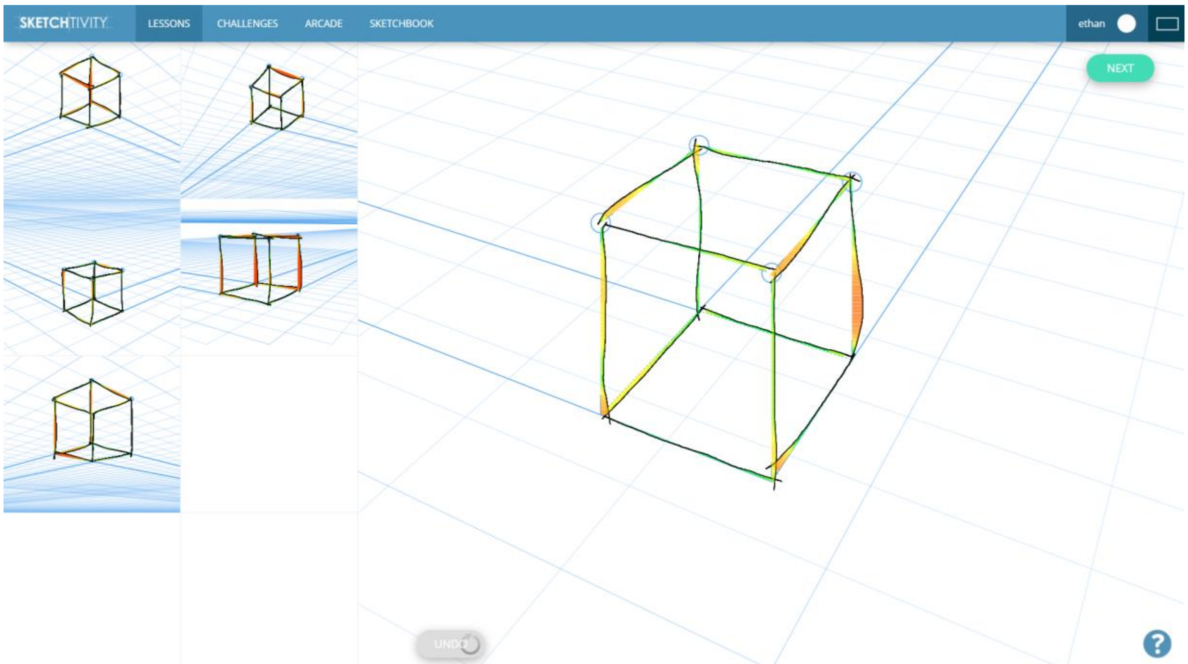

Figure 7. Example of a Lesson in Sketchtivity

In order for this type of tool to be developed to a truly effective level, more research needs to be done to best understand how it can most fully meet its potential in an engineering course. First, as stated above, there is no method for consistently evaluating sketches without input from subject-matter experts. For this program to provide useful feedback, more work needs to be done on the development of such a method, including the differences between sketching on paper versus sketching on a digital surface.

As this program continues to be implemented into courses, several studies will need to take place. A study very similar to the one presented in this paper will need to be conducted to understand the impact of using this type of program on skills such as spatial recognition and sketching skill. There have been students who have used this program as part of the curriculum, but the sample size is currently too small to attempt to detect any significance in these measurements. However, the general feedback from the students has been positive and very useful for continuing developments of the program[21].

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