A Write Way to Teach Statics: The Influence of Including Regular Writing Assignments in Promoting Student Success in Learning Engineering Statics

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Abstract

Writing has been shown to improve metacognition in students as well as develop discipline-specific knowledge. Engineering education researchers have corroborated these findings by showing increased conceptual understanding in engineering students who embrace writing. Engineering statics courses have been a particular focus. Yet much of that work focuses on four-year university students, and nothing has appeared in the literature since 2015. The present work investigates the influence of including a weekly writing assignment in an engineering statics course taught at a community college. Results from a control group (with no writing intervention) and a treatment group (with a writing intervention) are compared. The results suggest that writing assignments may assist low-performing students to improve their grades in engineering statics. They also confirm that community college students share the same disregard for the role of writing in the learning and practice of engineering as their four-year university counterparts. More data is needed to overcome the limitations of small sample size and formulate more definitive conclusions from the research.

Introduction

Professional engineering educators have long been interested in methods which can reveal the level of conceptual understanding in their students. The confusion matrix is a prominent example [1]. The confusion matrix offers deep insight into student thinking, but it does so only when paired with excerpts of transcripts which exemplify each cell of the matrix. Classification of results requires students to verbalize their thinking into a video or audio recording, which is then transcribed and analyzed. All of that work for every student in even a small class requires a large investment of effort and time. Yet the outstanding results which the confusion matrix offers prompt the question: Is there a way to achieve similar insights into student thinking while compressing the time it takes to receive those insights?

Writing offers a potential solution. Empirical evidence demonstrates that writing reveals thinking in the writer and improves metacognition in students [2]-[4], which has been shown to be an essential aspect of developing discipline-specific knowledge [5]. Researchers have verified this finding specifically for engineering students [6]-[7]. Indeed, metacognitive abilities can explain the difference between high-performing and low-performing students [8].

Writing skills within discipline-specific contexts are best learned by diligent practice within those contexts [5], and so writing in the engineering context is best learned by students within engineering classes [9]. Yet the common provision among engineering educators is to outsource writing instruction by requiring students to take a technical writing course from the English department [9]-[10]. Accordingly, a culture of writing being something apart from engineering has developed, creating internal resistance in engineering students from embracing writing assignments when they are included in their engineering classes [7], [10]-[11].

Such a situation is highly unfortunate considering the documentation within the literature that including regular writing assignments in engineering courses greatly benefits student learning. Writing assignments in engineering courses enhance communications skills and improve overall GPA [10]. They enhance learning in engineering students [12]-[13], helping them to think more critically and more deeply about the concepts within engineering course content [14]-[15]. Researchers have also shown that the final course grades in engineering courses improve with the intervention of regular writing assignments [6].

The literature contains research into the effect of including regular writing assignments in a wide range of specific engineering courses [6]-[7], [10]-[17], [19]-[20], and some researchers have reported positive benefits from integrating writing faculty as team instructors in engineering courses [18] as well as placing writing centers directly within an individual engineering department [21]. Yet a concentration of interest among researchers appears to center on the influence of including regular writing assignments within engineering statics courses [6], [11], [16]-[17], [19]. Such interest does not surprise considering that most engineering students, regardless of major discipline, take a course in engineering statics.

The most common writing assignments employed within engineering courses require students either to write a short paragraph explaining a concept encountered in class [6], [14], [16]-[17] or to keep a log or journal of their learning throughout the term [11], [13]-[15], all with encouraging results. Yet nothing appears in this research space in the literature after 2015, and all of the research reported prior to that year focuses on engineering undergraduates at four-year universities. What influence would including a regular writing assignment have on the performance of engineering students attending a two-year community college? This present work seeks to answer that question.

Methodology

Description of data sources

The research for the present work relies on data collected from students at Howard Community College (HCC) in Columbia, Maryland. In fiscal year 2023, 13,378 credit students were enrolled, 26% of which students attended full-time during Fall 2023 [22]. The mean college-wide student-to-faculty ratio is 19:1 [22]. In the author's experience, most engineering classes offered at HCC have a similar ratio, and the engineering statics course is no exception. Engineering students at HCC, regardless of discipline concentration, take engineering statics as part of their program. Other than the introduction to engineering class, which most students take their very first semester on campus, engineering statics is the first *bona fide* engineering course these students take.

The students providing data for this research took an engineering statics course as part of one of two groups: a control group (n_c = 16) taught during the Spring 2023 semester which did not include any regular writing assignment and a treatment group (n_t = 14) taught during the Fall 2023 semester which did include a weekly writing assignment. The author taught both of these classes. Each class followed the same schedule of topics.

Both groups were assigned traditional analytical homework assignments which were almost identical for both groups. In addition, each group completed three exams and a final exam, all of which were very similar for both groups. Within the present work, the phrases *almost identical* and *very similar* mean that each assignment had the same number of questions that tested the same topic at the same level but with different numerical values. For example, each group was assigned an exam problem asking students to perform the addition of vectors $\overleftarrow{V_1}$ and $\overleftarrow{V_2}$, but where one group might see $\overleftarrow{V_1}$ = 2 N ∡ 30° and $\overleftarrow{V_2}$ = 5 N ∡ 90°, the other group could see $\overleftarrow{V_1}$ = 3 N ∡ 180° and $\overleftarrow{V_2}$ = 7 N ∡ 120°.

The data for the present work were collected from surveys administered at the start and end of each semester and the gradebook for each class after the respective semesters had concluded. Although grades provide an incomplete measure of student learning, this present work uses exam grades and the final course grade to assess student performance. In addition, survey data were collected for the treatment group at the beginning and end of the semester to assess what if any changes in attitudes and perceptions took place over the semester. The survey administered at the end of the semester contained the same questions as the initial survey as well as additional free-response questions. The responses to those free-response questions provide some insight into student attitudes regarding writing and their perception of its place in engineering education.

Characteristics of the control group

For the control group, 10% of the final course grade came from participation, which was essentially an attendance grade. Students had weekly homework assignments. Homework was completed by hand and submitted on paper, which the instructor graded as well as annotated with feedback. As the semester progressed and became increasingly busy, time constraints influenced the annotated feedback to appear less frequently. Students in the control group also completed three exams, a final group project which included a written report, and a final exam as part of the course. Although the final project includes a writing aspect, the grade students receive is essentially for completion (i.e., students who meet the requirements receive full credit). Because HCC does not employ a +/- grading system, all grades assigned are straight letter grades where A = 90%-100%, B = 80%-89.9%, C = 70% - 79.9%, D = 60% - 69.9%, and F = 0% - 59.9.

Characteristics of the treatment group

The treatment group had homework assignments, three exams, a final project, and a final exam just as the control group did. All exams had the same number of questions testing the same concepts in the same order, and the final project remained unchanged. However, for the treatment group, the proportion of the grade from participation was replaced with an equivalent proportion from weekly quizzes administered on paper in the classroom. Each quiz contained either one question with two parts or two separate but related questions. The instructor graded each part separately according to the following rubric: 80% credit was granted for making an attempt to solve the problem, 10% credit was granted for providing a logical and systematic approach to a solution, and 10% was granted for providing a correct solution.

The difference between the control group which had a participation grade and the treatment group for which the participation grade was exchanged with weekly quizzes may appear significant on the surface, but in practice the difference is minimal at best and not likely to influence the results from the present work. The majority of students in the control group often attended class solely to obtain their participation points. For the students in the treatment group, the effect of the weekly quizzes was similar to that of the participation/attendance grade for the control group. The majority of students provided responses on their quiz papers which clearly demonstrated a failure to embrace the content of the quiz question(s); they would simply provide some response so they would get their B. Accordingly, although the source of 10% of the final course grade is different for the control and treatment groups, the effect on final course grades is at best very minimal.

Regular writing assignment in the treatment group

The main feature which differentiates the treatment group from the control group is the homework. With the exception of a few additional problems over the course of the semester, students in the treatment group received the same homework problems as the students in the control group. However, where the students in the control group submitted homework assignments on paper which they completed by hand, students in the treatment group provided numerical solutions electronically through the learning management system used at HCC.

Furthermore, for the treatment group, the analytical homework solutions comprised only 80% of the homework grade as opposed to a full 100% of the homework grade for the control group. The remaining 20% of the homework grade for the treatment group came from a writing assignment attached to each weekly homework assignment. That writing assignment was the same for each week, which was as follows: "Using a minimum of three grammatically correct sentences, each of which expresses a complete thought, provide your response to the following prompt: *How easy or difficult was this assignment for you, and why? What particular aspects or parts gave you the most trouble? How do you plan to overcome your challenges?*"

In alignment with earlier cited research [2]-[4], [6]-[8], the intention behind this writing assignment was to encourage engineering students to improve their performance through enhanced metacognition. In an attempt to encourage the students to engage with the writing component of their homework assignments, the instructor graded these writing assignments for completion only. Because this component of the homework assignment was also submitted electronically, the instructor was able to provide feedback to student submissions more frequently and consistently than what had been provided to the control group. The greater frequency and consistency resulted from students in the treatment group submitting their assignments around the due date more often (as opposed to the control group handwritten assignments which were sometimes submitted well past the due date).

Demographic comparisons

Figure 1 compares various demographic characteristics for the control group (shown in yellow on the left side of each two-bar comparison) and the treatment group (shown in red on the right side of each two-bar comparison). These characteristics include race/ethnicity, gender, age,

cumulative GPA coming into the engineering statics course, and the income level of the household from which the student entered college. These data were collected from surveys administered at the beginning of the statics course for both groups. As such, these data points convey self-reported values.

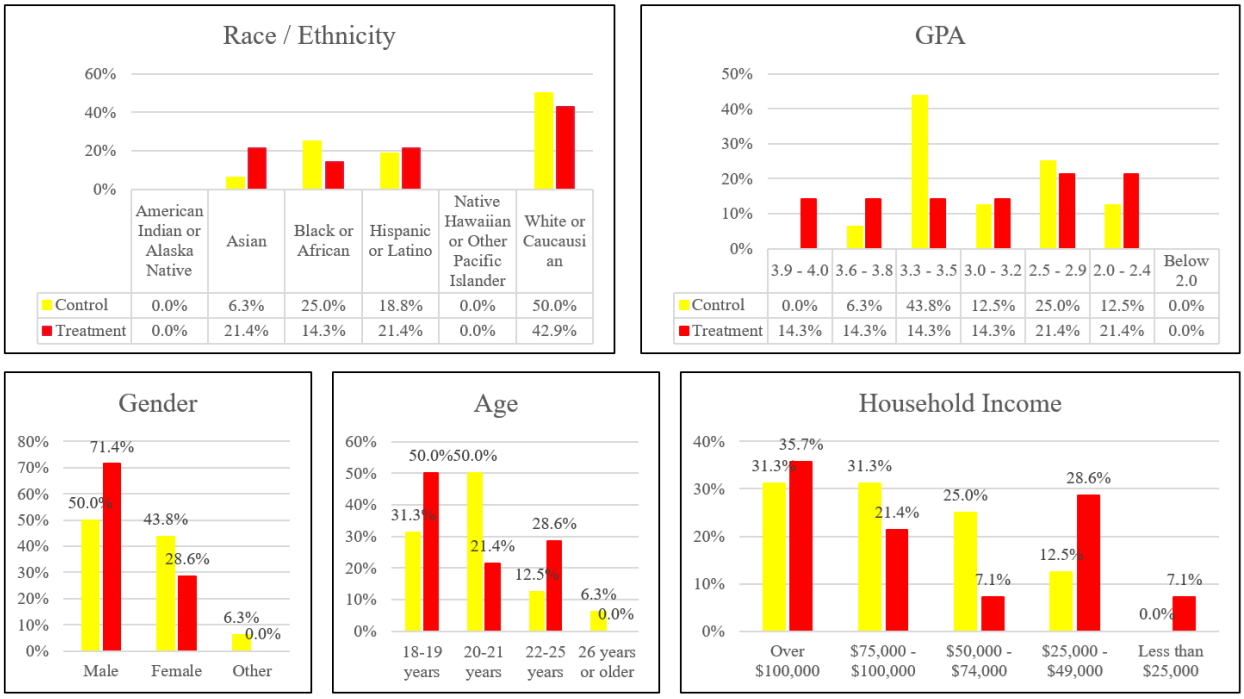


Figure 1 Comparison of demographic characteristics of the control and treatment groups

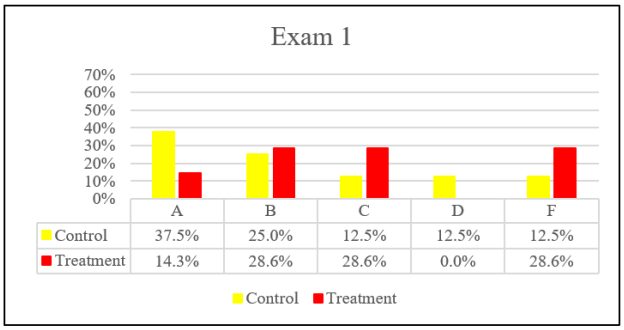
In order to assess the similarity of the demographic characteristics of the control and treatment groups, χ^2 goodness of fit hypothesis testing was performed for the distributions of each of the demographic characteristics shown in Figure 1. Appendix A provides details regarding these statistical tests. Based on the assessment of the results of those tests, the control and treatment groups are essentially similar in their demographic characteristics, and comparisons between the two groups are for the most part appropriate.

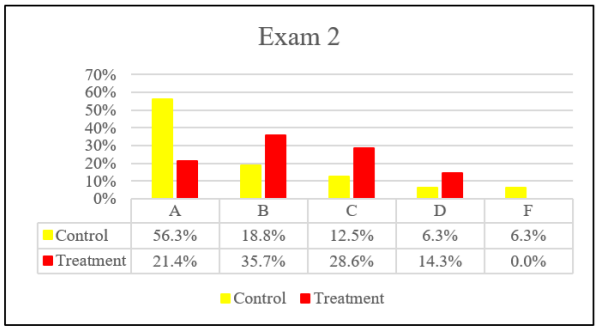
Results

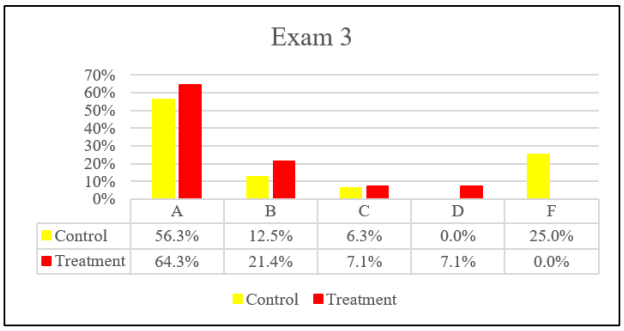
Exam grades

Figure 2 contains bar charts comparing the proportions of students within each letter grade category for each of the three exams administered during each of the research semesters. In each case, higher performing students (A/B) appear towards the left side of the chart, and lower performing students (D/F) appear towards the right. As seen in Figure 1, for each two-bar comparison Figure 2 shows the control group on the left side in yellow and the treatment group on the right side in red. Figure 2 also includes a table of the mean exam score for each exam from both the control and treatment groups. One can observe that for the first exam, administered towards the beginning of the semester, the distributions for the two groups are both more or less essentially uniform with representation in most if not all grade categories.

However, as the semester progresses, the distributions of the results from successive exams change as more students earn higher grades, resulting in a shift of the bulk area of the distribution to the left.







Mean Exam Scores	Control	Treatment
Exam 1	81	73
Exam 2	86	79
Exam 3	72	90

Figure 2 Comparison of exam grades for the control and treatment groups

Statistical hypothesis testing largely confirms these observations. Appendix B contains the details of that testing, which failed to detect evidence of a statistically significant difference in the distributions of the mean scores of Exam #1 and Exam #3 at the 0.05 significance level. However, a statistically significant difference at the 0.05 level was shown for the distributions of the mean scores of Exam #2. Observing the two distributions for Exam #2, one can observe that the control group distribution is more skewed than the treatment group distribution. The results of the χ^2 hypothesis testing make sense in light of this observation.

In addition, the difference in the mean scores for each exam was evaluated with matched-pair t-testing at the 0.05 significance level. For all three exams, the statistical tests failed to produce evidence of a statistically significant difference between the mean scores at the 0.05 significance level. However, each of the difference in mean scores for all three exams represents a practically significant difference between the control and treatment groups.

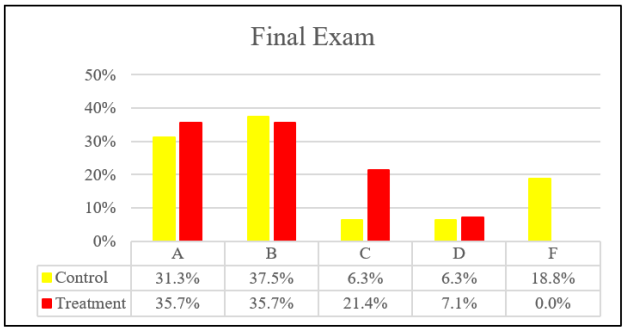
An example often used to explain the distinction between statistical significance and practical significance is a study of two groups trying to lose weight in which a control group adopted an exercise regimen and a treatment group added the Atkins diet to the same exercise regimen [23]. After a year, both groups had lost weight, but the treatment group had lost an average of 4 pounds more than the control group. This difference of four pounds was found to be statistically significant at the 0.05 significance level, which means that the probability the difference occurred by random chance is at most 5%. In essence, the diet drove the difference.

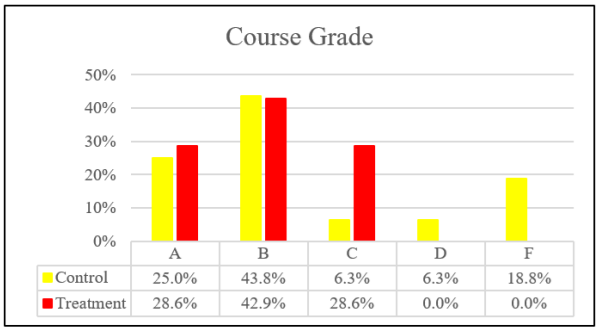
However, losing only four pounds over the course of a year is not very meaningful in practice. Hence, the study showed a statistically significant difference from adopting the diet but not a practically significant one [23].

Viewed through this lens, the statistical tests did not detect a statistically significant difference between the mean scores of the control and treatment groups for any of the three exams. Yet for all three exams, the differences between the mean scores are practically significant. As shown by the table inside Figure 2, for Exam #1 and Exam #2 the difference is a full letter grade. For Exam #3, the difference is two letter grades.

Final grades

Figure 3 contains bar charts comparing the proportions of students within each letter grade category for the final exam and the final course grade. In each case, the shift toward higher performance noted earlier when comparing the first three exams has become more prominent. As seen earlier in Figure 1 and Figure 2, for each two-bar comparison Figure 3 shows the control group on the left side in yellow and the treatment group on the right side in red. Figure 3 also includes a table of the mean final exam grade and mean final course grade from both the control and the treatment groups. Of special note is the absence of low performing students from the final course grade distribution for the treatment group, suggesting that the writing instruction may have influenced lower performing students to achieve higher grades.





Mean Scores	Control	Treatment
Final Exam	70	85
Course Grade	76	85

Figure 3 Comparison of final exam and course grades for the control and treatment groups

Again, statistical hypothesis testing confirms these observations. The same χ^2 goodness-of-fit hypothesis testing was performed for the distributions of the control and treatment groups for each of the final exam and the final course grade just as was performed previously for the demographic characteristics and the exam grades. These tests provide evidence of a statistically significant difference in the control and treatment group distributions for both the final exam grade and the final course grade at the 0.05 significance level. This statistical evidence supports

the earlier observation that the inclusion of a weekly writing assignment appears to promote higher performance among low performing students.

In addition to comparing the distributions for the control and treatment groups for the final exam and final course grade, the mean final exam and final course grades were also subjected to statistical hypothesis testing. For both the final exam and the final course grade, evidence to support a statistically significant difference in the mean grades of the control and treatment groups was not observed. However, as may be seen in the table inside Figure 3, one does observe a substantial practically significant difference between the two groups for both mean final exam and final course grades.

Survey responses

The treatment group responded to a survey administered at the beginning and end of the semester. Table 1 lists the survey questions. Question Q1 was asked only at the beginning of the semester. Questions Q2 through Q5 were asked at both the beginning and end of the semester, and questions Q6 through Q8 were asked only at the end of the semester. Quantitative results from the survey appear in Figure 4. Qualitative results and further details regarding all of the results from the survey appear in Appendix C.

Table 1 Survey questions

ID	Question
Q1	How long has it been since you last took a course in English composition or writing?
Q2	Do you think of yourself as a writer?
Q3	Do you think of yourself as an engineer?
Q4	On a scale from 1 being very poor to 10 being very good, how would you rate your writing skills?
Q5	How do you feel about requiring engineering students to complete graded writing assignments in an engineering class?
Q6	How helpful do you feel the graded writing assignments were in helping you to learn engineering statics? Explain your response.
Q7	How helpful do you feel more extensive writing assignments would be to learning engineering statics?
Q8	How helpful do you feel more extensive writing assignments would be to preparing you for an engineering career?

As may be seen in Figure 4, a majority of the students have taken a writing class within the previous two years, but at the start of the semester a vast majority did not identify as a writer. Over the course of the semester, that proportion changed as slightly more students reported identifying themselves as a writer. A similar shift occurred with the students self-identity as an engineer; by the end of the semester all of the students self-identified as an engineer, a particularly encouraging result considering the vast majority of the class belongs to one or more traditionally underrepresented group.

Surprisingly, a majority of the students downgraded their rating of their writing skills across the semester. The qualitative results from the survey reveal little regarding why. However, the results regarding student attitudes towards writing in engineering contexts do not surprise. Those results align well with findings from research studies of four-year university engineering students with regards to an attitude that writing has little if any place in learning and practicing engineering. Comparing qualitative responses with quantitative results, the bulk of the students believe that engineering statics is best learned by working practice problems and that writing has little if anything to do with that. A small minority feel that writing is either not necessarily helpful or hurtful or only marginally so if it is helpful. Intimations appear of a possible role for writing in engineering practice but not for learning engineering statics.

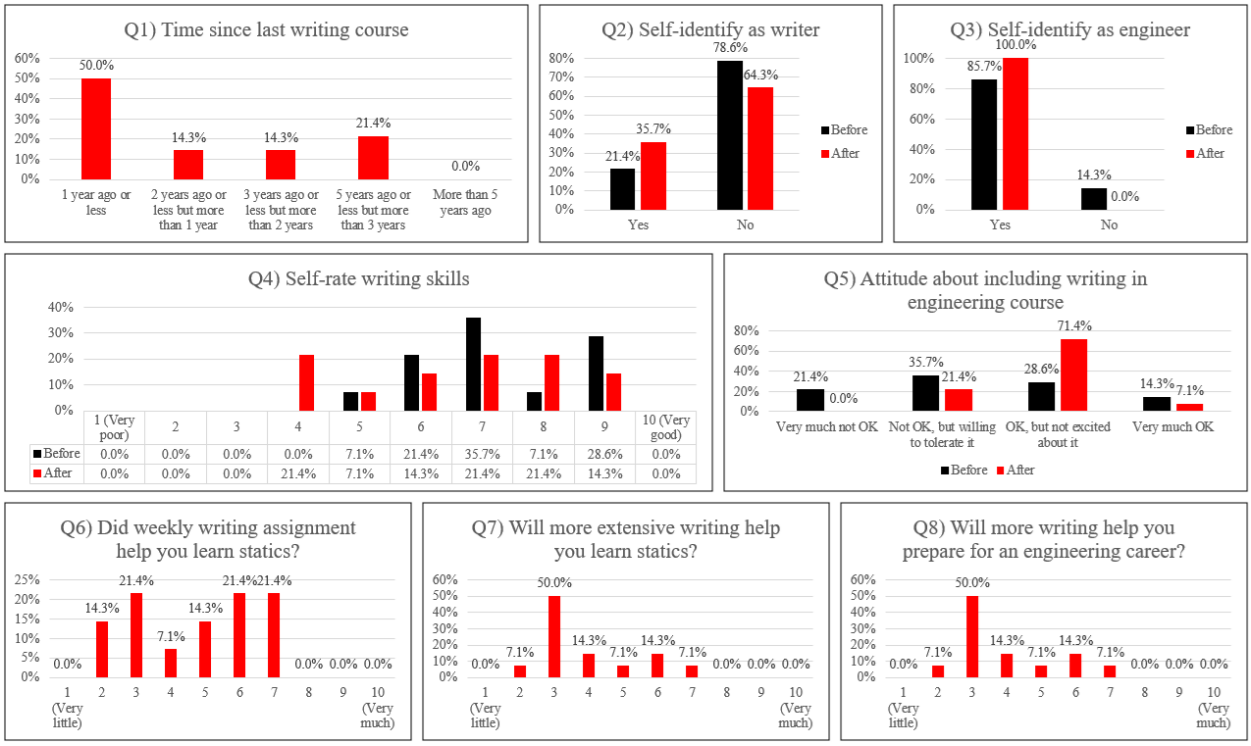


Figure 4 Quantitative results from student survey

Discussion and Next Steps

Similarity of the control and treatment groups

The demographic data analysis shows the control and treatment are essentially similar, making comparisons of the two groups appropriate. However, given the small sample sizes involved, the author cautions against forming any definitive conclusions from the data or the attendant analysis. Small sample sizes limit the applicability of research results to a larger population. Thus, the results observed in the present work suggest rather than conclude.

The author notes that the treatment group students appeared to engage with learning in class more than did the control group students. Their questions contained more conceptual inquiries, as opposed to the questions from control group, which were mostly procedural. The

class was more enjoyable for the instructor to teach, and the course evaluations suggest the students enjoyed the class as well. Although these data points are anecdotal, they do lend themselves to the positive results shown in the present work.

These differences may result from the increased feedback which the writing assignments gave the instructor opportunity to provide. More positive feedback generally results in an increased positive social perception, which in turn would encourage the student-initiated interactions observed in the treatment group.

Interpretation of analysis

Most of the students at the start of the semester were at least skeptical about the inclusion of writing assignments in their engineering statics class and then became more accepting by the end of the semester, a result reflecting the observation of Maharaj and Banta [11]. Despite that acceptance, the bulk of the students displayed the typical attitude that writing has little if anything to do with learning engineering statics, although a significant minority embraced the idea of writing being a part of engineering career practice. Because of their expected attitude towards writing, students saw little if any benefit from requiring more writing in an engineering statics class.

Again, those results conformed to expectations. However, three aspects of the results from the present work were unexpected. First, considering the substantial practical difference between mean exam grades shown in the inset table in Figure 2, a statistically significant difference was expected but not observed. The small sample sizes may have influenced this failure to observe a statistically significant difference in the mean exam grades. Nevertheless, the practical difference in mean exam grades is notable, especially for Exam #3, and the final exam grades and final course grades are both statistically and practically significant, representing a positive outcome. Especially encouraging is the noticeable shift of the distributions which suggest the final grades of low-performing students may improve as a result of regular writing assignments. A larger sample size could reveal more consistent and less mixed results in this aspect. Accordingly, more data are needed.

Second, as seen in the bar chart in inset Q4 of Figure 4, almost half of the treatment group students downgraded their writing skills rating across the semester. If this result is to be believed, the students are essentially declaring that their writing skills became *worse* over the course of the semester. It may be that the written report attending the final project influenced some students into reassessing their self-image of their writing abilities; the requirements for the report concerning both content and formatting were rather detailed. Furthermore, the final project was a group assignment, and some students may have struggled with writing in a group setting. The data provided by the surveys do not shed any light on why the self-ratings downgraded over the course of the semester. Interviews need to be conducted to reveal the mechanisms at work here.

Third, although the shift in attitudes about a regular writing assignment shown in inset Q5 of Figure 4 conformed to expectations, the minority of students (14.3%) who reported a more negative attitude at the end of the semester than at the beginning surprised. This result suggests

that some students did not experience the benefits documented in the literature from including regular writing assignments in an engineering statics course.

While it is easy to label these students as those who simply did not embrace the assignment (after all, benefits will not be realized for students with resistant attitudes), a different writing prompt may have elicited different results. One of the more popular approaches for including writing assignments in an engineering statics course requires students to write a paragraph explaining a concept [6], [14], [16]-[17], an exercise which reveals conceptual understanding (or the lack thereof) in students. The approach for the present work asked students to reflect upon the challenges they encountered in completing analytical problems. Both approaches will surely increase metacognition in students, but reflecting on individual performance does not necessarily lead to increased conceptual understanding. The survey data do not reveal the reason behind this shift in attitude from a minority of the students. As such, interview data are needed to reveal the underlying mechanisms at work here.

Summary of results and future work

One can summarize the results from the present work as follows:

- Including regular writing assignments in an engineering statics course may help low-performing community college students to earn higher final grades.
- Perceptions of identity and attitudes about writing and the role of writing in learning engineering statics among community college students conform to expectations.

Repeating the analysis for separate subgroups within the data (race/ethnicity, gender, etc.) to examine the influence of regular writing assignments on learners from traditionally marginalized groups would certainly be interesting. However, the small sample size from the aggregate samples means that any further separation would produce even smaller sample sizes. Any results from those even smaller sample sizes would not be very meaningful.

Future work includes the collection of more data, either to increase the sample size of the present work or to repeat the research described in the present work with a larger sample size. In either case, more data are needed. More data would allow for more definitive conclusions to be drawn from the data rather than suggestions. More data would also allow for the analysis of results with respect to traditionally marginalized groups. In addition, interviews to investigate the surprising shifts observed in aspects of the writing skill self-rating results and attitudes about including writing in an engineering course could provide additional insights that explain the observed shifts.

Using a different writing prompt may provide more positive results, particularly with respect to the attitude shift among engineering students who embrace writing as the aid that it can provide in learning engineering statics as reported in the literature. Those positive results can come as students realize the benefits writing can offer in increasing their conceptual learning, and that realization is best had by experience. Using a writing prompt that more directly prompts conceptual understanding may provide more positive results than the present work.

Writing can play an important role in helping engineering students learn course content, but the benefits from regular writing assignments require a culture in which students and faculty embrace writing as an important aspect of individual engineering identity. So long as writing is perceived as something apart from engineering or something to be outsourced, engineering educators are less likely to produce the holistic engineers which solutions to the increasingly complex challenges of the future will require. Given the role community colleges play in providing undergraduate engineering students into that pipeline, all faculty, not just those at four-year universities, must embrace an engineering culture that champions writing.

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Appendix A: Statistical Testing of Demographic Data

In order to assess the similarity of the demographic characteristics of the control and treatment groups, χ^2 goodness of fit hypothesis testing was performed for the distributions of each of the demographic characteristics shown in Figure 1. The null hypothesis (H_0) in each case was that the distribution of the control group is equivalent to the distribution of the treatment group for the same demographic characteristic. The alternative hypothesis (H_A) in each case was that the two distributions are not equivalent. Also in each case, the control group provided the expected distribution, and the treatment group provided the observed distribution.

Table A1 shows the results of this statistical testing at the 0.05 significance level. Although the author had no justification for specifying $\alpha = 0.05$, no justification for using any other value was observed. Lacking any justification for using any specific value, the most commonly used value ($\alpha = 0.05$) was selected.

In each case except for race/ethnicity, the hypothesis testing fails to provide evidence of a statistically significance difference between the distributions of the control and treatment groups. In the case of race/ethnicity, evidence of a statistically significant difference at the 0.05 significance level is shown. However, as seen in Table 1, the evidence for an extensive difference in the distributions is not apparent inasmuch as the test statistic (χ^2_{race}) is just slightly greater than the critical value ($\chi^2_{crit,race}$). Accordingly, the author assesses that the control and treatment groups are essentially similar in their demographic characteristics, and comparisons between the two groups are for the most part appropriate.

Table A1 Goodness of fit hypothesis test results for demographic characteristics

Characteristic	Test Statistic, χ^2	Critical Value, χ^2_{crit}	Test Result
Race/Ethnicity	1.250	1.145	Reject H_0
Gender	-1.179	0.103	Fail to reject H_0
Age	-0.225	0.352	Fail to reject H_0
GPA	0.536	1.635	Fail to reject H_0
Household Income	-0.150	0.711	Fail to reject H_0

Appendix B: Statistical Testing of Exam and Course Grade Data

The same χ^2 goodness of fit hypothesis testing performed for the demographic data (detailed in Appendix A) was performed for the distributions of the control and treatment groups for each of the three exams. Table B1 shows the results of this hypothesis testing at the 0.05 significance level. For Exam #1 and Exam #3, the hypothesis testing fails to produce evidence of a statistically significant difference between the distributions for the control and treatment

groups. However, evidence of a statistically significant difference between the distributions for the control and treatment groups is shown for Exam #2 at the 0.05 significance level.

Table B1 Goodness of fit hypothesis test results for exam grades

Exam	Test Statistic, χ^2	Critical Value, χ^2_{crit}	Test Result
Exam #1	0.333	0.711	Fail to reject H_0
Exam #2	1.000	0.711	Reject H_0
Exam #3	-0.500	0.711	Fail to reject H_0

In addition to comparing the distributions for the control and treatment groups for each exam, the mean exam grades were also subjected to statistical hypothesis testing. The difference between the mean exam grades was evaluated with matched pair t-testing at the 0.05 significance level. The null hypothesis (H_0) in each case was that the difference between the t-score of the mean exam grade for the control group (t_c) and the t-score of the mean exam grade for the treatment group (t_t) is zero, or H_0: $t_t - t_c = 0$. The alternative hypothesis (H_A) in each case was that the difference between the two t-scores is not zero, or H_A: $t_t - t_c \neq 0$. Table B2 shows the results of this matched pair t-test at the 0.05 significance level. Because the hypothesis testing conducted was two-tailed, the test statistic and critical value columns in Table B2 provide absolute values of their respective quantity. For each of the three exams, evidence to support a statistically significant difference in the mean exam grades of the control and treatment groups was not observed. That said, one does observe a substantial practically significant difference between the actual mean exam grades of the two groups.

Table B2 Matched pair t-test hypothesis test results for exam grades

Exam	|Test Statistic|	|Critical Value|	P-value	Test Result
Exam #1	1.499	2.160	0.145	Fail to reject H_0
Exam #2	1.492	2.160	0.161	Fail to reject H_0
Exam #3	1.841	2.160	0.093	Fail to reject H_0

For each of the final exam and final course grade distributions, the same χ^2 goodness-of-fit hypothesis testing was performed for the distributions of the control and treatment groups for each of the final exam and the final course grade as detailed in Appendix A. Table B3 shows the results of this hypothesis testing at the 0.05 significance level. For both the final exam and the final course grade, the hypothesis testing rejects the null hypothesis, thereby providing evidence of a statistically significant difference between the distributions for the control and treatment groups. This statistical evidence supports the earlier observation that the inclusion of a weekly writing assignment appears to promote higher performance among low performing students.

Table B3 Goodness of fit hypothesis test results for final exam and course grades

Item	Test Statistic, χ^2	Critical Value, χ^2_{crit}	Test Result
Final Exam	0.833	0.711	Reject H_0
Course Grade	0.857	0.711	Reject H_0

In addition to comparing the distributions for the control and treatment groups for the final exam and final course grade, the mean final exam and final course grades were also subjected to statistical hypothesis testing. Just as was done with the mean exam grades, the differences between the mean final exam grades and between the mean final course grades were evaluated with matched pair t-testing at the 0.05 significance level. Table B4 shows the results of this matched pair t-test at the 0.05 significance level. Just as was done in Table B2, the test statistic and critical value columns in Table B4 provide absolute values of their respective quantity. For both the final exam and the final course grade, evidence to support a statistically significant difference in the mean grades of the control and treatment groups was not observed. That said, one does observe a substantial practically significant difference between the actual mean final exam and final course grades of the two groups.

Table B4 Matched pair t-test hypothesis test results for final exam and course grades

Item	|Test Statistic|	|Critical Value|	P-value	Test Result
Final Exam	1.695	2.160	0.119	Fail to reject H_0
Course Grade	1.466	2.160	0.172	Fail to reject H_0

Appendix C: Detailed Survey Response Results

The treatment group responded to a survey administered at the beginning and end of the semester. Table C1, which is identical to Table 6 in the body of the paper, lists all survey questions. Question Q1 was asked only at the beginning of the semester. Questions Q2 through Q5 were asked at both the beginning and end of the semester, and questions Q6 through Q8 were asked only at the end of the semester.

Table C1 Survey questions

ID	Question
Q1	How long has it been since you last took a course in English composition or writing?
Q2	Do you think of yourself as a writer?
Q3	Do you think of yourself as an engineer?
Q4	On a scale from 1 being very poor to 10 being very good, how would you rate your writing skills?
Q5	How do you feel about requiring engineering students to complete graded writing assignments in an engineering class?
Q6	How helpful do you feel the graded writing assignments were in helping you to learn engineering statics? Explain your response.
Q7	How helpful do you feel more extensive writing assignments would be to learning engineering statics?
Q8	How helpful do you feel more extensive writing assignments would be to preparing you for an engineering career?

Question Q1: How long has it been since you last took a course in English composition or writing?

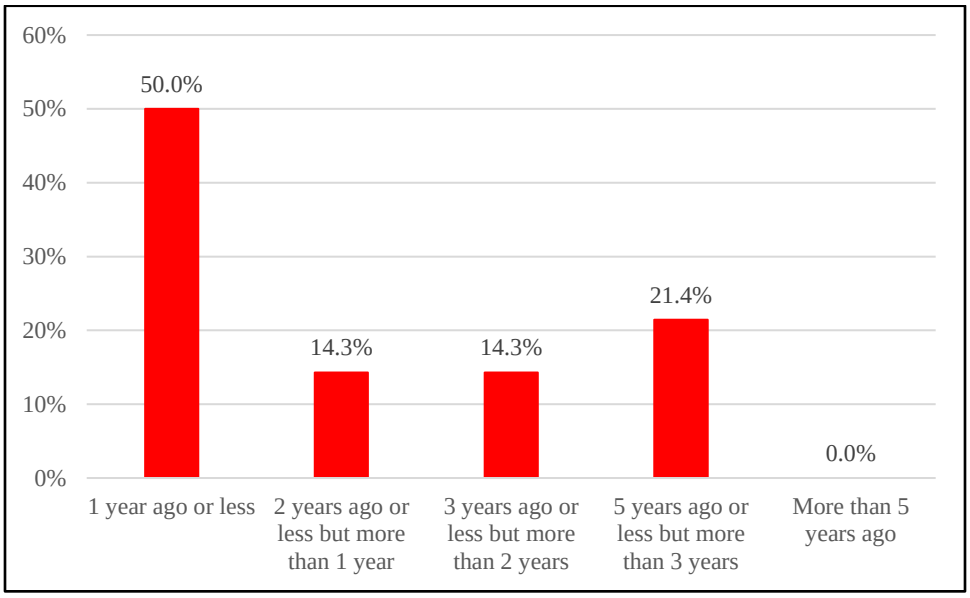


Figure C1 Time since treatment group students took a writing intensive course

Figure C1 compiles the student responses to question Q1. Although a substantial proportion last took a writing intensive course between three and five years prior to the start of the semester, a majority of the students (64.3%) took a writing intensive course within the two years immediately preceding the beginning of the semester.

Question Q2: Do you think of yourself as a writer?

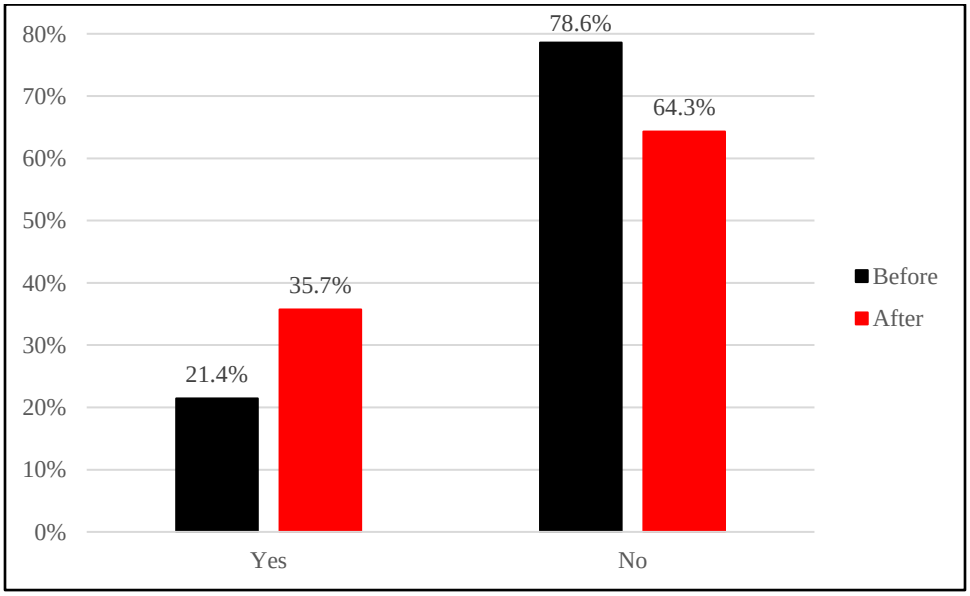


Figure C2 Student responses to question Q2

Despite the recent exposure to writing assignments, the vast majority of the treatment group students did not self-identify as a writer in response to question Q2. As shown by the black bars on the left side of each two-bar comparison in Figure C2, almost 79% of the treatment group students did not identify themselves as a writer at the start of the semester. Interestingly, 14.3% of the students did not identify as a writer at the start of the semester but did identify as a writer at the end of the semester.

Question Q3: Do you think of yourself as an engineer?

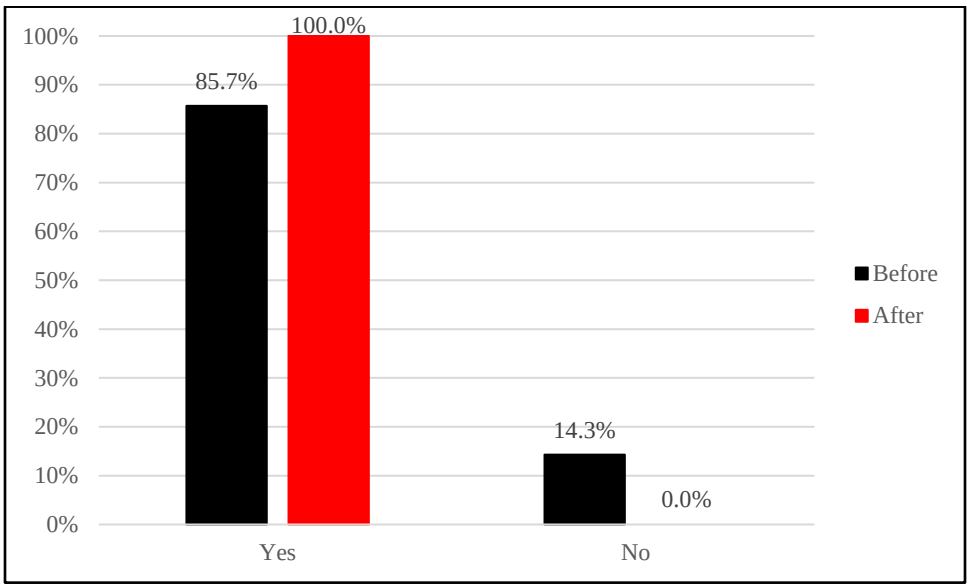


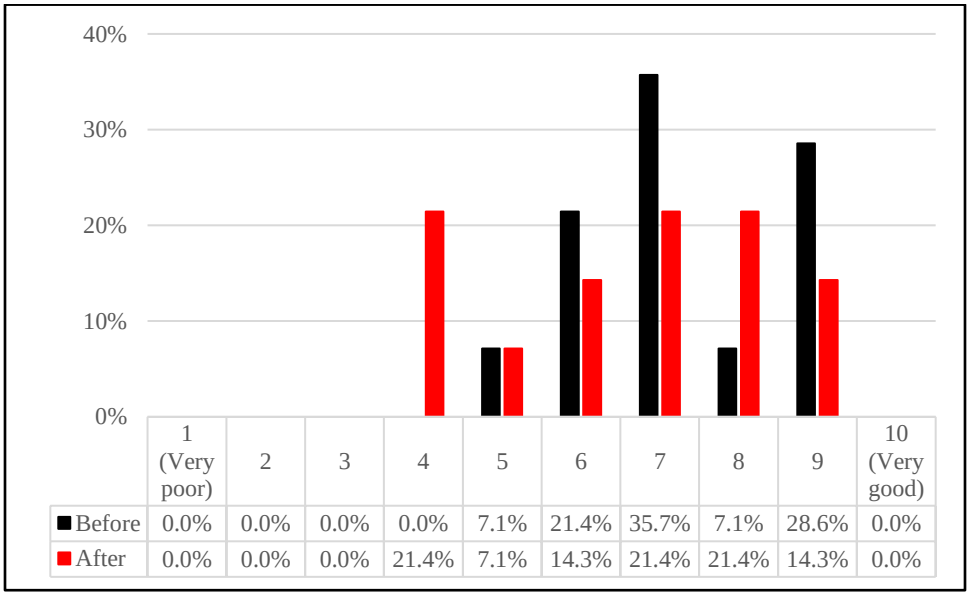
Figure C3 Student responses to question Q3

The student responses to question Q3 as displayed in Figure C3 show that, where a vast majority of students did not self-identify as writers (78.6%), a vast majority of the students did self-identify as an engineer (85.7%) at the start of the semester. Encouragingly, Figure C3 also shows that the 14.3% of the treatment group students who did not self-identify as an engineer at the start of the semester did self-identify as an engineer at the end of the semester.

Question Q4: On a scale from 1 being very poor to 10 being very good, how would you rate your writing skills?

The student responses to question Q4 appear in Figure C4. As with Figure C2 and Figure C3, the black bars on the left side of each two-bar comparison represent treatment group student responses at the beginning of the semester, and the red bars on the right side represent treatment group student responses at the end of the semester. Considering the proportion of treatment group students with an incoming GPA of at least 3.0 shown in Figure 1 (57.2%), observing the bulk of the students thinking that their writing skills are above average does not surprise. What does surprise is the substantial minority of students (at least 21.4% from what Figure C4 displays) who rated their writing skills worse at the end of the semester than they did at the beginning.

To investigate this feature of the results further, the difference in the number of rating category levels was calculated for each student in the treatment group individually and then assembled into the bar chart appearing in Figure C5. As may be observed in Figure C5, the proportion of treatment group students who rated their writing ability worse at the end of the semester than at the beginning of the semester is 42.8%. Additionally, the initial and final self-ratings for about two thirds of those students differed by at least two categories.



	1 (Very poor)	2	3	4	5	6	7	8	9	10 (Very good)
Before	0.0%	0.0%	0.0%	0.0%	7.1%	21.4%	35.7%	7.1%	28.6%	0.0%
After	0.0%	0.0%	0.0%	21.4%	7.1%	14.3%	21.4%	21.4%	14.3%	0.0%

Figure C4 Student responses to question Q4

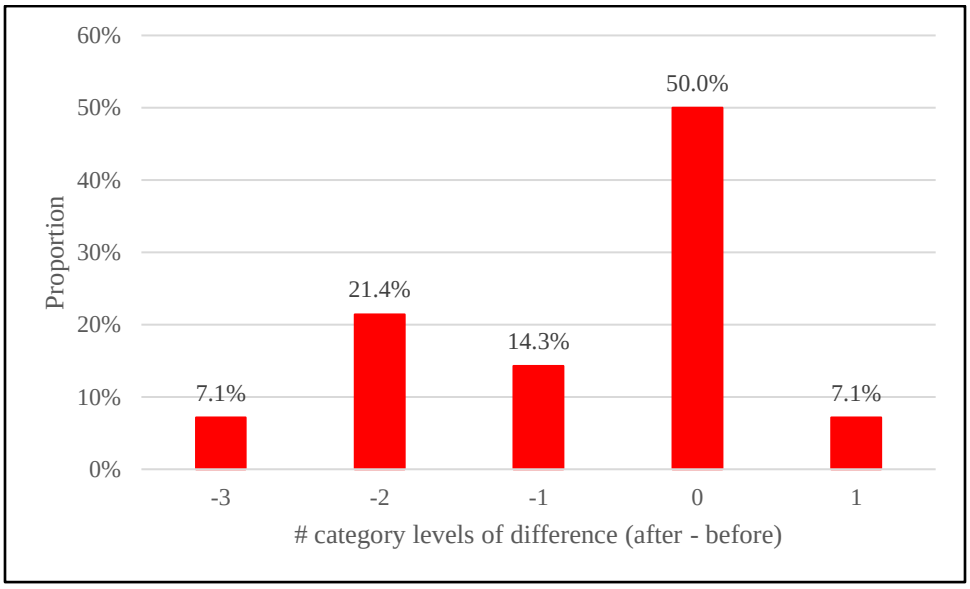


Figure C5 Difference in self-rated writing ability across the treatment semester

Further evidence for the difference in the before and after self-ratings was obtained through χ^2 goodness-of-fit hypothesis testing. As with the statistical testing performed previously to compare distributions, the distributions of the initial and final writing ability self-

ratings were compared at the 0.05 significance level. With a test statistic same $\chi^2 = 0.767$ and a critical value same $\chi^2_{crit} = 3.325$, the hypothesis test failed to reject the null hypothesis, leading to the conclusion that evidence of a statistically significant difference between the two distributions is not observed at the 0.05 significance level.

Question Q5: How do you feel about requiring engineering students to complete graded writing assignments in an engineering class?

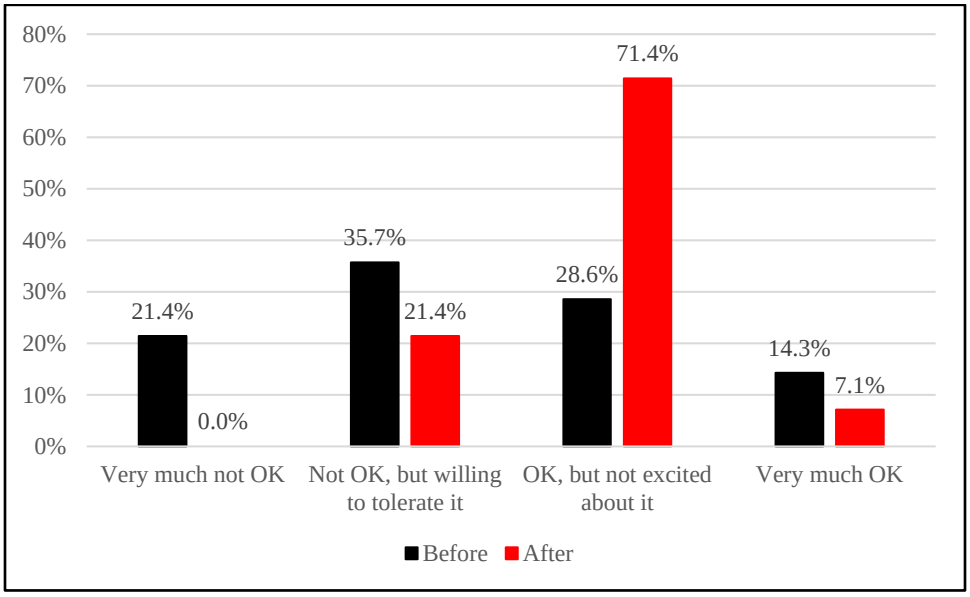


Figure C6 Student responses to question Q5

Question Q5 required students to respond with one of four possible answers: Very much not OK; not OK, but willing to tolerate it; OK, but not excited about it; or very much OK. The allocation of an even number of potential responses was intentional; it forces students to avoid selecting an uncommitted neutral option in the center, an option which reveals little if anything about student perceptions. Figure C6 shows the proportions of student responses at the beginning and end of the semester to question Q5. A shift towards a more favorable impression may be seen by a visual comparison of the before and after distributions, a result which is encouraging for the wider adoption of writing assignments within the culture of engineering education. Statistical hypothesis testing with the χ^2 goodness-of-fit test confirms this observation. With a test statistic of χ^2 = -0.400 and a critical value of $\chi^2_{crit} = 0.352$, the hypothesis test failed to reject the null hypothesis. Therefore, evidence of a statistically significant difference between the two distributions is not observed at the 0.05 significance level. The shapes of the before and after distributions are statistically similar.

However, half of those who responded with the most positive response at the beginning of the semester downgraded their response at the end of the semester. This observation introduces an interesting feature into the shift of perceptions towards more positive responses that occurred over the course of the semester. To investigate that observation further, the difference in the number of rating category levels was calculated for each student in the

treatment group individually and then assembled into the bar chart appearing in Figure C7. The resulting distribution observed from the data in Figure C7 shows a symmetry centered over a slight increase in positive response over the course of the semester, suggesting that the incident of decrease from the most positive response may be an outlier event.

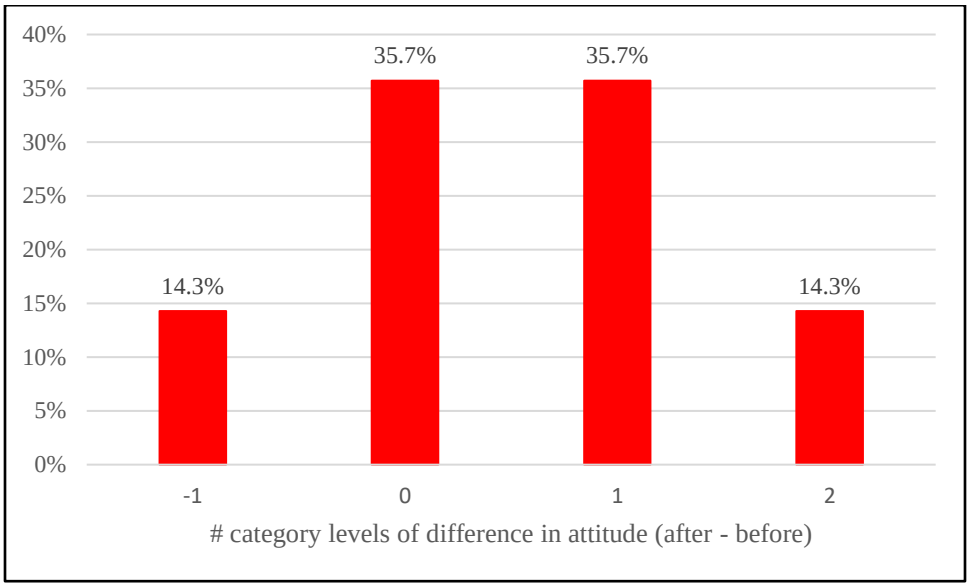


Figure C7 Difference across the treatment semester in student perception of including writing assignments in engineering courses

Question Q6: How helpful do you feel the graded writing assignments were in helping you to learn engineering statics? Explain your response.

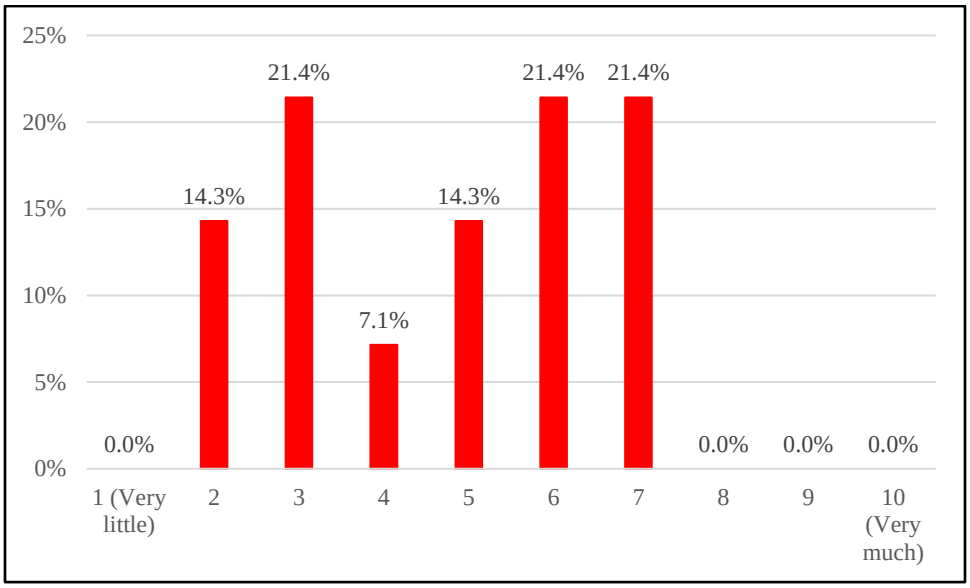


Figure C8 Student responses to question Q6

Question Q6 was the first of three questions included only in the survey at the end of the treatment semester. Figure C8 shows the proportions of students who responded within each

rating category. The data appear to be split with about half the students perceiving writing to be less helpful in learning statics and the other half perceiving a role for writing that is not necessarily helpful or unhelpful in learning engineering statics.

Table C2 Treatment group student free-form responses to question Q6

Student	Q6 Rank	Explanatory Response
HS20	2	I wanted more time to solve statics problems.
NG93	2	It wasn't much to really help. More so elaborate on what is being learned and see if you can use what you learned in a document and explain it, even though that could be difficult for people.
BL28	3	Writing assignments never really helped me understanding anything other than writing.
DA26	3	If I had to write about something, I have to know what I'm writing about. For me that would look like learning the topic first via practice problems and then being able to re-word the process or concept.
MP88	3	I can't really think of a way that writing assignments have helped me improve in engineering statics since I've learned almost everything this semester from doing practice problems repeatedly.
NR69	4	I feel like writing should not be a part of engineering, but I don't think its [*sic*] the worst thing in the world if it does contain writing.
JC67	5	I think writing assignments can be helpful because they essentially force you to explain the topic you learned. Just like in lab reports, you summarize the concepts. Personally, that always helps me remember those specific topics. However, I'm not sure that it is the most efficient way to learn the entirety of the subject. It takes a lot of extra brain power and time to formulate an intelligible piece of writing about the subject. It might end up taking away from learning all of the material. At the same time, I don't know, it might be a good idea! Formulating your thoughts like you do when you write is a very important skill for being an engineer.
ML42	5	Since most of the problems we deal with are solved with mathematical approaches, I think that having written assignments is excessive and unnecessary.
BR89	6	I'm In between because I feel like we didn't do much writing except for the homework or during the final project. Personally writing is not my strong suit and it did help with revise to see what i [*sic*] have accomplished but that was about it. I would also rather spend my time on working on practice problems as I learn more this way.
OA25	6	In a way I could figure out what I need to ask the instructor.
SH55	6	I think when we get lots of writing assignments, or assignments in general on our own we tend to just focus on getting them completed instead of actually learning.
BU34	7	The reason I responded with a 7 is mainly due to the writing assignments dose [*sic*] make you reflect on what you have done and will make you go back and do some reading however my writing skills are not the greatest.
TV85	7	I prefer to learn my reports on a small set of notes.
VJ83	7	I feel as if the written report was a good practice for real life engineering reports. However, I wouldn't really specifically say it directly correlated to help learning statics.

Table C2 lists the free-form responses which students provided along with their ranking response to question Q6. The individual responses are grouped by ranking category to help with the identification of any trends related to ranking response. Comparing responses on the lower end of the distribution where writing is perceived to be less helpful, the common thread appears to be that engineering statics is best learned by working practice problems, a process with which the students believe writing has little if anything to do. On the higher end of the distribution, the common thread appears to be a declaration that writing is either not necessarily helpful or hurtful or if it is helpful only marginally so. Intimations appear of a possible role for writing in engineering practice but not for learning engineering statics.

Question Q7: How helpful do you feel more extensive writing assignments would be to learning engineering statics?

Question Q7 was created with the intention of exploring student perceptions in building off of question Q6. Where question Q6 asked about the helpfulness of the current level of writing inclusion in learning engineering statics, question Q7 asked about the helpfulness of an increased level of writing inclusion. Figure C9 shows the proportion of treatment group students who responded with each ranking category. The bulk of the data suggest that students perceive the inclusion of more writing assignments to be less helpful in learning engineering statics, a result that does not surprise considering the common threads revealed in the free-form responses to question Q6.

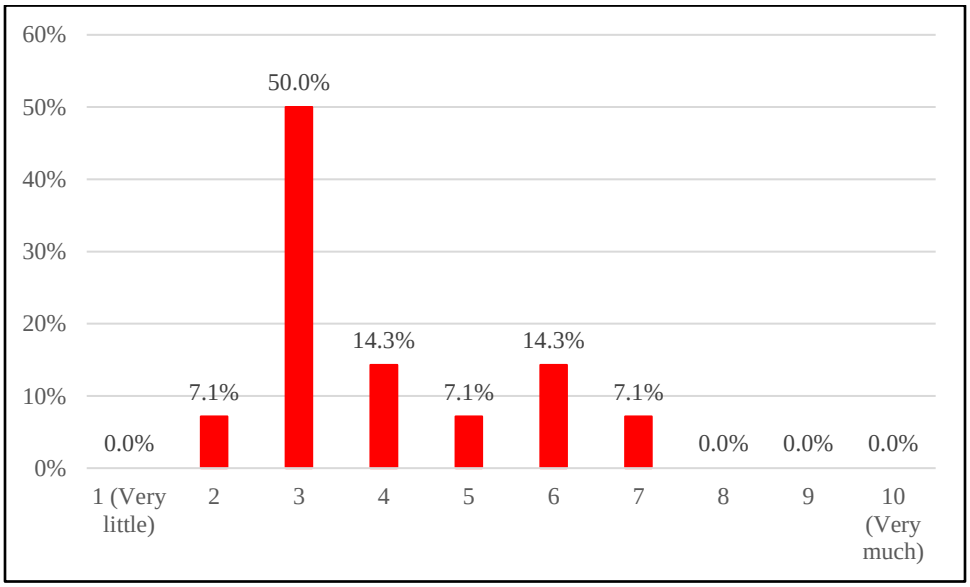


Figure C9 Student responses to question Q7

Question Q8: How helpful do you feel more extensive writing assignments would be to preparing you for an engineering career?

The final question of the final survey asks students to consider the content of question Q7 in a different context, that being a career as an engineer. The proportions of students who responded with each ranking category appears in Figure C10. The change in context provided a

mirrored response of what students provided in answer to questions Q6 and Q7. Where the majority of treatment group students perceive writing having a less important role in learning engineering statics, the bulk of those students perceive writing having a more important role in an engineering career. Of special note is the substantial minority of students (35.7%) who believe writing has less important place in an engineering career.

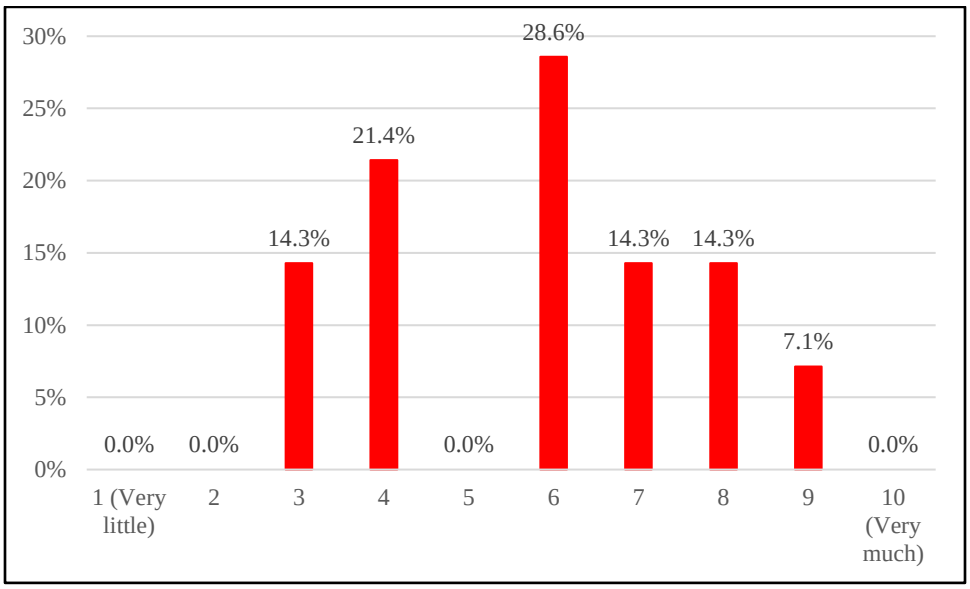


Figure C10 Student responses to question Q8