Do the Write Thing: Bolstering Student Comprehension in Introductory Statistics Courses

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Abstract
Many researchers opine that writing is an effectual tool that may be employed to strengthen students' understanding in introductory statistics courses. Much of the research, supported by surveys and other subjective evaluative instruments, boasts that students achieve a heightened sense of comprehension in elementary statistics courses when they engage in some monitored form of writing. Few studies, however, measure objective, across-group student performance in introductory statistics courses vis-à-vis the presence or absence of an infused writing experience. This comparative investigation, involving seven classes and spanning over a five-semester period, explores the effect that short technical reports seem to have on students' grasp of statistical concepts in such courses. Study results imply that students who participate in a structured and guided technical writing experience in introductory statistics courses demonstrate a significantly greater level of content mastery when compared to students who do not. Particularly, mastery is gauged by student performance on objective, discipline-specific assessment that is administered face to face at the end of the semester.

Key Words: Writing across the curriculum, statistical literacy, rubrics, Welch's *t*-test, Welch-Satterthwaite equation, student projects

1. Introduction

In a recent issue of *Amstat News*, Rob Santos, Vice President of the American Statistical Association (ASA) gently rebukes statisticians for their slow rise to the challenge of making statistics understandable to those outside of the statistical community (2016). In particular, he posits that "students of statistics are not uniformly afforded the opportunity to acquire and practice communication skills, especially to nonstatistical audiences such as the general public" (2016). What makes his plea for change so poignant is that the ASA's Board of Directors endorsed newly revised curriculum and pedagogy for the teaching of statistics in the *Curriculum Guidelines for Undergraduate Programs in Statistical Sciences*; out of the four guidelines championed, the ability to communicate stands as a key principle that is necessary for cultivating critical thinking and sharpening problem-solving skills (2014). Arguably, improving students' communication skills via introductory statistics classes remains one of the greatest challenges in academia but promises to yield rewarding results, according to many researchers. In fact, the incorporation of writing into these classes, among other activities, has been touted as one of the most effective means by which these rewarding ends may be achieved.

2. Writing Across the Curriculum: A Fresh Look

Arguably, the transition from the student as memorizer to the student as critical thinker crystallized around the 1970s with a James Britton-inspired movement, in which writing becomes central to the process of evaluating student learning. Dubbed as Writing Across the Curriculum (WAC), this notion of employing writing as a tool that educators used in all subject areas began gaining momentum in educational circles, especially colleges and universities, around the 1980s; a counterattack waged by the educational community, in response to the literacy emergency ensuing in America, was a submergence of students into a culture of writing, which forced them to synthesize and analyze information at a higher-order level of thinking, some claimed (Harris and Schaible 1997). Essentially, scholars agree that "Britton and his colleagues lent substantial credence to the idea that cross-curricular writing programs could enhance student learning" (Bazerman et al. 2005).

WAC advocates praise the basic foundation of the movement, especially the component referred to as learning to write or writing in the disciplines (WID). The purpose of this phase of WAC thought is to use writing as a means of demonstrating mastery within a specific course of study. Learning to write is not to be understood as *learning how to write physically* but rather as *learning in order to write intelligently* about a particular discipline. Bazerman described WID as WAC's second phase, citing that writing at this level is "based on a realistic assessment of the roles written language actually takes in disciplines and disciplinary classrooms" (1991). At the crux of WID thought exists the notion that students practice and develop their writing skills with a context that is "fundamental to understanding a given academic subject" (Odell and Swersey 2003). Specifically, learning statistics through an engaging, non-passive mode of data-gathering and writing echoes one of the six recommendations discussed in the revised *Guidelines for Assessment and Instruction in Statistics Education* (GAISE), supported by the ASA; the recommendation of fostering active learning in introductory classes gets at the heart of incorporating a writing experience to increase student mastery of concepts and to make it easier for students to communicate statistical ideas (ASA GAISE 2016).

3. More College Students Enrolling in Introductory Statistics Courses

Enrollment in introductory statistics courses has been on a steady incline over the past few decades. Published every five years, the American Mathematical Society's Conference Board of the Mathematical Sciences (CBMS) survey provides details concerning these growing trends with respect to course offerings within mathematics and statistics departments alone. According to both 2005 and 2010 CBMS surveys, postsecondary enrollment in non-calculus-based, elementary-level statistics courses reached approximately 449,000 in fall 2010, a 40% increase in enrollment from fall 2005 and nearly double the enrollment from fall 1995; these enrollment trends from fall 1990 – fall 2010 are highlighted in Figure 1 (Lutzer et al. 2007; Blair et al. 2013).

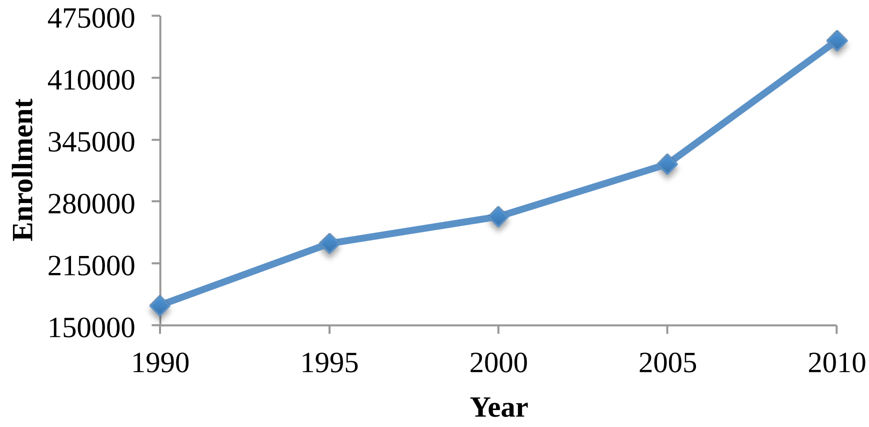

Figure 1: Postsecondary enrollment in elementary-level statistics sources in the U.S., fall 1990-fall 2010 (reflects courses housed in mathematics or statistics departments and includes those who may be enrolled through distance learning).

A parsing of Figure 1 enrollment between two- and four-year colleges and universities reveals similar findings over time. Among two-year colleges, enrollment continually increased, climbing to 137,000 in fall 2010, an 85% increase in enrollment from ten years prior; among four-year colleges and universities, enrollment rose steadily, skyrocketing in fall 2010 to 312,000, a whopping 54% increase in enrollment from only five years before; Figure 2 illustrates such trends (Lutzer et al. 2007; Blair et al. 2013).

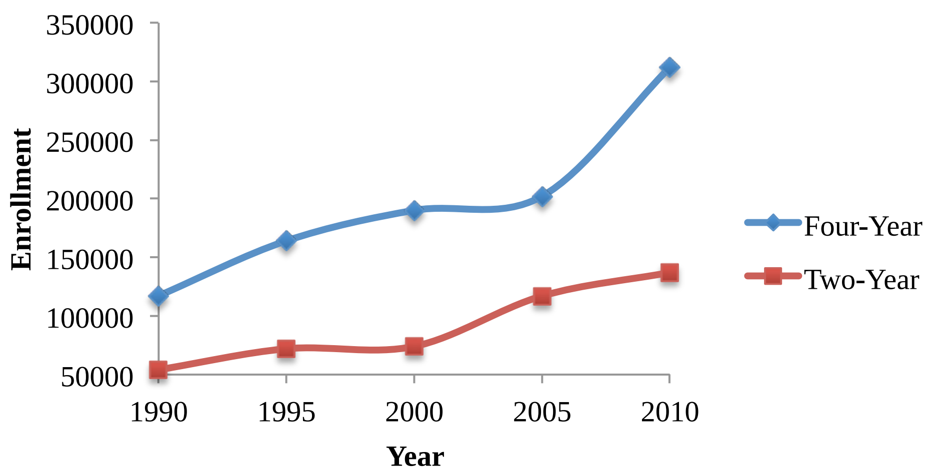

Figure 2: Postsecondary enrollment in elementary-level statistics courses in the U.S. by college type, fall 1990-fall 2010, separated into two- and four-year colleges and universities (reflects courses housed in mathematics or statistics departments and includes those who may be enrolled through distance learning).

With enrollment on a consistent rise, a myriad of instructional strategies becomes vital in the strengthening of student competency in introductory statistics courses. A pedagogy of writing-inclusiveness within specific disciplines has evolved through time, becoming a key component in mathematics and statistics courses. Historically, students have been met with their fair share of significant challenges that come along with passing these particular courses. From lack of motivation to the confrontation of statistics anxiety to the strain of attempting to decode obscure symbols and their meaning, the struggles students face in these type of courses are no less than formidable (Krantz 1999; Perry 2004).

Interestingly, the introductory statistics course "is often the one and only statistics course taken by students who are not majoring in this (the statistics) discipline" (Garfield et al. 2002). What obfuscates the dilemma even more concerning strengthening comprehension in these courses is that, unlike in mathematics, they are not solely taught by statistics faculty. They may also be taught by faculty in other disciplines for which statistics training is integral, including psychology, nursing, economics, and sociology (Shambare 2011; Hayat et al. 2013; Delucchi 2014). Integrating writing is one strategy that many researchers have championed as a key instructional component as faculty and students alike seek to convey and learn important statistical concepts and to mitigate aforementioned student struggles (Fung 2010). A case study follows, in which the author explores final-exam grades in introductory statistics courses vis-à-vis the student writing experience.

4. Assessing Comprehension: A Unique Case Study

4.1 Background

This case study involves specific classes I taught at Fashion Institute of Technology (FIT), a New York City-based, four-year, public college whose claim to fame is its top-five ranking among all fashion schools in the world. With an enrollment of approximately 10,000 students, the college is lesser known for its 2+2 programmatic setup, whereby students obtain bachelor's degrees by first completing associate's degrees the initial two years and then applying separately to bachelor's-degree programs to be completed during the final two years. Part of the State University of New York consortium of colleges, FIT offers thirty-six program majors, spanning its Schools of Art and Design, Business and Technology, and Liberal Arts. It even makes available through its School of Graduate Studies seven programs that lead to master's degrees. Although the School of Liberal Arts only offers two majors (Art History and Museum Professions; Film and Media), it currently offers an impressive twenty-three minors, including mathematics, from which students may choose to declare and pursue. One of the courses students may use toward fulfilling requirements for the mathematics minor is MA 222: Statistical Analysis, the equivalent of a traditional, non-calculus-based, introductory statistics course. This is the course at the center of the current study.

When I taught this course prior to summer 2010, students were assessed using scores from quizzes, in-class laboratory assignments using software, three exams, and a final exam. At the end of each semester that I taught the course, I customarily stored course grades, along with scores students earned on final exams. Following that summer, my interest in my department turned to teaching courses in financial literacy and Emporium-style developmental math courses. Subsequently, two years had passed since I had taught the statistics course. In the hiatus, I had an interesting conversation with a colleague, who evaluated his teaching of this same course via exams, a writing assignment, and a final exam. Hence, I decided on a whim to make an adjustment and implement the writing evaluative measure in my own class the next time I was to teach. I would continue with quizzes and Excel assignments; but students would now take two exams, complete the report instead of taking the third exam, and take the final exam. I simply thought of this as a neat, no-frills idea – that students would be writing in my statistics class, and it would count toward their grade. As was my custom, of course, I continued to store course grades, along with final exam scores.

It was during the summer of 2013 that I had an inkling to analyze student scores on the final exam using with- and without-writing results across groups. I decided that it would be a good idea to analyze results in both situations. To avoid any semblance of self-imposed bias onto the objective nature of the study, I no longer considered scores on final exams to analyze for semesters after the time of my aha moment. In other words, during the summer of 2013, I initiated the inquiry process of student performance from these two separate groups. As a result, students' final exam scores in my statistics classes after 2013 were disqualified from being included in this study, even though I kept report-writing an integral component of the course requirements (and still do!).

4.2 A Closer Look at the Writing Assignment

By mid-semester, students have an understanding of basic statistical concepts undergirding the course. The description of the writing assignment that follows provides a general overview of the project, giving attention to the project's objective, mission, guidelines, relevant dates, and penalties concerning plagiarism. The project description may be viewed as a DOCX file and downloaded at the URL that follows. Instructors should feel free to tweak the project description to their liking (http://goo.gl/cPJlGb).

Over the next month, students learn relevant statistical material and absorb it as material to be mastered for the writing assignment and later on the final exam. I stress that students will not have to take a third exam and should learn the techniques through this different filter or lens, one requiring them not to regurgitate but to assimilate and closely dissect. Although some researchers suggest that projects of this sort are more meaningful when students work in small groups (Bull and Clausen 2000; Curran et al. 2013; Baki and Baki 2014), weaker students may often hide behind stronger students and fail to pull their fair share of the workload. Working individually on the project requires each student to grapple with a specific statistical technique and to use it to analyze data of his or her own choosing (Singer and Willett 1990). This project, hence, is an individual project. To process the data for the writing assignments, students are expected to use software that instructor has exposed them to in the course.

Admittedly, since many of the students are still groping in the dark concerning what is expected, I continue to provide them support by having the director or assistant director from our college's Writing Studio to visit the class and give a guest lecture about the writing process in general and with respect to writing for a statistics class in particular (Bazerman et al. 2005). The Writing Studio offers students one-on-one and group feedback on their writing and works collaboratively with students during the writing process to help develop, focus, and execute ideas. Among its many-pronged foci, the Studio's consultants collaborate with student writers online or in face-to-face meetings to enhance the learning process and contribute to students' developing writing abilities; too, it collaborates with faculty to provide students with quality writing experiences across the curriculum. This always proves useful, as students are able to ask specific questions of the director, and I as a faculty member can have another professional colleague share the burden and joy of engaging students on a level that they are not accustomed to dwelling with respect to a mathematics or statistics course.

So that students do not feel as though they have to reinvent the wheel, I provide them with general recommendations for how the paper should be structured. The textbook used in the course boasts a special section specifically addressing the structural skeleton of technical writing pieces and steers students toward contemporary ideas about the report-writing process (Gibson and Dillard 2016). As the description outlines, all students are encouraged to follow the basic steps for the paper's organization: i) background statement; ii) design and procedures; iii) results; iv) analysis and discussion; and v) conclusion. Although the paper will still be a challenge to write, students sense guidance as it relates to how their paper should be structured (Harris and Schaible 1997).

Further, I share with students the rubric to be used to grade their papers. The extent to which most of them have partaken in the writing experience is limited to basic essays and a traditional research paper, which probably involved little to no mathematics or statistics. Details from the rubric not only serve as a mechanism to help them see how I tend to evaluate their work, but it also guides the work's development, preventing many of the errors before they happen (Bahls 2012). On purpose, forty points of the paper strictly come from my approving student topics approximately two weeks before the report is due. I have learned that this reduces the chance that students procrastinate and wait until the deadline is near before beginning, which in turn decreases the probability of plagiarism and other forms of academic dishonesty. The rubric may be viewed as a DOCX file and downloaded at the URL that follows; instructors may tweak and use (http://goo.gl/QzbhjN).

4.3 Description of the Study and Data

My mission was to analyze grades that students scored on the final exam when they had participated in the writing assignment and when they had not. In group 1, students took quizzes, three exams and a final exam. These students were enrolled in the course during spring 2008, fall 2008, and spring 2010. In group 2, the third exam was replaced by the writing assignment, and all other assignments remained the same. This is the only exam students were not allowed to keep in their possession after taking it (or to sneak pictures of using their cell phones). In fact, students were closely monitored, being only allowed to use non-phone-based calculators. Further, my teaching style remained rather similar throughout the observational span. Arguably, that I took a two-year break from teaching the MA 222 course could very well be interpreted as a disadvantage for students in group 2 since I lost a sense of momentum that comes with teaching a course during contiguous semesters. Table 1 displays students' scores on the final exam in both groups.

Table 1: Student Scores on Final Exam.
(Group 1 includes three exams. Group 2 replaces third exam with technical paper.)

Group 1

Spring 2008				*Fall 2008*				*Spring 2010*			
81	88	77	77	70	87	83	90	90	70	83	80
96	85	85	88	73	70	67	63	80	100	40	90
81	65	81	96	70	73	80	73	77	80	83	100
62	88	73	96	87	60	60	73	90	100	77	97
69	92	88	81	67	80	60	80	77	83	60	100
65	77	88		67	53	80		90	93		

Group 2

Spring 2012	*Spring 2012*	*Spring 2013*	*Spring 2013*
87 73 53 80	80 90 73 83	73 70 93 83	77 83 87 87
93 90 67 100	97 97 70 90	83 83 90 93	87 100 87 97
70 70 73 93	87 87 90 77	87 77 77 93	77 83 63 83
97 80 97 83	73 73 90 57	90 80 80 77	80 83 83 83
80 93 87 90	87 93 93 67	80 87 83 93	73 73 87 90
90 80 90 87	77 83 83	67 87	90 100 97 73

To analyze the data, the technique of comparing two independent group means is appropriate. The assumption of independence of sampled scores is met. Both sample sizes are large enough, which confirms the efficacy of the central limit theorem. Summary statistics needed to apply the technique include each sample's size, mean, and variance. Computed from Table 1, summary statistics for group 1 (subscripted by *third* to denote when students took the third exam) are as follows: $n_{third} = 68$, $\bar{x}_{third} = 79.191176$, and $s^2_{third} = 153.02261$. Summary statistics for group 2 (subscripted by *written* to denote when students wrote the paper instead of taking the third exam) are as follows: $n_{written} = 93$, $\bar{x}_{written} = 83.322581$, and $s^2_{written} = 91.286115$. Average final exam scores are compared to see if they are virtually the same when students took the third exam versus when they wrote the technical paper. Null and alternative hypotheses, respectively, are shown:

$$H_0: \mu_{third} = \mu_{written}$$
$$H_1: \mu_{third} \neq \mu_{written}$$

4.4 Testing for Homogeneity of Variance

Customarily, the method assumes there is no significant difference between group means. Here, the null hypothesis is that average final exam scores are roughly the same whether students completed the writing assignment or took the third exam. To test this hypothesis, a close look at the $\bar{x}_{third} - \bar{x}_{written}$ distribution becomes paramount. Since drawn samples are large enough in this case, an assumption that this difference distribution is normal is fair. It has a mean of $\mu_{third} - \mu_{written} = \mu_{\bar{x}_{third}} - \mu_{\bar{x}_{written}} = 0$ (assuming a true null) and a pooled or unpooled standard error, which is to be determined, depending on if variances in both groups are equal or not. Thus, a moment is needed to discuss equality (or inequality) of sample variances so that we know how best to proceed with respect to standard error in the group-means test. The following two hypotheses are tested:

$$H_0: \sigma^2_{third} = \sigma^2_{written}$$
$$H_1: \sigma^2_{third} \neq \sigma^2_{written}$$

The folded-form F test considers the ratio of the two sample variances, in which the larger is divided by the smaller. This statistic is then compared to a cutoff value based on a certain alpha. In the case of the two groups of final exam scores, the test statistic, denoted by F', is shown in equation (1):

$$F' = \frac{s_{third}^2}{s_{written}^2}. \tag{1}$$

For this study, $F' = 1.676$. The rejection region is defined by an *F* cutoff value having degrees of freedom ν_{third} and $\nu_{written}$, where $\nu_{third} = n_{third} - 1$ and $\nu_{written} = n_{written} - 1$. Since the F' ratio will always be greater than one, the rejection region in the upper tail of the *F* distribution is key. "Should anyone try to determine whether a significant difference exists by referring to the conventional *F* table, he or she needs to remember that the listed critical value at a significance level of 0.05 actually means a significance level of 0.10 in the case of the folded form *F*-test" (Ferguson 1981). Thus, in order to get accurate results, a cutoff value, referenced by $1 - \frac{\alpha}{2}$ to account for said adjustment, is of interest. Here, when $\alpha = 0.05$:

$$F_{\nu_{third},\, \nu_{written},\, 1-\frac{\alpha}{2}} = F_{67,\, 92,\, 0.975} = 1.55.$$

Hence, since $F' = 1.676 > 1.55 = F_{\nu_{third},\, \nu_{written},\, 1-\frac{\alpha}{2}}$, H_0 is rejected. Thus, sample variances in the study are in fact significantly different. In the overall test of group means, this would require use of the unpooled standard error $\left(\sqrt{\frac{s_{third}^2}{n_{third}} + \frac{s_{written}^2}{n_{written}}}\right)$ rather than the pooled version in the test statistic.

4.5 Results

Since σ is unknown in both groups and since it has been determined that sample variances are unequal, Welch's *t*-test is used to examine for significant differences between group means. Using the unpooled standard error, the test statistic, denoted by t_{test}, follows:

$$t_{test} = \frac{(\bar{x}_{third} - \bar{x}_{written}) - (\mu_{third} - \mu_{written})}{\sqrt{\frac{\sigma_{third}^2}{n_{third}} + \frac{\sigma_{written}^2}{n_{written}}}}$$

$$\approx -2.298$$

The *t*-critical value, denoted by t_{crit} and placed within the confines of a two-tailed test, has specific degrees of freedom. Since it has been shown that sample variances in this study are unequal, the effective degrees of freedom needed to determine this critical value are found using the Welch-Satterthwaite approximation equation, given by equation (2):

$$df \approx \frac{\left(\sum_i \frac{s_i^2}{n_i}\right)^2}{\sum_i \frac{\left(\frac{s_i^2}{n_i}\right)^2}{n_i - 1}} \tag{2}$$

In particular, the approximation of the degrees of freedom for the current two-group data is given by:

$$df \approx \frac{\left(\frac{s_{third}^2}{n_{third}} + \frac{s_{written}^2}{n_{written}}\right)^2}{\frac{\left(\frac{s_{third}^2}{n_{third}}\right)^2}{(n_{third} - 1)} + \frac{\left(\frac{s_{written}^2}{n_{written}}\right)^2}{(n_{written} - 1)}}$$

$$\approx 121$$

Using these degrees of freedom with a two-tailed scenario in which $\alpha = 0.05$, the *t* table reveals that $t_{crit} = \pm 1.9798$.

Finally, nonnegative values of t_{test} and t_{crit} are compared to get results:

$$t_{test} = |-2.298| \geq |\pm 1.9798| = t_{crit}\,.$$

Since $2.298 \geq 1.975$, the null hypothesis is rejected, supporting that $\mu_{third} \neq \mu_{written}$. At $\alpha = 0.05$, these data reveal, then, that there is a significant difference in final exam scores when students took the third exam (M = 79.19, SD = 12.37) as opposed to when students completed the writing assignment (M = 83.32, SD = 9.55), t (121) = 1.9798, p = 0.023273. In this study, average final exam scores significantly different between the two groups. In fact, students scored significantly higher on the final exam when they wrote the technical paper compared to when they took the third exam. Essentially, if we conducted this experiment 100 times under the same conditions, a difference this large would be obtained between the two means strictly due to chance in five of those instances.

5. Discussion

Of note, both WAC advocates and critics alike seem to shy away from assessing WAC effectiveness through invoking a comparison *across groups* with respect to student performance within a specific discipline. If the goal is to show how effective writing assignments help students contextualize and internalize course content, careful analysis of end-of-course content mastery would appear to be appropriate focal points, in which one compares results across groups with and without writing in the mix. Of course, a test of this nature is challenging because of the difficulty in achieving results that are uninfluenced by significant changes in instructors' teaching execution and other subtle factors that may be laden with bias.

While one may further argue that marked variability in students' academic ability before the course began could have contributed to stated results, there is no notable reason as to why this should be assumed. To parse the pre-study data in this manner would muddy the study's integrity. Perhaps pre- (and post-) tests may be administered to gauge statistics fitness within groups, but to venture outside of normal assumptions concerning across-group student ability before instruction is unwise. Hence, this study exploits basic assumptions, which supposes that all students began the course at a ground-zero level with respect to statistics knowledge. In this case, the assumption is that all students have fulfilled the academic prerequisite of arithmetic proficiency either by passing the appropriate developmental courses, by passing placement exams administered on the first day of classes for developmental courses, or by exempting the course via transfer credit. Ultimately, prior to the start of the course, aptitudinal differences that may exist across both groups in the course's subject matter are attributed to chance.

Assuming all things being "equal" concerning students' initial statistical ability level, evaluative measures within the statistics discipline itself (i.e., regular statistics final exams) may assist in better measuring the effectiveness of writing as a vehicle to gauge student course mastery. Assessment involving mere summaries of student and faculty perceptions of increased knowledge within subject matter can be rather subjective and buttressed by no concrete, empirical attestation. "While not without some merit, comments based on informal impressions, and even quantitative measures of course satisfaction do not directly signify student learning" (Delucchi 2014). As much as possible, the qualitative numbers themselves must do the talking, not the students or faculty.

6. Final Word

In sum, this article compared final-exam scores in the author's introductory statistics classes for students when they participated in a technical writing assignment and when they did not. The study involved seven of the author's classes at FIT and spanned over the course of five semesters. Students in group 1 took the final exam after having completed a series of quizzes, lab exercises, and three exams. Students in group 2 took the same final exam after having completed a series of quizzes, lab exercises, two exams, and a technical writing assignment. Results of the study revealed that students in group 2, on average, scored significantly higher on the final exam than their counterparts in group 1. Results appear to corroborate what other studies seem to suggest with respect to the infusion of writing into the statistics curriculum at the introductory level: that, if administered and integrated thoughtfully, the integration of writing in such classes tends to suggest increased student statistical content grasp and serves as an invaluable pedagogical tool in the instructor's teaching bag. In fact, even though different studies have approached the testing of this notion over time through an array of modalities, it has yet to be shown that the presence of writing cripples, stunts, or otherwise hinders the level of student comprehension in introductory statistics courses.

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