The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #43956

Controlled Trial Illustrating Benefits of Increased Sketching and Spatial Visualization Training for Female Engineering Students

Prof. Nathan Delson, University of California, San Diego

Nathan Delson, Ph.D. is a Senior Teaching Professor at the University of California at San Diego. His interests include robotics, biomedical devices, product design, engineering education, and maker spaces. In 1999 he co-founded Coactive Drive Corporation (currently General Vibration), a company that provides force feedback solutions. In 2016 Nate co-founded eGrove Education an educational software company focused on teaching sketching and spatial visualization skills.

Dr. Huihui Qi, University of California, San Diego

Dr.Huihui Qi is an Associate Teaching Professor in the department of Mechanical and Aerospace Engineering, at the University of California San Diego.

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Abstract

Engineers often employ freehand sketching to generate design concepts and effectively communicate ideas to their peers. Another benefit of freehand sketching is that it has been shown to improve spatial visualization skills and subsequently improve graduation rates in engineering disciplines. This study was conducted to determine the impact of increasing the number of freehand sketching training assignments using spatial visualization training software in a freshman engineering class. This paper analyzes the impact of sketch training by gender. The motivation for this analysis was to address a gap in spatial visualization ability among female engineering students. The question being explored was if and in what areas additional sketch training helps female and male students, and if this training can help level the playing field. To address these questions, a controlled trial was conducted within a freshman-level mechanical design course where students learned Computer-Aided Design (CAD) and constructed basic robots. In the Control Section, comprising 82 students (57 male, 23 female, and 2 who did not identify gender), participants were assigned 6 freehand sketching assignments on paper. In contrast, the intervention group, consisting of 70 students (43 male, 18 females, and 2 who did not identify gender), completed 146 sketching assignments using software that provided automatic grading of sketches. Accordingly, both sections completed tasks that taught sketching and spatial visualization skills, but the Intervention section had many more sketching assignments. Pre- and post-course assessments of spatial visualization ability were conducted using the PSVT:R standardized test. Students also completed Pre and Post surveys to rate their skills in a range of areas including, CAD, use of shop tools, communicating design ideas to teammates, and applying engineering theory to the project. The Intervention sections showed increased PSVT:R scores over the Control section for the all students in the section with p= 0.0019, and higher benefits for students who enter with low and mid level Pre-PSVT:R scores. There were significantly higher gains in PSVT:R for female students who entered with Low Pre-PSVT:R scores with an increase in 16% compared to 4% in the Control section, p = 0.0073. The survey also showed statistically significant improvement in CAD ability among male students (p= 0.043) and female students (p= 0.013). In this study the higher amount of freehand sketch training correlated with benefits for all engineering students, but especially for female engineering students and helped close the gap in a number of areas between genders that was apparent at the beginning of the course.

Introduction

Practicing engineers draw sketches for concept generation, analysis, preparation for Computer Aided Design (CAD), and sharing concepts with colleagues [Yang 2009; Wu et al. 2019; Zainuddin et al. 2019]]. In team projects sketching is used to explain design concepts to one’s teammates [Elsen et al. 2012]. Furthermore, freehand sketching has been shown to increase spatial visualization (SV), which is the ability to mentally manipulate, analyze, and comprehend two-dimensional (2D) and three-dimensional (3D) objects or shapes in space. Improving SV skills has been shown to increase graduation rates and academic accomplishment [Sorby 2012]. Research has indicated that women on average have lower spatial visualization scores, possibly due to lower level of building activity at a young age, but that this skill is teachable and especially beneficial for female students as highlighted in the report "Why so few? Women in science, technology, engineering, and mathematics" [Hill et al. 2010] which lists SV training as a way to level the playing field between male and female STEM students. Reilly et al. [2017] underscore the significance of spatial ability in STEM education and the potential for targeted interventions to mitigate gender disparities in this area, thereby contributing to a more gender-balanced representation in STEM-related fields. Prior studies by the authors of this paper [Delson et. al 2023] described a controlled trail to evaluate the benefit of increased sketch training in a in a freshman introduction to mechanical design class. This publication evaluates the data from this study to discern the impact by gender. This paper explores the benefit of sketching in in a freshman introduction to mechanical design class and explores the following research questions as it impacts male and female students:

1. Does adding additional sketching instruction to a class with CAD and hands-on design have measurable benefits?
2. Do the benefits of sketch training extend beyond improving spatial visualization ability into areas such as the ability to communicate with teammates?
3. Does sketch training just benefit a subset of students such as those who enter a class with low spatial visualization ability, or does its benefit extend to all student levels?

This paper describes a controlled trial in a freshmen level hands-on mechanical design class at the University of California at San Diego in the Department of Mechanical and Aerospace Engineering. The course, MAE 3: Introduction to Mechanical Design**,** covers hands-on design, CAD, and application of physics to machine design. A controlled trial was conducted where the intervention was in how freehand sketching was taught. The Control Section had just 6 sketching assignments of orthographic and isometric freehand sketches drawn on paper. An Intervention Section used software that automatically graded student sketches, and students were assigned 146 sketching assignments. All other course assignments remained the same. Student performance was measured with a pre- and post- spatial visualization test and student surveys.

Background

SV has been correlated in numerous studies to performance in math and science [Wai et al. 2009; Norman 1994]. SV has been shown to be a learnable skill and SV training has increased graduation rates in engineering majors, especially among women and other Underrepresented Minorites (URMs) [Sorby 2012; Hill et al. 2010]. An effective way to increase SV ability is through freehand sketching of orthographic and isometric shapes. Such training has been shown to increase college graduation rates from 61% to 76% for students entering with low SV skills in a study that tracked over 7000 students for 10 years [Sorby 2009; Sorby 2012].

A number of methods besides sketching have been associated with learning SV skills including hands-on building and CAD instruction [Uttal et al. 2013; Reilly et al. 2017; González Campos et al. 2019]. This raises the question as to whether an introductory class that includes hands-on design and CAD instruction provides sufficient SV training, or if there is benefit for incorporating explicit SV training in such courses, which is the motivation for research question 1. Freehand sketching on its own is a fundamental skill in many engineering disciplines. It not only serves as a communication tool among engineers, but also plays a critical role in engineering design and problem solving [Uziak et al. 2018]. This raises the question as to whether there are benefits to teaching sketching besides increasing SV skills, and therefore is the motivation for research question 2. Finally, SV training through sketching has been identified as an effective method for increasing the number of women and other URMs in STEM [Hill et al.

2010]. This motivates the 3rd research question as to whether the benefits of sketch training extend beyond those students who enter a class with low SV skills.

Methodology

This study was conducted in a freshman level introduction to mechanical design course for mechanical and bio engineering students. In the first four weeks of the class students worked on an individual project where they built a simple pendulum clock, and in the process were introduced to CAD, shop tools, a laser cutter, and 3D printers. In the following six weeks students worked in teams of 3 to 4 on an open-ended joystick controlled robot project. The class had 2 separate lecture sections taught by 2 different instructors (authors of this paper), which allowed for a controlled trial. The class assignments were identical except for the sketching assignments. Each student also had a 3-hour lab section that was run by an undergraduate tutor.

The Control section had 85 students and the Intervention section had 73 students. The difference between the two sections was in the sketching instruction. In the Control section freehand sketching was covered in a lecture in week 2, and the homework consisting of 6 hand drawn orthographic and isometric drawings completed on paper. In the Intervention section sketching was taught using a software program, Spatial Vis [eGrove Education, Inc. 2023], where students sketch orthographic and isometric sketches on a mobile device or a computer. The program automatically grades the sketches and motivates student persistence []. The Spatial Vis software has 9 modules that include 2D rotations, orthographic, isometrics, flat patterns, and rigid body rotations. Over the first 4 weeks 146 sketching assignments were assigned which had a total estimated completion time of 6.1 hours. In both sections, freehand sketching was also used throughout the projects. Students drew their desired shapes for their clock pendulums. The first team assignment in the robot project was for each student to draw 3 concepts for the robot, and to share these concepts with their teammates. In the robot project it was common to see students sketching in the Design Studio as they shared concepts with their teammates.

A pre- and post- spatial visualization test was conducted in week 1 and 9. The test was the Purdue Spatial Visualization Test Rotation Section, PSVT:R [Guay 1976]. The PSVT:R consists of 30 multiple choice questions. The test was implemented on the Canvas Learning Management System for an uninterrupted timed 20 minute block. Course credit for the pre-and-post tests were given based on completion rather than the PSVT:R score.

Assessment was also conducted through surveys which were part of weekly reflection assignments. In the first survey students were asked about their hands-on, design, and fabricating skills that they entered the class with. In week 4 students began to work in teams and survey questions were added relating to communicating with teammates, and how included and valued one felt by one's teammates. The last survey asked summary questions about the course.

Results

The results of the PSVT:R pre- and post- tests are shown in Tables 1-3. Table 1 shows the results for all students, Table 2 for male students, and Table 3 for female students. The students are categorized based upon their incoming spatial visualization ability. The Low group has a pre-PSVTR of 60% or below, which is the same as Sorby's [2012] categorization, the Mid group is defined with scores between 60% and 90%, and a high group is defined as 90% and over. Only students who completed both the pre- and post- test were included in these Tables. All students completed the pre-test, but 3 in the Control Section and 11 in the Intervention Section did not complete the post-test. In the Control section there were 57 males, 23 females, and 2 students that did not identify gender. In the Intervention sections there were 42 males, 18 females, and 2 students that did not identify gender. A two-sample t-test was performed without assuming that the populations have equal variances to determine statistical significance. The t-test was performed using the pre- to post- change in PSVT:R for each student, and the *p-value* is shown in the rightmost column of Table 1. A *p*-value of less than 0.05 was used to indicate a statistically significant difference between the Control and Intervention sections.

Table 1: All Student - PSVT:R Pre and Post Average Test Scores

Grouping by Incoming Spatial Visualization Ability	Control			Intervention			*p-value*
	No. of Students	Pre-Test	Post-Test	No. of Students	Pre-Test	Post-Test	
Low: Pre-PSVTR <= 60%	20	50%	54%	18	46%	69%	0.0065
Mid: 60% < Pre-PSVTR < 90%	43	77%	77%	31	77%	84%	0.0388
High: Pre-PSVTR >= 90%	19	95%	93%	13	98%	95%	0.5181
Complete Section	82	74%	75%	62	72%	82%	0.0019

Table 2: Male Students - PSVT:R Pre and Post Average Test Scores

Grouping by Incoming Spatial Visualization Ability	Control			Intervention			*p-value*
	No. of Students	Pre-Test	Post-Test	No. of Students	Pre-Test	Post-Test	
Low: Pre-PSVTR <= 60%	9	48%	51%	10	44%	58%	0.2314
Mid: 60% < Pre-PSVTR < 90%	30	75%	74%	23	77%	85%	0.0492
High: Pre-PSVTR >= 90%	18	95%	94%	9	98%	94%	0.2725
Complete Section	57	77%	77%	42	74%	80%	0.0232

Table 3: Female Students - PSVT:R Pre and Post Average Test Scores

Grouping by Incoming Spatial Visualization Ability	Control			Intervention			*p-value*
	No. of Students	Pre-Test	Post-Test	No. of Students	Pre-Test	Post-Test	
Low: Pre-PSVTR <= 60%	11	51%	57%	8	50%	82%	0.0073
Mid: 60% < Pre-PSVTR < 90%	11	80%	85%	7	76%	81%	0.7883
High: Pre-PSVTR >= 90%	1	90%	73%	3	97%	96%	n too low
Complete Section	23	67%	71%	18	68%	84%	0.0327

Class Surveys

A weekly reflection and survey were conducted with Likert scale multiple-choice questions. For this study, only the results from the beginning of the class (pre) and end of the class (post) were analyzed. The complete wording of the Likert questions and answer choices are shown in Appendix I. The survey results analyzed by gender are shown in Table 4. The table shows the sum of the top 2 Likert responses, such as Effective and Very effective to indicate the percentage of students with a positive assessment in each topics area. To show the effect of training more clearly both the pre- and post- questions are shown when the same question were present in both surveys. In Table 4 the pre- and post- questions were listed in adjacent rows, and the questions for which there was only post data, were listed in the bottom rows of the table. The difference between the Control and Intervention percentages are shown in the “Post Diff” columns.

Table 4: Top 2 Likert Responses to Survey

	Male			Female		
	Control n=57	Intervention n=42	Post Diff	Control n=23	Intervention n=18	Post Diff
Pre-PSVT:R	77%	74%		67%	68%	
Post-PSVT:R	77%	80%	4%	71%	84%	13%
Pre-Tool Use	51%	46%		35%	21%	
Post-Tool Use	91%	82%	-9%	63%	89%	26%
Pre-CAD	49%	46%		30%	16%	
Post-CAD	78%	71%	-7%	58%	72%	14%
Pre-Sketching	39%	24%		57%	68%	
Post-Sketching	67%	73%	6%	42%	72%	30%
Pre-Oral Comm.	43%	44%		30%	53%	
Post-Oral Comm.	59%	69%	10%	58%	78%	20%
Pre-Theory	37%	40%		17%	37%	
Post-Theory	65%	67%	1%	37%	67%	30%
Pre-Feel Included	84%	52%		39%	63%	
Post-Feel Included	91%	82%	-9%	68%	72%	4%
Post-Valued	93%	89%	-5%	74%	89%	15%
Post-Listened to	91%	87%	-5%	84%	89%	5%
Post-Present to Teammates	89%	87%	-2%	74%	94%	21%
Post-Teamwork in Group	74%	76%	2%	63%	78%	15%

See Appendix I for wording of survey questions.

Table 4 shows data from just the top 2 Likert responses, but to determine statistical significance the complete distribution from all the students need to be considered. Because there were some differences in the Pre ratings between the Control and Intervention, as shown in Table 4, a direct comparison of Post ratings could be biased. Accordingly, a statistical comparison was performed on the difference between the Pre and Post ratings within each section. In both the Control and Intervention sections one would expect that students would improve their abilities in the subject areas covered in the course, and thus the statistical analysis performed evaluated whether there were statistically significant differences in these improvements. Table 5 shows the average difference in Likert ratings for each category which was evaluated in pre and post surveys (Post minus Pre). The 5 scale Likert data is not continuous, and therefore the two-sided Wilcoxon rank sum test, implemented in Matlab via the ranksum function, was used rather than a t-test as is recommended by the widely cited article by Clason et al. [1994] for use with Likert data. To check whether there is an increase in the mean in the Intervention relative to the Control the "right-tailed" hypothesis is used in the Matlab ranksum command. The statistical significance is represented by the *p-values* shown in Table 5. A *p*-value of less than 0.05 was used to indicate a statistically significant difference between the Control and Intervention group.

Table 5: Difference Between Post and Pre Likert Rating with Statistical Significance

	Male			Female		
	Control n=57	Intervention n=42	*p-value*	Control n=23	Intervention n=18	*p-value*
Tool Use	0.76	0.84	0.228	0.68	0.89	0.204
CAD	0.56	0.82	0.043	0.47	1.11	0.013
Sketching	0.59	0.89	0.041	0.21	0.17	0.570
Oral Comm.	0.41	0.45	0.403	0.63	0.33	0.769
Theory	0.46	0.75	0.074	0.47	0.39	0.703
Feel Included	0.27	0.52	0.111	0.47	0.22	0.739

Summary

In terms of the standardized test to measure SV ability, the PSVT:R, there were statistically significant improvements in the Intervention section when evaluating all students (i.e. both genders) as shown in Table 1 with p-value of 0.0019. The highest improvement was with students who entered the class with low scores; these students had only a 4% increase in the Control section yet a 25% increase in the Intervention section with a p-value of 0.0065. In the male population there were statically significant increases in PSVT:R scores in the students who entered with mid scores and the complete male group (Table 2). In the Control section the complete male group kept a constant PSVT:R score of 77%, while in the Intervention section it increased from 74% to 80% with a p-value of 0.0232. The largest gains in PSVT:R scores where among female students who entered the class with low scores (Table 3). This group of students entered the Control section with a score of 51% and increased their score to 57%. However, in the Intervention section this groups entered with a 50% score and increased it to 82%, with a p-value of 0.0073. There was also a statistically significant difference in the group of all females, with the Control section raisings its score from 67% to 71% and the Intervention raising its score from 68% to 84%, p-value of 0.0327. Among students who entered the class with high Pre-PSVT:R scores there were no statistically significant results. Indeed, some drops in Post-PSVT:R scores were observed at this level. These drops and lack of gains could be attributed to both a ceiling effect of the test, and the fact that student grades were based on completing the PSVT:R tests but not the scores they achieved.

The Likert survey results shown in Table 4 were analyzed in terms of the percentage of students who indicated the top 2 responses, such as Effective and Very effective. Among female students the responses in the Intervention section were higher than the Control in all categories, with gains over 10% in 9 out of the 11 questions. Areas that showed gains of 20% or higher included Tool Use (using hand-on Making tools), Sketching (using freehand sketching to communicate a design idea), Oral Communication (ability of using oral explanations to communicate a design idea), Theory (ability to apply engineering theory to a design project), and Presenting to Teammates (able to present your design ideas to your teammates).

Among male students, the Likert data shown in Table 4, there was not a large a difference between the Control and Intervention section. In 6 of the questions there was an increase in the Intervention section, but in 5 question there was a decrease. The one question where there was a difference of 10% or higher was in Oral Communication, where there was a 10% increase in the Intervention section compared to the Control.

The Likert questions also illustrated differences between the male and female populations before they entered the class. Table 4 shows that male students entered the class with higher ratings in the Pre categories of: Pre-PSVT:R, Pre-Tool Use, Pre-CAD, and Pre-Theory. At the end of the class, male students in the Control section rated higher than the female students in all 11 categories. However, at the end of the class in the Intervention section females rated higher than males in 7 of the categories, and in 3 categories the difference was within 2%. This indicated that by enlarge the female students and male students in the Intervention section where much more equal at the end of the class than in the Control section.

It is interesting that female students initially rated themselves as significantly higher than male students in sketching (Table 4), but then showed a smaller increase or even a decrease in the Post sketching rating. One reason for this could be that at the time of the Pre rating students were not that familiar with what technical sketching is, so the responses may have been more related to artistic sketching. No data was collected on students' interpretation of the term sketching ability and if it changed during the class. Accordingly, this is an unsupported hypothesis.

Table 5 shows data that for all students, including those that had ratings in the lower 3 Likert responses in the Pre or Post survey. Therefore, the results in Table 5 differ from those in Table 4 in that weaker students are more represented, and that statistical significance can be evaluated. The values in Table 5 are the average differences between Pre and Post surveys, and the fact that all values are positive in the table is an indication that growth occurred in all skill categories and that broad learning occurred in both the Control and Intervention sections. Most of the categories do not show statistical significance. However, statistical significance is present in CAD ability, with $p=0.043$ for male students and $p=0.013$ for female students. There is also statistical significance in Sketching ability for male students with $p=0.041$. The differences in other areas were mixed which possibly reflects the limited number of the students in the Control and Intervention sections, and that fact that some sections started at a higher level that others which leaves less room for growth.

Limitations

In a controlled trial any differences between the 2 groups that are not the topic of the study can lead to inadvertent impact of the results. The largest of these uncontrolled variables was likely that the 2 sections had different instructors and different lab tutors. However, it should be noted that students preferred the lectures in Control section; in the Control section 56% of the students indicated that they learned "A Large Amount" or a "Very Large Amount" from the lecture compared to 35% in the Intervention section. Accordingly, any benefits observed in the Intervention were despite having less learning from the lectures. Also, there may have been some factors that could have caused the students not to be split completely randomly between the Control and Intervention Sections. While the lecture time for both sections was the same, the lab times and days varied which may have impacted enrollment choices. However, Table 4 shows that in most Pre-categories there were no significant differences between Control and Intervention sections. The Intervention section was somewhat lower in Pre-Tool Use and Pre-CAD, and somewhat higher in Pre-Oral Communication and Pre-Theory. Other limitations of the study include the limited number of students in the study, and that the Likert survey data was that it included self-reported assessment of ability, rather than an objective assessment as was possible with the PSVT:R SV test.

The focus of the intervention was on how freehand sketching was taught. In the Control section the sketching was done on paper, and grading was performed manually by tutors who returned the graded sketches within a week. In the Intervention section the sketching was done on phones, tablets, or computers, and grading was performed real-time with feedback hints. Also, in the

Intervention section there were many more sketching assignments, 146 vs 6. It was not possible to provide real-time grading for assignments done on paper, and also not practical in this class to grade 146 assignments manually. Accordingly, it is not possible to discern if the differences between the Control and Intervention groups are due to the number of sketching assignments alone, or if the real-time feedback or medium of sketching contributed to the differences in outcomes between the groups. The use of sketching software allowed multiple benefits simultaneously. Accordingly, it is not possible to distinguish benefits of the intervention that related to the larger number of assignments or real-time feedback. Also, it was not possible to separate out in there were learning differences due to the difference between sketching on a screen rather than paper.

Conclusions

SV ability has been correlated to success in STEM [Kine 2017], yet low SV rates have been noted in female students and concerns have been raised as to this reducing female success in STEM [Hill et al. 2010]. To address these concerns, this study evaluates SV training in respect to gender. SV has been shown to be a learnable skills and gains have been noted through freehand technical sketching, hands-on design activities, and learning CAD [González Campos et al. 2019; Reilly et al. 2017; Uttal et al. 2013; Sorby 2009; Wai et al. 2009]. There are courses that focus on SV training and utilize sketching assignments exclusively [Bairaktarova et al. 2019; Sorby 2001]. There are also freshmen introductory design courses which incorporate hands-on design and CAD. This raises the question as to whether it is beneficial to add sketching assignments to classes that already include hands-on design and CAD.

The first research question considered was to evaluate “Does adding additional sketching instruction to a class with CAD and hands-on design have measurable benefits?” This controlled trial study shows that there is a statistically significant benefit in additional sketching assignments for all students. The Intervention section had a statistically significant increase in the standardized PSVT:R scores for both male and female students, with a gain of 1% for the Control section and 10% for the Intervention section. The gains for the female students were even higher. In the Control section female students entered with a Pre-PSVT:R score of 51% and increased their score by 6% to 57%, which can be explained as due to CAD, design activities, and a small amount of sketching assignments. However, a much greater increase was observed in the Intervention section where female students entered with a score of 50% and increased it by 32% to 82%, which illustrates a much higher gain (32% vs. 6%) and the added gain is attributed to the large number of sketching assignments.

The second research question “Do the benefits of sketch training extend beyond improving spatial visualization ability into areas such as the ability to communicate with teammates?” This study used survey question relating to CAD, tool use, applying engineering theory, and working with teammates. When evaluating the top 2 Likert responses, in both the Control and Intervention sections male students expressed higher ability in a wide range of areas at the beginning of the class. At the end of the class, male students in the Control section rated higher than the female students in all 11 categories. However, at the end of the class in the Intervention section females rated higher than males in 7 of the categories, and in 3 categories the difference was within 2%. By enlarge the female students and male students in the Intervention section where much more equal at the end of the class than in the Control section in categories ranging from applying engineering theory to the ability to present design concepts to teammates. Accordingly, the benefits of training to sketch extended beyond just increasing scores in SV. The benefits in improved CAD and sketching ability were statistically significant in terms of the difference between Pre and Post skills with p-values of ranging from 0.013 to 0.043.

The third research question "Does sketch training just benefit a subset of students such as those who enter a class with low spatial visualization ability, or does its benefit extend to all student levels?" Here we see that the majority of students do benefit from an increase in sketching assignments in the PSVT:R standardized SV test. For male students we see large gains in Post-PSVT:R for students who enter at both low and mid level Pre-PSVT:R scores, but not at a statistically significant level of confidence. For female students we see large gains in Post-PSVT:R for students who enter at low Pre-PSVT:R scores with statistical significance of p-value of 0.0073. For female students who enter with mid level PSVT:R scores, the gains were similar for both the Control and Intervention section. For both male and female students who enter the class at a high level in their PSVT:R score did not show much gains and there were some drops, but the scores above 90% can be impacted by a ceiling effect that makes it hard to demonstrate benefit. The Likert survey question showed that both male and female had a statically significant increase in CAD ability with p-value of 0.043 for males and with a p-value of 0.013 for female students. Therefore, one can conclude that sketch training benefited a wide range of students, albeit at different levels.

In conclusion, using sketch training software allowed adding assignments and self-paced learning that would not have been feasible without the software. Benefits were shown that extended learning gains beyond those achieved with existing assignments in hands-on design, CAD, and a small number of sketching assignments. To verify these findings, additional trials should be conducted to determine if these results can be duplicated, and the number of students studied increased.

Disclosure

Nathan Delson has an equity interest in eGrove Education, Inc., a company that may potentially benefit from the research results. The terms of this arrangement have been reviewed and approved by the University of California, San Diego in accordance with its conflict of interest policies. In addition, a Small Business Innovation Research (SBIR) grant was awarded to eGrove Education, Inc., by the NSF (Award # 1648534).

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Appendix I: Survey Question Details

Questions on Both Pre- and Post- Survey

Topic	Question Language and Likert Choices
Tool Use	Rate your ability of using hands-on Making tools. Relative to average student in the class. Very ineffective, Ineffective, Medium, Effective, Very effective
CAD	Rate your ability with Computer Aided Design (CAD). Relative to average student in the class. Very ineffective, Ineffective, Medium, Effective, Very effective
Sketching	Rate your ability of using freehand sketching to communicate a design idea. Relative to average student in the class. Very ineffective, Ineffective, Medium, Effective, Very effective
Oral Communication	Rate your ability of using oral explanations to communicate a design idea. Relative to average student in the class. Very ineffective, Ineffective, Medium, Effective, Very effective
Theory	Rate your ability to apply engineering theory to a design project. Relative to average student in the class. Very ineffective, Ineffective, Medium, Effective, Very effective
Feel Included	To what extent do you feel included and welcome in the class? Very ineffective, Ineffective, Medium, Effective, Very effective

Questions Just in Post- Survey (includes questions relevant to teamwork)

Topic	Question Language and Likert Choices
Valued	Rate how well other members of your team value your contributions. Not Valued At All, Not Valued, Neutral, Highly Valued, Very Highly Valued
Listened to	Rate how well your teammates listen to you. Do Not Listen Well At All, Do Not Listen Well, Neutral, Listen Well, Listen Very Well
Present to Teammates	Rate how effective were you able to present your design ideas to your teammates. Very ineffective, Ineffective, Medium, Effective, Very effective
Teamwork in Group	How effective was the teamwork in your group for the past week? Very ineffective, Ineffective, Medium, Effective, Very effective