Effects of gender, effort, and spatial visualization abilities in an engineering graphics class

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Abstract
The objective of this study is to understand the interaction between gender, spatial visualization ability, effort, and course outcomes in an engineering graphics course. Within engineering, spatial visualization ability is essential to many applications, beginning with engineering graphics. Engineering graphics courses are commonly introductory-level classes in engineering programs, creating challenges for women, who on average score lower on tests of spatial visualization ability. Improved understanding of gender differences in engineering graphics classes could therefore help identify pedagogical areas to support women and increase their retention in engineering programs. Although a gender gap exists in spatial ability and performance in engineering graphics classes, female students still achieve positive course outcomes. We hypothesize that: 1) female students put more effort into engineering graphics courses; and 2) that this greater effort (measured as time spent on homework, homework scores, quiz scores and attendance) by female students reduces the gender gap in course and exam grades. By analyzing scores on homework, quizzes, exams, and attendance in addition to total course score, we can better assess differences between students and quantify the relative importance of different factors like effort and ability on student performance. We present data from three semesters of a freshman-level engineering graphics course at a large research university and analyze differences in spatial visualization ability and course outcomes of male students (n=232) and female students (n=76). Female students scored lower on spatial visualization tests and course exams but had higher performance in less time-restricted, effort-related outcomes, such as attendance and homework scores, compared to male students. However, on average, female students had lower overall course grades. After accounting for the spatial ability gender gap by comparing students in groups of similar visualization ability, we found that female students with high spatial visualization abilities tended to have better performance on less time-restricted, effort-related outcomes and took more time on homework, but still had lower exam and course scores than their male counterparts. It appears that the gender gap in performance may not be explained fully by spatial visualization, but could be related to gender differences in testing. Better understanding of the differences between male and female students of similar visualization ability could help educators identify opportunities to leverage these differences in developing pedagogical strategies to support women in introductory engineering graphics courses and further engineering pursuits.

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Introduction

There is a persistent underrepresentation of women in engineering fields, with only 12% of US engineering positions held by females [1]. One factor contributing to this underrepresentation is that women tend to have lower spatial visualization ability (for example, the ability to mentally rotate shapes) [2] - [4], predisposing them to struggle in courses requiring advanced spatial skills such as in engineering graphics [3], [5] - [7]. Introductory engineering graphics courses, where students are required to mentally rotate and sketch objects from different viewpoints, are commonly used as early gateway classes in undergraduate engineering curriculums [3], [8]. A better understanding of the performance of women in these classes provides an early opportunity to support women to ensure that they receive the tools to progress successfully in engineering fields [6], [9].

The gender disparity in engineering is dependent on a complex interaction of factors such as societal expectations, childhood experiences, etc. [7], [10]. These factors can drive differences in learning styles that create pedagogical biases towards certain groups of students [11]. Although these factors can be addressed at many stages of the education pipeline, the scope of this paper focuses on an undergraduate class early in the curriculum, which is an important time frame where women are more likely than men to leave the engineering track [3], [12]. The aim of this study is to analyze several variables within an engineering curriculum where gender differences exist: spatial visualization ability, performance in introductory engineering graphics courses, and work-ethic with respect to classroom tasks, within the context of self-efficacy and persistence in engineering. Understanding the factors related to the gender gap in engineering is an important first step toward future studies of targeted interventions to better meet the pedagogical needs of a more diverse student population.

It has been widely reported that women tend to have lower spatial visualization ability than men [2], [3], [5], [6], [8], [13], [14]. It has also been shown that visualization ability can be improved with training, such as an engineering graphics course, irrespective of gender [2], [5], [8], [14] - [16]. Mixed outcomes have been reported with respect to the presence of a gender difference in the magnitude of this improvement [2], [5], [8]. If spatial visualization can be improved with training, introductory level engineering graphics courses present an ideal target for reducing the gender gap in spatial visualization ability, which could help women early in the engineering pipeline.

A student's spatial visualization ability score has been found to be correlated with their final grade in an engineering graphics class [8], [14], [15]. Hsi et al. found that, in an engineering graphics class, spatial visualization ability was correlated with the overall course grade, such that women, who had lower average spatial visualization scores, also tended to have lower performance in the course. However, the gender difference was not present for grades on homework or projects. Therefore, they attributed the discrepancy in final grade to the lower exam scores of women compared to that of men [2]. It has been hypothesized that females employ slower strategies in solving rotation problems than males, which may contribute to the discrepancy in scores observed on time-restrictive spatial visualization tests [13] and course exams that require heavy use of spatial visualization ability [2].

The high homework and project grades of women relative to exam grades and visualization ability found by Hsi et al. is supported by many studies that have found that women in engineering tend to have stronger study skills than their male colleagues. In a study of freshman engineering students, women self-reported being more comfortable with their study habits than their male counterparts [17]. Similarly, in a study of engineering students, women scored higher than men on assessments for study-habit related metrics such as: attitude toward learning, motivation to study, time management, and use of study aids [18] - [20]. This higher level of study abilities in women has been correlated with positive outcomes in improving spatial visualization. In a study of an engineering graphics class, there was a greater improvement in spatial visualization scores among women who reported their commitment to completing class assignments as “high” [8]. Stronger study habits observed in women is one example of a gender difference in engineering beyond the gap in spatial visualization ability.
Self-efficacy (the personal belief in one’s ability to succeed or accomplish a task) is another area where gender differences have been observed. Many studies have reported that women in technical undergraduate programs have lower self-efficacy than their male counterparts [5],[17], [21] – [23]. Some of these studies indicated that women have lower self-efficacy despite maintaining similar course grades to men [17], [21] - [22]. One study found that self-efficacy was correlated with spatial visualization ability for engineering students [5]. Research has pointed to effort rather than ability as being key to retaining and promoting women in technical fields by promoting self-efficacy [12], [24]. The factors that have been attributed to influencing self-efficacy more in women than in men are understanding and learning course material, critical-thinking, getting help, and effort [25] - [26]. Self-efficacy has been shown to be correlated with women’s plans to persist in engineering fields [27] - [28]. By further understanding gender differences in effort levels in an engineering graphics context, we can better devise pedagogical strategies targeted at improving self-efficacy and retention of female students.

The objective of this study is to determine if women do in fact put more effort into an introductory engineering graphics class, and to determine if this extra effort can compensate for their lower average spatial visualization ability, resulting in equal course outcomes such as exam and homework grades. We hypothesize that: 1) female students put more effort (measured as quiz scores, time spent on homework, attendance, and homework scores) into engineering graphics courses; and 2) that this greater effort by female students results in roughly equal average course and exam grades for men and women. While other studies have observed gender differences in spatial visualization ability, exam scores, final course scores, and homework scores individually, this study analyzes relationships of all of these metrics simultaneously to understand the extent to which the gender gap in spatial visualization ability alone predicts performance.

Methods

Data was gathered at the University of California, Berkeley from three semesters of a freshman-level engineering graphic class, E25: Visualization for Design. The course focuses on the basics of engineering drawings as well as teaching the use of AutoCAD. The number of students enrolled in each semester along with the gender breakdown are presented in Table 1. Fall 2015 and Spring 2016 were taught by the same professor and Fall 2016 was taught by a second professor. After removing data from students who submitted less than half of the homework assignments (n=4), or who did not take the final exam (n=1), the sample size was 308 (n=76 women and n=232 men). These are the sample sizes for all statistical tests, unless otherwise reported.

Table 1. Number of male and female students in each of the semesters studied.

Semester	Male students	Female students	Total students
Fall 2015	103	35	138
Spring 2016	26	9	35
Fall 2016	108	32	140

A paper version of the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R) [29] was administered in the first month of each class to assess spatial visualization ability. The PSVT:R test was given with a 20-minute time limit and was scored out of 30 total points. We report the results as the number of correct answers rather than a percentage. Students were told the results of their PSVT:R test. In Fall 2015 and Spring 2016, students with low PSVT:R scores were given the opportunity to complete extra problem sets and seven students elected to participate, the results of which will be addressed in a future study.

From all semesters, the following metrics were recorded: PSVT:R score, midterm exam score, final exam score, homework score, attendance, and average quiz score. The midterm was administered in a 2-hour time period, outside of class. Quizzes were administered with relaxed time constraints, and, although requiring technical understanding, were generally graded to give full credit for participation. In two of the semesters, students were asked when submitting each of 10 homework assignments to state how much time they spent working on homework activities, including reviewing notes and reading the textbook.

Students participated in a group project, but because the project had group rather than individual grades, those scores are not reported or analyzed here. Based on instructor weighting of course components, minus the course project, an uncurved total course score was calculated for all semesters using the same weighting of 27% for homework, 3% for attendance and quizzes, 23% for the midterm, and 47% for the final exam. The attendance score was based on the percentage of approximately 10 in-class assignments that were attempted by each student. Exam and homework scores had different averages in the different semesters. Because we were interested in relative performance of the students, for these scores as well as the final course score, we calculated the standard score (z-score) separately for each semester.

An exploratory factor analysis was performed in MATLAB using the maximum likelihood estimate method and the varimax rotation option. Total course scores were excluded from the factor analysis because this parameter was directly calculated from the other metrics. Because it is robust to outliers and doesn't assume a normal distribution, the Wilcoxon rank-sum test was used to compare gender differences for each metric. Spearman's rank correlation coefficient was used to calculate the correlation between different course metrics. A significance level of .05 was used for all statistical tests.

Results

An exploratory factor analysis was used to investigate relationships between course metrics. All six course metrics had a correlation coefficient above .3 with one or more other metrics. To test that the data was factorable, several tests were performed. The Kaiser-Meyer-Olkin measure of sampling adequacy was found to be .73 and Bartlett's test for sphericity (χ^2 (306) = 709.14, $p <$ .05) was significant, suggesting that the data has reasonable factorability. When one factor was used with maximum likelihood estimation factor analysis, the p-value was highly significant ($p <$ .001), so we rejected the null hypothesis of a single factor. With two factors, we failed to reject the null hypothesis (p = .641), suggesting that two factors are sufficient to explain the covariation in our data.

Factor 1 explained variation in PSVT:R, midterm exam, and final exam score (factor loadings > 0.68, Table 2). Because Factor 1 largely explains performance on time-constrained exams that require heavy use of a student's spatial visualization ability, we designated it as the "ability factor." Factor 2 explained variation in homework score, attendance, and quiz score (factor loadings > 0.63, Table 2), all of which are activities with relaxed time-constraints. Success in these metrics depends on effort-related characteristics such as conscientiousness and good study skills and so we designated Factor 2 as the "effort factor." The designations of "ability factor" and "effort factor" are made for convenience and conciseness; we do not mean to imply that these factors can completely quantify a student's effort or ability. When the data was analyzed separately for men and women with two factors, the factor loadings for all analyzed metrics were similar. Both genders showed greater loading for Factor 1 on PSVT:R, midterm exam, and final exam scores, and greater loading on Factor 2 for homework, attendance, and quizzes.

Table 2. Factor analysis results of scores normalized for all three semesters.

Metric	Specific variance	Factor 1 loading ("Ability factor")	Factor 2 loading ("Effort factor")
PSVT:R	0.53	0.68	0.06
Midterm exam	0.34	0.79	0.19
Final exam	0.23	0.86	0.18
Homework	0.29	0.35	0.77
Attendance	0.39	0.00	0.78
Quizzes	0.59	0.13	0.63

Based on the relative loadings of the different metrics, PSVT:R, midterm exam, and final exam scores were designated "ability factor" metrics and homework score, attendance, and quiz score were designated "effort factor" metrics. Most metrics are affected, to varying degrees, by both the "ability factor" and the "effort factor," suggesting that success requires both effort and ability. This is especially true of homework, which had a loading of 0.35 on the "ability factor" and 0.77 on the "effort factor." We designated homework as an "effort factor" metric because of its larger loading on the "effort factor," and because homework did not have strict time constraints, which we hypothesized should reduce the influence of spatial visualization ability on performance.

As summarized in Table 3, metrics related to the “ability factor” (midterm and final exam) were strongly correlated with PSVT:R score ($rs(306) > .45$, $p < .001$). In contrast to “ability factor” metrics, “effort factor” metrics did not correlate strongly to PSVT:R score ($rs(306) < .25$, homework $p < .001$, attendance $p = .03$, quizzes $p = .08$), supporting the results of factor analysis. Note that the course score is calculated as a weighted sum of the midterm, final exam, homework, attendance, and quizzes. When correlations were calculated separately for male and female students, the differences between the female and male correlation coefficients were not statistically significant.

Table 3. Correlation coefficients between course metrics.

Metric	1.	2.	3.	4.	5.	6.	7.
1. PSVT:R	---	.49***	.56***	.55***	.24***	.13*	.10
2. Midterm		---	.68***	.81***	.47***	.14*	.26***
3. Final			---	.94***	.50***	.15**	.27***
4. Course score				---	.65***	.24***	.36***
5. HW					---	.32***	.32***
6. Attendance						---	.19***
7. Quizzes							---

* (*p*<.05) ** (*p*<.01) *** (*p*<.001)

Males had statistically significantly higher average PSVT:R scores than women in two of three semesters (Table 4). Enrollment for this course is lower in spring semesters, and so the higher PSVT:R scores of women in Spring 2016 may be due to the small sample size. PSVT:R scores for Fall 2016 are higher than Fall 2015, likely due in part to the fact that the PSVT:R scores were administered a few weeks later in the semester than in Fall 2015 and Spring 2016. The distribution of PSVT:R scores is skewed towards high scores, indicating that the student population includes many high visualizers, with 15% of men achieving a perfect score (Figure 1a). The distributions of PSVT:R scores of men and women are similar, with a slightly lower PSVT:R mean score for women.

Table 4. PSVT:R scores in each of the semesters studied.

	Females		Males		
Semester	*n*	*M (SD)*	*n*	*M (SD)*	*p*
Fall 2015	35	21.9 (4.7)	101	25.4 (4.4)	<.001
Spring 2016	9	25.4 (4.4)	26	24.6 (4.8)	.583

Fall 2016	32	25.4 (4.0)	105	26.5 (4.0)	.087
All semesters combined	76	23.8 (4.7)	232	25.8 (4.3)	<.001

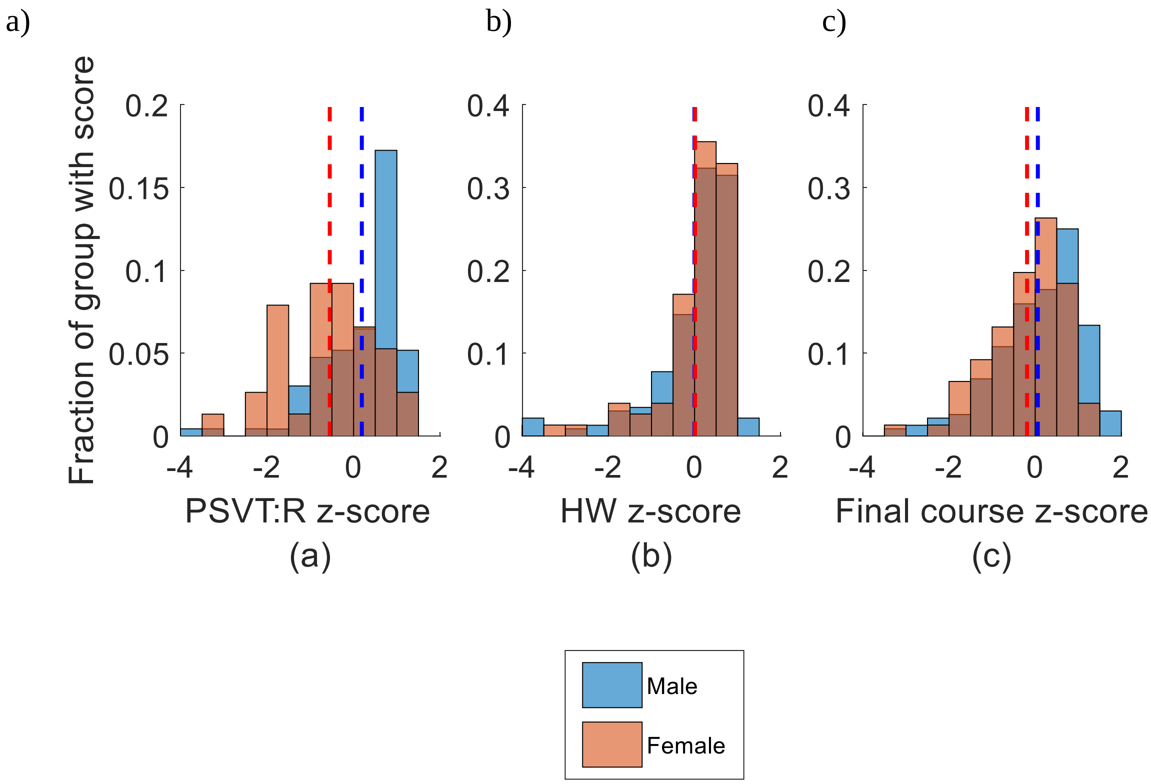

Figure 1. Distributions of student standardized scores for (a) PSVT:R, (b) HW, and (c) final course score. Blue dashed line indicates male mean and red dashed line indicates female mean.

Because women on average have lower spatial visualization ability, and because the exams in this class included several problems on orthographic projection and sketching that required students to use their spatial visualization ability, we would expect different outcomes on exams for women and men. Women did have lower midterm and final exam scores than male students, as reported in Table 5 in the form of standard scores. Women also had lower final course scores. These differences were statistically significant.

Table 5. Standardized exam and final course scores.

Metric	Female average (*SD*)	Male average (*SD*)	*p*

Midterm standard score	-0.19 (0.90)	0.06 (1.02)	.01
Final standard score	-0.20 (0.93)	0.07 (1.01)	.03
Final course standard score	-0.19 (0.89)	0.06 (1.03)	.01

In support of Hypothesis 1, in "effort factor" metrics, such as homework, average number of hours spent on class homework, attendance, and quizzes, the average for women was higher than that for men (Table 6, Figure 1b). Figure 1b shows female homework scores shifted more to the right than seen with PSVT:R score. These are assignments where students are not under time pressure but students do need to be diligent and conscientious in the completion and submission of the activities. Homework assignments included many sketching and projection activities that required spatial visualization ability, but despite the female students' lower average PSVT:R scores, there was not a statistically significant difference between men and women in homework grades. Women also spent more time on homework, a result that was statistically significant. However, the higher performance of women in "effort factor" metrics did not fully reduce the gender gap in class performance — women had lower exam grades and lower grades in the class as a whole, as stated earlier.

Table 6. Standardized homework scores and other "effort factor" metrics.

Metric	Female average (*SD*)	Male average (*SD*)	*p*
Homework standard score	0.01 (0.94)	0.00 (1.02)	.75
Attendance	95.05 (10.35)	94.26 (14.82)	.49
Quizzes	91.30 (12.18)	90.24 (16.39)	.47
Homework hours (*n*=170)	5.74 (1.47)	5.19 (1.48)	.04

The gender difference in "effort factor" metrics may be confounded by the fact that the female students are more likely to be low visualizers. Do women put in more effort because of some social factors related to their gender or because of their low visualization ability? Do low visualizing men also put in more effort compared to high visualizing men? To check this, we broke down all students into groups with similar spatial visualization ability based on PSVT:R score: low (< 21); middle (21 - 25); and high (> 25).

We can qualitatively assess interactions of variables on the average performance for low, mid, and high visualizers using interaction plots like those used in an analysis of variance. A positive trend exists between spatial ability and midterm performance for both men and women, as shown in Figure 2a. We can also see that female low visualizers performed better than male low visualizers on the midterm. This same trend is not seen for high visualizers. Instead, male high visualizers scored higher on average on the midterm. Similar trends are seen in the final exam and final course score. While spatial visualization ability seems to have the largest influence on test scores and the class performance as a whole, it appears that gender modifies the effect of spatial visualization, such that male and female students with the same visualization ability may not have the same experience on exams.

a) b)

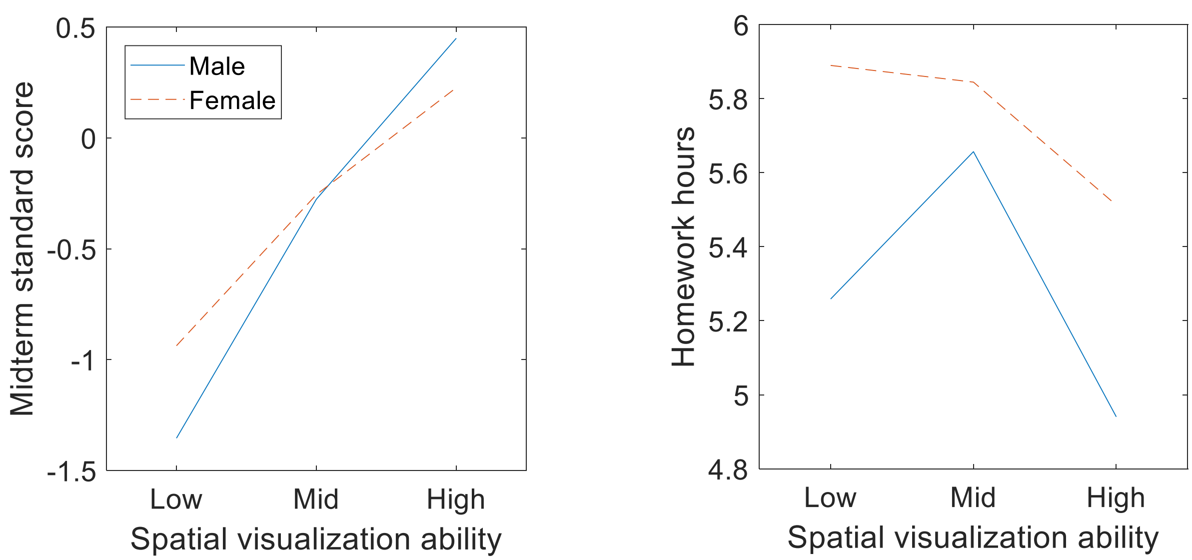

Figure 2. Interaction plots showing influence of gender and spatial visualization ability on (a) midterm standardized score and (b) homework hours.

Figure 2b shows that spatial visualization also appears to have some effect on the average number of homework hours reported by students with different spatial visualization levels, with high visualizers generally spending less time than their low visualization peers. The influence of gender is more obvious here, with female students spending more time than their male peers for all three visualization levels. Rather than modifying the effect of spatial visualization, gender has a small direct effect on effort level, as measured by number of hours spent on the homework. A similar trend can be seen in homework standard scores, with females outperforming their male peers at all three visualization levels.

To further test our hypotheses regarding differences in performance between male and female students, we quantitatively examined the performance of high and low visualizers. We compared male low visualizers to female low visualizers, and male high visualizers to female high visualizers, using the Wilcoxon rank-sum test to quantify the difference between means of these individual groups. In both high and low visualization levels, woman had higher performance on all "effort factor" metrics: homework, attendance, quizzes, and number of homework hours reported (when available). A summary of these data is shown for high visualizers in Figure 3 and for low visualizers in Figure 4, with all scores shown as standard scores.

In "ability factor" metrics, high visualizer men tended to outperform high visualizer women. There was a statistically significant difference between the standardized midterm scores of high visualizer men (n=146, M=0.4, SD=0.7) and high visualizer women (n=36, M=0.1, SD=0.7), p=.013. High visualizer men also performed slightly better on the final exam, and had higher standardized final course scores (M=0.4, SD=0.8) than high visualizer women (M=0.2, SD=0.6), p=.028. Because of the large number of men who had a perfect score, the average PSVT:R score for high-visualizer men (M=28.3, SD=1.3) was slightly higher than that of high-visualizer women (M=27.8, SD=1.3), but this difference was small in magnitude.

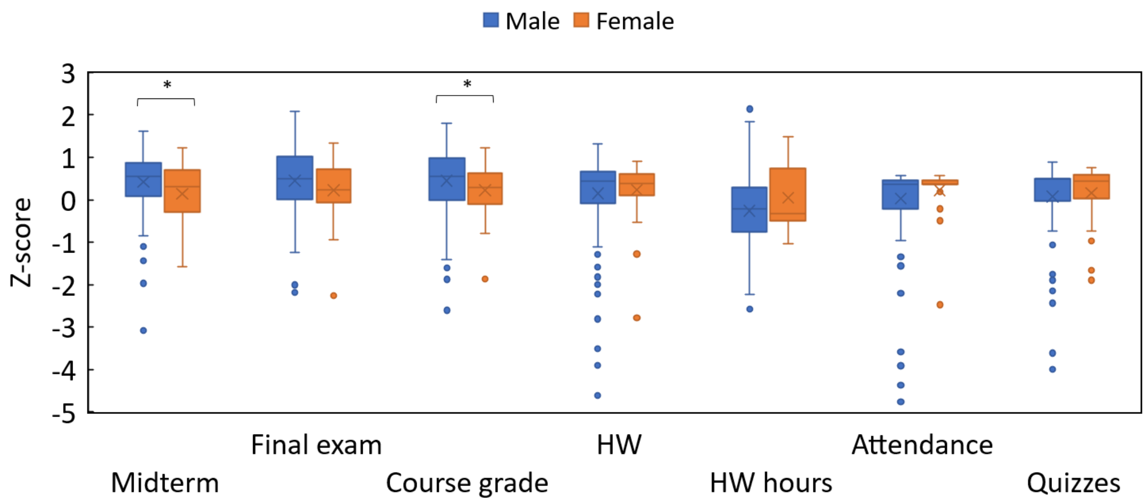

Figure 3. Standardized scores for high visualizers showing lower scores for females in "ability factor" metrics and higher scores for females in "effort factor" metrics. The mean standard scores are indicated with an x and outliers are shown as dots. * (p<.05)

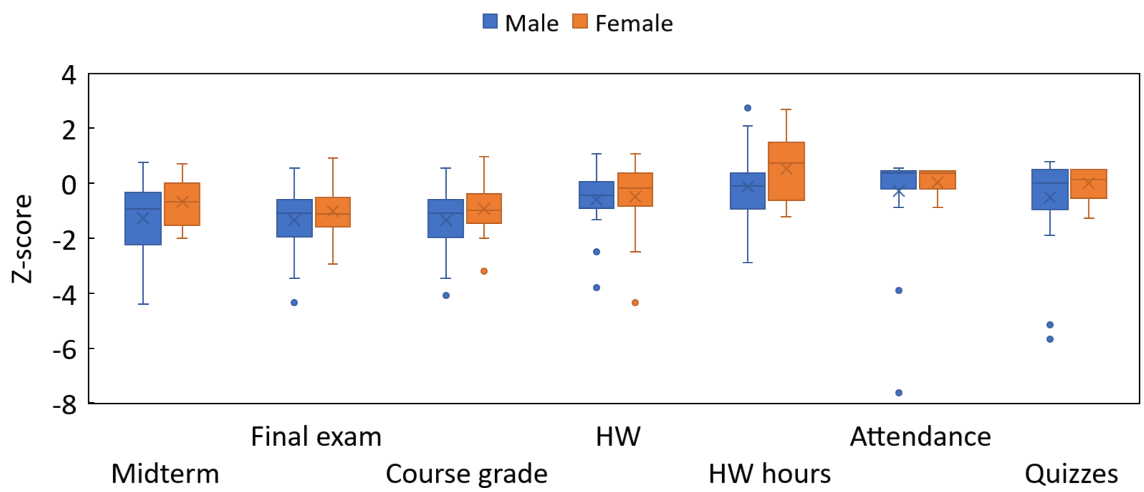

Figure 4. Standardized scores for low visualizers showing high scores for females in "ability factor" metrics and "effort factor" metrics.

In contrast to high visualizers, low visualizer women (*n*=18) had higher mean exam scores and total course scores than low visualizer men (*n*=26), in addition to their higher "effort factor" related performance, although these differences were not statistically significant. Low visualizers' average scores on all performance metrics were lower than high visualizers. The difference between low visualizer and high visualizer performance was not as large for "effort factor" metrics as it was for "ability factor" metrics. Both male and female low visualizers spent more time on homework than their high visualizer counterparts. Mid-level visualizers fell between the trends of low and high visualizers and showed no clear trends.

Figure 3 shows the average time spent on homework versus the total course score, for men and women. Low visualizers and high visualizers are shown separately. Generally, both male and female high visualizers tend to spend less time than low visualizers while maintaining high course scores. Similarly, male and female low visualizers have lower course scores, but also a high amount of variation in the amount of time they spend each week—some low visualizers spend little time, while some spend a large amount of time. However, women (as reflected in Figures 2-4) spent more time than their similar visualization-ability peers, without that being reflected in equivalent course score. A performance barrier remains—no women in these semesters scored better than one standard deviation above the mean for total course scores.

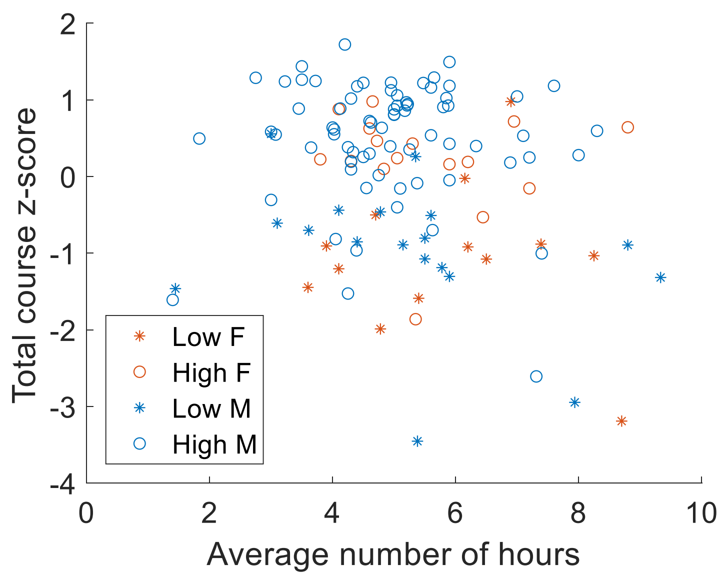

Figure 3. Average number of hours spent on homework and studying versus standardized total course score for low and high visualizing men and women. Women: higher average number of hours, lower course score. Men: lower average number of hours, higher course score.

Discussion

The objective of this study is to explore differences in effort and course outcomes for men and women in an engineering graphics course. We hypothesized that: 1) although female students have lower spatial visualization ability than male students, they outperform male students in effort-related components of an engineering graphics course; and that 2) this greater effort would work to close the gender gap in final course score. Because our data set spans multiple semesters with different instructors, there are external variables that influence student performance that are not controlled for. However, analysis of our results indicated that, while female students did tend to outperform male students in effort-related metrics, female students still, on average, had lower course scores. Our analysis highlights several interesting interactions between gender, visualization ability, effort, and performance that should be the focus of further study.

It appears that the lower performance of females on exams is what ultimately lowers their overall course results compared to their male counterparts. We found that although women performed better on metrics without strict time constraints like homework, high visualizer women performed worse than high visualizer men on exams, which had strict time constraints. This suggests that performance on exams could be influenced by other factors related to gender, possibly time-pressure or test anxiety, in addition to spatial visualization ability. This is in line with previous studies that have suggested that the lower performance of female students on exams with a large spatial visualization component may be less significant when time-constraints are removed [13], [14] and that female students are more likely to report testing anxiety [18]. Other social factors, such as stereotype threat, may also be contributing to this performance gap [30]. Future studies will focus on examining the impact of time-constraints on exams as a possible method to account for gender differences in learning and testing styles, and what exam questions best draw out differences in student effort.

The gender gap is not present, or is reversed, in “effort factor” metrics. Because improving spatial visualization ability is an important outcome of the course and exams are a key course component for accurately assessing student performance, simply increasing the weight of “effort factor” metrics is not a viable solution for addressing the gender gap. Rather, the finding that female students on average invest more effort can be employed to target the gender gap in spatial visualization ability by providing access to extra practice and help.

The finding that female students in engineering tend to be diligent students is not unique. Other studies have found that female students in engineering have stronger study skills [17] - [20]. This has been hypothesized to be a result of the lower representation of women in engineering [31]. Sonnert and Fox found an increasing difference in undergraduate GPA (favoring women) with decreasing representation of women in a given major area [31]. Sonnert and Fox suggested that because engineering is perceived as a technically intensive and difficult field, only the very strongest female students choose to pursue engineering, while a more varied distribution of male students enter the field. The over-representation of high achieving female students in engineering aligns well with our findings that, even with lower spatial visualization ability, female students consistently outperform their male counterparts in “effort factor” course metrics.

Our results indicate that female low visualizers had strong performance on “effort factor” metrics and also had higher performance in exams and final course score than their male low visualizer peers. This is consistent with previous findings that extra work can significantly improve performance in low visualizers [9], [14], [32]. Providing structured additional help outside of the class requirements could help female students with lower visualization ability to improve their performance in entry-level engineering graphics courses. Because female students seem willing to invest more effort (as indicated by our results), they may be especially helped by additional training such as study sessions and extra problem sets. Future studies will look at the impact of extra help on the course outcomes with respect to gender.

Outside of increasing spatial visualization skills, successful strategies correlated with higher self-efficacy in female students include mastery of course material, critical-thinking, getting help, and effort [25] - [26]. Emphasizing additional effort-related components to a course, instead of focusing on exams, could not only improve spatial visualization, but target self-efficacy for female students. Improving self-efficacy may help to retain female students beyond these introductory graphics courses.

Conclusion

In addition to confirming the effect of spatial visualization ability on performance in an introductory engineering graphics class, our analyses reveal connections between gender, visualization ability, course performance, and effort level. Female students generally had a higher level of effort compared to male students, but this effort wasn't reflected uniformly in performance on exams and total course score. While female low visualizers tend to invest more effort and achieve better course and exam grades, a performance barrier appears to exist for female high visualizers on time-limited exams. Our findings indicate promising areas for targeted spatial visualization training, based on the fact that low visualizer females seem to exert a high level of effort in the class, but also identify an area of concern, indicating a possible gender bias in timed exams. The finding that gender differences exist in spatial visualization ability, effort level, and test-taking ability highlights the need to understand how student characteristics affect learning styles and educational needs in this type of course. Future research should investigate the efficacy of different pedagogical strategies for diverse student populations. In addition to potentially improving outcomes in engineering graphics classes, a deeper understanding of the impact of gender-related differences in learning and testing can be widely applicable to the engineering curriculum.

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