AC 2012-4530: USING WRITING ASSIGNMENTS TO IMPROVE CONCEPTUAL UNDERSTANDING IN STATICS: RESULTS FROM A PILOT STUDY

Mr. Chris Venters, Virginia Tech

Chris Venters is a Ph.D. candidate in engineering education at Virginia Tech. His primary research interests involve studying conceptual understanding among students in early undergraduate engineering courses. He received his B.S. in aerospace engineering from North Carolina State University and his M.S. in aerospace engineering from Virginia Tech.

Dr. Lisa D. McNair, Virginia Tech

Lisa McNair is an Associate Professor in the Department of Engineering Education at Virginia Tech, where she also serves as Assistant Department Head for Graduate Education and co-directs the Virginia Tech Engineering Communication Center. Her research includes interdisciplinary collaboration, communication studies, identity theory, and reflective practice. Projects supported by the National Science Foundation include interdisciplinary pedagogy for pervasive computing design, writing across the curriculum in statics courses, and a CAREER award to explore the use of e-portfolios to promote professional identity and reflective practice. Her teaching emphasizes the roles of engineers as communicators and educators, the foundations and evolution of the engineering education discipline, assessment methods, and evaluating communication in engineering.

Dr. Marie C. Paretti, Virginia Tech

Marie C. Paretti is an Associate Professor of engineering education at Virginia Tech, where she co-directs the Virginia Tech Engineering Communications Center (VTECC). Her research focuses on communication in engineering design, interdisciplinary communication and collaboration, design education, and gender in engineering. She was awarded a CAREER grant from NSF to study expert teaching practices in capstone design courses nationwide, and is Co-PI on several NSF grants to explore design education. Her work includes studies on the teaching and learning of communication in capstone courses, the effects of curriculum on design cognition, the effects of differing design pedagogies on retention and motivation, and the dynamics of cross-disciplinary collaboration in both academic and industry design environments.

Using Writing Assignments to Improve Conceptual Understanding in Statics: Results From a Pilot Study

Introduction

Statics serves as a foundational course to many engineering disciplines that rely on Newtonian mechanics to analyze problems. In the engineering community, statics has long been known to be a troublesome course for beginning engineering students. Most often this manifests itself in the form of low first-time pass rates, but several recent publications from the engineering education community indicate that bad grades are not the only indicators of the problem [1-3]. These reports, among others, indicate that many students, even those who pass statics, have difficulty conceptualizing the topics that we consider essential knowledge for engineering students. This learning deficiency can provide complications as students enter courses that build on the statics foundation.

The primary purpose of this ongoing study is to determine whether writing can be used in engineering courses like statics to improve learning for students. In part, this study builds on previous studies by authors like Hanson and Williams [4] and others who have studied Writing to Learn (WTL) in the classroom. While Hanson and Williams in particular used writing in a statics course in an effort to improve the self-assessment and writing skills of their students, this study uses a similarly styled intervention but looks instead for conceptual learning gains and better performance from students. In addition, the use of a more structured experimental setup and larger sample size helps provide more generalizable and transferable results.

The study specifically aims to answer the following research questions:

- Does the inclusion of the process problem writing assignments affect student conceptual understanding in statics, and if so, how?
- Does the inclusion of the process problem writing assignments affect student performance in statics, and if so, how?
- How do teaching assistants perceive and handle grading for writing problems in engineering?

Literature Review

Issues in Teaching and Learning Threshold Concepts

A current problem in engineering education involves the teaching of threshold concepts to students. By threshold concepts, we mean concepts that are not only an integral component of a discipline, but also transform ways of thinking and provide a "portal" into higher levels of understanding [5]. For students, they are the foundational theories and explanations required for advanced courses; for experts, they serve as the organizers of facts and theories, the 'big ideas' identified in *How People Learn* [6]. For both of these reasons, these threshold concepts are necessary for student development and success and, thus, are generally presented in introductory level required courses. Unfortunately, these concepts can also be among the most difficult to learn, and as large numbers of students struggle to do so, so do educators struggle in finding ways to effectively teach them.

As pointed out by Streveler, *et al.* [7], the large amount of literature that currently exists on conceptual knowledge does not typically include the post-secondary levels of engineering. In the pieces that do, there appears to be wide agreement among engineering educators as to the importance of constructivism in learning [8, 9]. Particularly, they focus attention on the constructivist view that students build their knowledge around preexisting notions and ideas. Thus, identifying and assessing this prior knowledge, particularly misconceptions that students commonly hold, is the focus of a great deal of current research. For threshold courses in areas of mechanics, thermal sciences, and many others, these common student misconceptions have largely already been identified [1, 7, 10]. In addition, concept inventories have been developed in a wide range of subjects as a means of assessing these misconceptions [2, 11-13]; "think aloud" sessions are also common, in which researchers analyze recordings of students describing their actions as they complete a problem [5, 7]. What remains to be done, however, is to research ways of correcting these misconceptions through effective teaching practice.

To complicate matters beyond merely prior knowledge, many of the threshold concepts related to engineering are difficult to teach even in the absence of preexisting misconceptions. Streveler *et al.* summarize research that shows that many engineering concepts are difficult to grasp because they involve "emergent phenomena," which occur indirectly as a result of the underlying principles and cannot be readily observed [7]. Another study reported in their article found that concepts such as force, heat, current, and light are difficult because students tend to internally represent these properties of these concepts as physical substances, incorrectly making analogies to familiar things like water. These problems can contribute to the development of false notions related to these threshold concepts that can get associated and imbedded into memory over time.

In order to begin to understand how best to handle student misconceptions and teach threshold concepts, a general understanding of the ways that knowledge is developed and organized in the mind must first be reviewed. In the past few decades, a wealth of information has been brought to the attention of the broader engineering education community [see Bransford et al., 2003 for a summary [6]). Even more recently, Redish and Smith have outlined what they consider four broad concepts related to thinking and learning that have important implications for teaching [14]. Of those concepts, "association" seems to highlight a critical step in the transition from novice to expert. For students who have misconceptions, replacing those notions with the correct scientific concept presented in the classroom may be a difficult process. At best, all that educators can do is minimize incorrect thoughts by making stronger the associations amongst the correct ones.

In light of the difficulties related to effectively teaching threshold concepts, several members of the engineering education community have begun working on ways to improve student learning in these areas. Steif, for example, discusses his use of visual images to accompany free body diagrams in a statics course to help students see beyond the math towards a deeper understanding of forces on bodies [3]. More recently, he and his colleagues have also experimented with increasing "body-centered talk" among students in an effort to increase their success in applying their conceptual knowledge to problem solving [15]. Although the results of their actual experimental design were of mixed success, they did find that students who talked more about the bodies in a problem (either spontaneously or when prompted) had higher success rates when solving statics problems. Others have attempted to increase understanding through the design of learning environments based on student learning preferences [10]. Most recently, Streveler *et al.*

describes a study that will attempt to help engineering students build a foundational knowledge in emergent processes as a foundation for future concepts [7].

Venters and McNair previously conducted a small exploratory study to examine problem-solving processes through "think-aloud" protocols [16]. The case study results of individual students indicated that students who employed a metacognitive approach to problem-solving in statics assignments were more successful in a setting where out of the 212 students who completed the course for a grade, 29.2% received a grade of "F", 30.7% received a grade of "D", and nearly half were retaking the course. On the other hand, students who employed methods indicative of behaviorist approaches, for example repeating exercises until memorization and conditioned response guided problem-solving, passed with lower grades and often had to retake the course multiple times. As an initial investigation of problem-solving behaviors in statics courses, this study examined theoretical approaches to learning that may guide future studies, and hypothesized that a cognitive approach would help guide future research.

We propose that "writing to learn" methods can also help in teaching and learning these threshold concepts. As with the think aloud method, this may be a way for instructors to understand a student's thought process and identify incorrect assumptions or analogies that the student makes when processing these concepts. Writing-to-learn can also be used to promote 'metacognition' in which students articulate the emergent processes, which may increase associations formed in memory and lead to more robust knowledge construction. Finally, these kinds of activities can support assessment and self-evaluation efforts as well. Through such metacognitive and reflective activities, students can articulate new ideas within constraints and enhance knowledge transformation about their prospective profession and practice in STEM fields.

Writing-To-Learn and Critical Thinking

Research on writing and student learning falls into two broad categories: learning to write and writing-to-learn. Studies of learning to write examine the ways in which students develop as writers, whereas studies of writing to learn focus on the ways in which writing tasks support content learning in a variety of disciplines.

Learning to Write: With respect to learning to write, studies of college students over the past few decades have explored both students' engagement with various forms of academic discourse [e.g., 17, 18-24] and their transition to the workplace [e.g., 18, 25, 26-36]. These and numerous other studies emphasize the importance of situated learning as students are enculturated into the discourse practices of a particular field or profession. They demonstrate the difficulties students face as they move from one writing context to another, where not only language but accepted organizational patterns, logical structures, evidence, audiences, purposes, style, and other factors may all shift. Based on this and related research, writing faculty have increasingly emphasized a metacognitive understanding of writing as an analytical, rhetorical process rather than a simple mastery of particular formats and grammatical rules. That is, transferable writing skills involve the ability to analyze the audience, purpose, and context for a given document and make appropriate choices with respect to content, organization, and style. This approach is reflected, for example, in the outcomes for first-year composition defined by the Council of Writing

Program Administrators (WPA), which also include ways for disciplinary faculty to build on the first-year outcomes [37].

Writing to Learn: The WPA outcomes statement also includes a strong emphasis on critical thinking and the role writing can play in the process of learning. This emphasis reflects the strong writing-to-learn movement that has slowly permeated education in recent decades. The movement in the U.S. has its roots in Janet Emig's seminal 1977 article, "Writing as a Mode of Learning," in which she stressed the ways in which the act of writing both corresponded to and supported the cognitive processes of learning [38]. In the decades since the publication of Emig's article, writing-to-learn has become a ubiquitous strategy in many fields across all levels of education. Hundreds of articles have been written both theorizing and empirically testing writing as a tool for learning, and numerous studies have demonstrated that writing can support learning in mathematics, the sciences, the social sciences, and the humanities [39-41] [e.g.,42, 43-46]. Two important review articles synthesize key issues in writing-to-learn research: Klein's 1999 examination of the hypotheses concern how writing influences learning and Bangert-Drowns, Hurley, and Wilkinson's 2004 meta-analysis of studies on the impact of writing-to-learn on academic achievement.

Although a decade old at this point, Klein's overview of cognitive theories regarding the role of writing still provides a useful overview of the ways in which writing practices can support learning [47]. He reviews four hypotheses: 1) the initial act of writing itself brings forth new knowledge as writers allow ideas to flow; 2) learning occurs as writers move through the revision process, as writers organize, link, evaluate, and refine their ideas; 3) different genre structures such as argument, compare/contrast, or analysis support learning by helping students move through logical processes; and 4) learning occurs as students plan their writing and set goals and sub-goals for problem solving. Klein notes that while each of these hypotheses have merit, and some degree of empirical evidence existed at the time of his writing to support them, much work remains to be done in more fully understanding the relationship between writing and learning, particularly in order to help faculty develop assignments to support specific types of learning.

Bangert-Drowns *et al.*'s review five years later reflects similar processes and gaps [48]. Their systematic review examined hundreds of articles on writing-to-learn written over the past hundred years, though as they note the majority of these articles were written in the 1980s and 1990s. After a rigorous evaluation process that allowed them to identify a core set of articles that provided empirical evidence of the academic effects of writing-to-learn assignments against control groups without those assignments, the authors conducted a statistical meta-analysis of these studies that considered not only whether the writing-to-learn exercises enhanced learning, but what factors appeared to influence the results. Their review indicates that indeed in a majority of the studies, statistically significant learning gains were associated with writing exercises. More importantly, however, they noted that significant gains were most often correlated with writing that included metacognitive reflection that allowed students to examine their level of understanding and their learning processes. Personal writing, in which students connect course content to their personal experience, emerged as least effective. Their analysis also indicated that for in-class writing, shorter assignments tended to have a more positive effect than longer ones; at the same time, longer treatment periods (e.g. a semester rather than a few

weeks) were also positively correlated to learning gains. Like Klein, Bangert-Drowns et al. note that while sufficient evidence exists to support writing as a tool for learning, much work remains to be done in terms of understanding the particular mechanisms at work and the specific contextual factors such as the nature of the assignment, the nature of the learning, the length of time, the impact of feedback and evaluation, and a host of other factors.

More recent research has continued to examine these contextual factors and explore in more detail the ways in which writing supports learning. For example, recent work by Carter, Ferzli, and Wiebe has examined the ways in which writing in disciplinary courses in college helps students develop a strong socialization into the practices and norms of the discipline, acting as a means of enculturation [49]. Their study, in many ways, seeks to bridge the divide between learning to write and writing-to-learn by identifying ways in which learning to write in a particular discipline supports not only students' ability to communicate in their chosen field, but also supports their broader learning of that field. Their study of students in a biology lab suggests that the laboratory report, when framed in terms of a model of apprenticeship and situated learning, supports students' socialization into the discipline in a variety of ways, including learning by writing in the particular genre of the lab report, learning by creating a report that can be used for future reference, and learning by providing alternate channels for processing information.

Writing and Critical Thinking: As suggested by the WPA outcomes statement, one of the key areas in which writing is said to support learning is in the area of critical thinking; writing assignments are frequently used both to promote and to assess critical thinking. Here, too, however, current research suggests that the connection is not inherent but again depends heavily on the pedagogical context. Key work in this area has emerged from Washington State University, where faculty leading assessment efforts in both critical thinking and writing have been exploring the relationship between the domains [50]. Their research suggests that while many claims about writing and thinking circulate through the literature, making that link function in practice for student learning requires conscious, explicit attention on the part of faculty as they design, discuss, and evaluate assignments. They note, specifically:

1. If faculty do not explicitly ask for critical thinking, students do not feel moved to do it;
2. If faculty do not define the construct critical thinking for students, students will not produce a definition;
3. If writing tasks call for summary and fact reporting, we have no reason to suspect that students' performances will incorporate critical thinking;
4. If faculty do not receive assistance in developing assignments that set high expectations and that explain clearly what those expectations are, there can be no reason to assume that course assignments and materials will include either. (p.66)

That is, while writing can support critical thinking and can promote disciplinary learning, it does not inherently do so. Achieving that learning requires intentional action on the part of faculty with careful attention to factors such as the context of the assignment, the ways the assignment is implemented in the course, and the kinds of feedback and evaluation employed.

Methods

Implementation

The pilot study was conducted at a large public technical university in the southeast during Spring 2011 in the form of a pseudo-experimental mixed methods design implemented in a single statics course. The course was offered in three sections, each having a maximum capacity of 155 students, with an initial total enrollment of approximately 400 students. Two of the sections were experimental sections receiving the intervention; the single remaining section was used as a control. One of the experimental sections (EX1) and the control section (C1) were both taught by the same instructor, a professor who had taught the course for many years; the second experimental section (EX2) was taught by a member of the research team.

The statics course at the institution was taught in a traditional lecture style format. Tests were given four times throughout the semester with roughly equal spacing between tests, and a comprehensive final exam was given at the end of the semester. Homework sets consisting of approximately six problems were assigned and collected twice weekly through an online course system that accompanied the course text.

For the pilot study, section C1 was taught as usual under the discretion of the instructor; EX1, taught by the same instructor, was conducted in a similar manner with the exception of homework assignments. In addition to the usual problems assigned to the control group, EX1 was also assigned one homework problem nearly each week (13 total) throughout the semester designed to elicit written explanations of course content; these were referred to as "process problems". These problems were adaptations of those created by Hanson and Williams (2008) in their study of writing in statics. Students in EX1 were given explicit instruction on how the written responses should be completed, including an example solution and the grading criteria that was used to evaluate their responses. In an effort to keep time requirements for students in the experimental section roughly comparable to those in the control group, students were asked to complete the process problem only for an existing homework problem that they normally completed anyway. Section EX2, although taught by a different instructor and thus having different lectures, homework problems, and test questions, had the same process problems as EX1 and was given the same instruction on how to complete the writing problems.

The instructions given to the students directed them to explain in words the objective of the problem and the steps that they used to complete the objective. Thus, equations were to be described without using mathematic symbols and students were to focus on what the mathematical elements actually refer to in a physical sense. For example, rather than simply writing $M_A=F*d$, students might have said, "To solve for the magnitude of the moment produced at point A by the force **F**, I multiplied the magnitude of the force, F, by the perpendicular distance measured from point A to the line of action of **F**." Students were told that they would be graded based on the detail and clarity of their responses, which should be written as to be understandable by another beginning statics student. More specifically, students were given the four grading criteria used on the grading rubric but were not given the rubric itself. The individual instructors decided how much to weight the process problem assignments, which made up some fraction of the 15% of the total grade assigned to homework.

The typed process problems were collected via an online course management system and graded by a team of two teaching assistants (TAs), each assigned to one of the experimental sections. The instructor of EX2, Venters, led the teaching assistants. Prior to the assignment being given to students, TAs met with Venters to familiarize themselves with the project and how to grade the written assignments. During the training session, Venters introduced the experimental objectives and rationale for the study to the TAs, highlighting their role and the importance of a fair and standardized grading procedure for the assignments. Venters also reviewed the instructions and typical format of the written assignments including examples of possible student solutions provided by Hanson and Williams (2008). The session ended with TAs brainstorming with Venters on ways to make the problem description and instructions clearer for students.

Following the initial training session, the TAs regularly met with Venters as a group once per week for the first few assignments to participate in norming sessions where they had an opportunity to practice using the rubric to grade actual student solutions and discuss any differences among grades that arose. Discussion of the prompts/rubric along with any proposed modifications continued until opposing groups agreed upon a grade with at most a one-point (out of 8 possible points) difference. At the point in the semester where the rubric remained unchanged for two consecutive weeks, the meetings were held as needed to monitor consistency and possible issues with grading.

Data Collection

Data collection for the pilot study occurred throughout the semester and consisted of quantitative and qualitative sources. Table 1 below links the proposed research questions of the study to the types of data that were collected to explore each question.

Table 1. Data Collected by Research Question

Research Question	**Data Collected**
Does the inclusion of the process problem writing assignments affect student conceptual understanding in statics, and if so, how?	Quantitative – Pre/post test scores from the Statics Concept Inventory Qualitative – Interviews using think-aloud/open-ended questioning protocols
Does the inclusion of the process problem writing assignments affect student performance in statics, and if so, how?	Quantitative – Student grade data Qualitative – Interviews using think-aloud/open-ended questioning protocols
How do teaching assistants perceive and handle grading for writing problems in engineering?	Quantitative – Reported time spent grading problems each week Qualitative – Observations of meetings/norming sessions

The results discussed in this paper will be mostly limited to the quantitative data collected for the first two research questions, focusing on exploring the relationship between the process problem writing assignments and conceptual understanding and course performance. The qualitative data collected for these questions, which is better suited to describe *how* the process problems may affect conceptual understanding and course performance, is still under analysis and will be presented in future work. Results from both the quantitative and qualitative data for the third

research question will be included in this paper as well. A more detailed description of the data collection process for each data source is given below.

The Statics Concept Inventory (SCI): The SCI was administered to both experimental and control sections twice during the semester, once as a pre-test during the first week of classes and again as a post-test near the end of the semester. Both administrations were conducted through an online system managed by Paul Steif and his team. Students were asked both times to complete the inventory outside of class within a one-week window as a required homework assignment without the assistance of notes, books, or other resources. Toward this end, students were told that they would receive full credit (worth one homework assignment each time) for competing the inventory with a score of 20% or better. This value was explained to students to be an attainable score for a beginning student yet would prevent passing scores due to random guessing. In reality, all students received credit simply for completing the inventory each time regardless of their score. To ensure that no scores were released to students or instructors until after the semester had ended, results were channeled through McNair, who emailed instructors the names of students who were to receive credit for the assignment. After final grades were turned in, the SCI pre- and post- scores were given to instructors to be added to the grade book prior to de-identification.

Student Grades: De-identified grade data was collected from each instructor for all sections after the end of the semester. Records included grades for traditional and process problem (if applicable) homework assignments, tests, and final exam, as well as final numeric grade and assigned letter grade. As mentioned above, SCI pre- and post-scores are also linked to the appropriate record.

Interactions with the Teaching Assistants (TAs): Once per week, TAs were emailed reminding them to report the approximate amount of time that they had spent grading the problem for that week. Their responses were collected and recorded throughout the semester. In addition, observational notes were taken by members of the research team present at the TA training and norming sessions described earlier. The observation protocol was open but focused on TA perceptions of the process problem assignments as well as any difficulties, concerns, and disagreements related to grading.

Results

Statics Concept Inventory

All quantitative analysis was conducted using the IBM® SPSS® 20 computer statistical package. Significance levels for all tests were set to 0.05. In experimental sections, records were excluded if the student had zeros on more than half (7 or more of 13 total) of the process problem assignments to help ensure that results reflected actual treatment effects. This reduced the total number of records from 87 to 61 (70% of the total) in EX1 and from 120 to 103 (86% of the total) in EX2.

To investigate the first research question of whether the process problems affect student conceptual understanding, the results from the pre- and post-administrations of the Statics

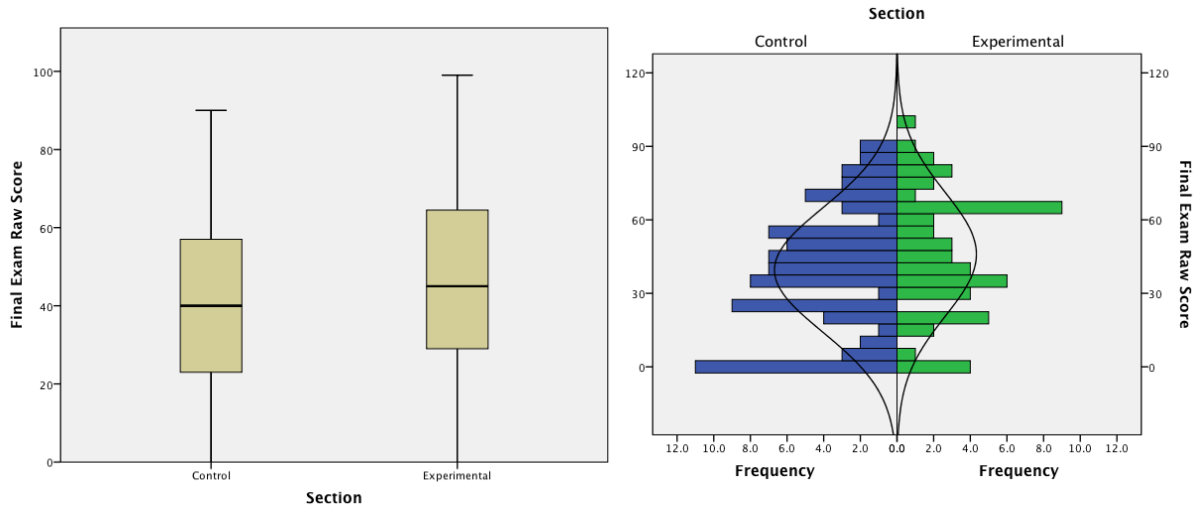
Concept Inventory (SCI) were analyzed. The numbers of students who completed each administration of the SCI, broken down by section, are summarized in the table below.

Table 2. SCI Completion Rates for Control and Experimental Sections.

Section	**Total # of Students**	**Selected Cases** (completed more than half of the process problems)	**# Completing the Pre-test (% of selected)**	**# Completing the Post-test (% of selected)**	**# Completing both Pre- and Post-test (% of selected)**
Control (C1)	99	99	85 (86%)	64 (65%)	56 (57%)
Experimental (EX1)	87	61	55 (90%)	46 (75%)	42 (69%)
Experimental (EX2)	120	103	94 (91%)	90 (87%)	84 (82%)

It should be noted that sections CI and EX1, which were taught by the same instructor and thus have fewer uncontrollable variables between them, will be the focus of these statistical results, especially for attributing any differences to the treatment effect. Statistical results for section EX2, which has no true control, will be reported only for comparative purposes and will be specifically labeled.

In an effort to further control for potential differences in SCI results merely due to oversampling of "good or bad students" self-selecting to take or not take the inventory, the samples were investigated for differences in academic performance. Since the final exam was comprehensive, common to both EX1 and C1, and not curved, it was chosen as a potential indicator. For students that took the pre-test, box plots and histograms shown below were first generated to compare final exam score distributions between sections.



Figures 1 and 2. Box Plots and Histograms Comparing Groups of Students in Each Section That Took the SCI Pre-test.

To test whether the final exam scores for students who took the pre-test in each section followed a normal distribution, the Shapiro-Wilk test was run. Results from the test indicated that the

final exam scores for the control section did not follow a normal distribution (p=.012), while the scores for the experimental section did (p=.277). As a result, non-parametric tests were chosen as a more robust option to investigate final exam score differences between the two sections though the equivalent parametric test was also run for comparison purposes. The non-parametric Mann-Whitney U test reported that the distributions for each section were not significantly different (p=.199). The parametric t-test gave similar results, reporting that the means were not significantly different (p=.147). Thus, there appeared to be no significant differences among final exam scores between students in different sections who took the SCI pre-test.

A similar process as described above was carried out to test for significant differences among students in different sections who did not take the pre-test, who did and did not take the post-test, and who did and did not take both tests. In all cases, no significant differences were found between samples using non-parametric or parametric tests. Thus, the samples drawn from each section seem to be similar academically. With this in mind, potential differences in conceptual understanding between sections as evidenced by differences in mean SCI scores could be explored.

Summary statistics for the pre- and post-scores for each section are given in the tables below.

Table 3. Summary Statistics for the SCI Pre-test.

Section	**Mean**	**Median**	**Variance**	**Standard Dev.**
Control (C1)	8.21	7.00	15.288	3.910
Experimental (EX1)	8.22	8.00	14.248	3.775
Experimental (EX2)	6.99	6.00	12.591	3.548

Table 4. Summary Statistics for the SCI Post-test.

Section	**Mean**	**Median**	**Variance**	**Standard Dev.**
Control (C1)	12.86	12.00	21.710	4.659
Experimental (EX1)	16.24	16.00	30.008	5.478
Experimental (EX2)	13.61	14.00	28.690	5.356

To test whether the pre- and post-SCI scores for each section followed a normal distribution, the Shapiro-Wilk test was run. Results from the test indicated that the pre- and post-scores for the control section were not normally distributed (p=.027 and p=.012, respectively). This non-normality was confirmed by looking at histograms of the scores. The Shapiro-Wilk test run for the pre- and post-scores of the experimental section did indicate normally distributed scores (p=.132 and p=.297, respectively). As a result, non-parametric tests were chosen as a more robust option to investigate score differences between the two sections; in some cases, though, the equivalent parametric test was also run for comparison purposes.

The non-parametric Mann-Whitney U test for independent samples was first run to look for significant differences between the experimental and control groups. The test indicated that the distributions of scores for the pre-test were not significantly different between sections (p=.916). However, post-test score distributions were found to be significantly different (p=.001), with the experimental section higher than the control. These results were confirmed by the parametric

independent samples t-test, which indicated no significant difference (p=.992) in mean score between the two sections for the pre-test. A statistically significant difference (p=.001) of approximately 3.4 points (out of 27 total) was reported between the post-test means of the experimental and control sections.

Next, the normalized gain for each student was calculated according to the formula given by Hake [51]. The mean normalized gain was then calculated for each section; the results are shown in the table below.

Table 5. Normalized Gain in SCI Scores

Section	Normalized Gain	% of Control Section Gain
Control (C1)	.2666	100%
Experimental (EX1)	.4466	168%
Experimental (EX2)	.3318	--

The average normalized gain for the experimental section was found to be 0.4466, compared to 0.2666 for the control section. This amounts to an increase of more than 1.5 times that of the control section. The normalized gains in each section were found to follow a normal distribution, and the t-test comparing the two sections showed a significant mean difference of approximately 0.18 (p=.002).

Finally, possible correlations between process problem grades and SCI scores were explored. An average process problem grade was calculated for students in the experimental section and correlated with their post-score on the SCI if available. Both parametric and non-parametric tests indicated no significant correlation between process problem average and scores on the post-test of the SCI.

Student Grades

To investigate the second research question of how process problems affect student performance in statics, course grades on tests and the final exam were analyzed. Tests for normality were first conducted in a similar manner to that described previously, and the results similarly indicated a combination of normal and non-normal distributions of test and exam scores for each section. However, both the non-parametric Mann-Whitney U test and the parametric t-test indicated no significant differences in the distributions of test and exam scores between control and experimental sections.

Interactions with the Teaching Assistants

Teaching assistants reported the approximate number of hours spent grading process problem homework for 10 out of the 13 assignments (hours for the last three assignments were not reported by either TA); for each of these weeks, the number of actual papers turned in per section was also recorded. Since the number of assignments turned in varied between sections and within each section as the semester progressed, the number of assignments graded per hour was calculated each week. The average across the entire semester for the TA assigned to EX1 was approximately 16.0 problems per hour, and the TA assigned to EX2 averaged approximately 24.6 problems per hour. This corresponds to a semester average of approximately 3.75 minutes per problem and 2.44 minutes per problem for each respective TA.

Both of the TAs were students enrolled in a technical engineering graduate program housed within the department offering the statics course. The TA assigned to EX1 was female, a US born citizen, and was in the first year of her master's program. The TA assigned to EX2 was male and a native of India who had completed a master's degree previously at another US institution. The TA assigned to EX2 was the only one to have previous experience grading, but neither of the TAs reported having ever used a rubric.

Overall, only a few minor changes were made to the original rubric through the training and norming sessions with the TAs. The final version of the grading rubric used for this pilot study is given in Appendix A. Differences in grading beyond the one-point limit initially stemmed from one TA's more strict interpretation of the rubric, which resulted in the same error being "double counted" in some cases. After the change was made, it is worth noting that TAs still did not always agree on which specific criteria to deduct points from, even though they were marking off for the same mistake. This had to do with interpretation of a mistake as either being a lack of student understanding (second criterion) or a lack of clarity in the explanation of a process (third criterion). However, the TAs were able to consistently grade submissions such that overall scores were within one point of each other.

During the semester meetings, the TAs were also asked how grading was going and if they felt that the grades they were assigning were reflective of student understanding of a topic. TAs did mention that grading the process problems was mentally demanding, more so than for an equal time spent grading traditional work-out problems according to the TA with prior grading experience. They both felt that grades on the first few problems were artificially lower mainly due to students not following the assignment instructions and having formatting-type errors. As the semester progressed, though, they felt that the scores were more reflective of actual understanding for the majority of the classes.

Discussion

The process problem writing assignments did seem to result in higher conceptual understanding for students in the experimental section, as evidenced by higher SCI post scores and higher gains when compared to the control section. While the exact mechanisms resulting in this increased understanding are not immediately evident based on the quantitative results from this pilot study, it is possible that the writing assignments may have prompted students to metacognitively reflect on their understanding of course concepts, thus strengthening their understanding in the process. Having to explain concepts in a language other than the typical language of mathematics may also have helped students to mentally encode concepts in more than one way, facilitating retrieval later in the semester. These possible explanations linking the writing assignments to higher conceptual understanding will be explored further in the qualitative data and in future iterations of this study.

It should be noted that is yet to be seen whether the process problems result in increased conceptual understanding even among students with lower course grades. Though the groups of students in each section that took the SCI post-test had final exam grades statistically similar to each other, they did have statistically higher final exam grades than groups that did not take the

post-test. Thus, it is not clear whether the nearly one-third of each section that did not take the post-test would have followed the same trend as those who did. This will need to be tested in future studies.

Despite the link between completing process problems and scoring higher on the SCI post-test, scores on the process problems themselves did not correlate with scores on the SCI post-test; this may be attributed to difficulties in grading. As the TAs reported, scores may not have been as reflective of understanding in the beginning of the semester when students were making more errors in formatting and not following the assignment instructions. However, correlations were still non-significant when using only a subset of the process problems not including the initial few. Another possible reason is that scores for process problems were necessarily assigned based not only on a student's understanding but also on how well they communicated that understanding to the TA. Process problem grade data was not collected on the criterion level in this pilot study, but future iterations may be able to do so to look for correlations between criteria-specific scores and the SCI score. Finally, compromises between rubric manageability and fidelity make it difficult to ensure that process problems can be graded thoroughly and in a timely manner.

There did not appear to be any differences in student performance in the course due to the process problems, as evidenced by statistically similar raw scores in both sections on common tests and the final exam. The non-effect on course performance may be a source of the sentiments expressed by some students in the interviews, who felt that the process problems did not help them. When using grades as the only indicator of understanding and the only source of feedback in the course, students and instructors alike could rightfully draw this conclusion. Interestingly, the same result was true even when limiting analysis only to students who took the SCI post-test and thus had verified differences in conceptual understanding between sections. It seems likely, though, that this disconnect is a result of traditional testing, which often assesses procedural knowledge through homework-like problems, not effectively assessing conceptual knowledge. This raises potentially important questions: is procedural knowledge (working problems) alone a reliable indicator of true understanding, and if not then what balance should course assessment try to reach between the two? Future iterations of this study will continue to look at the interplay between conceptual and procedural knowledge.

Teaching assistants seemed to manage the grading of the process problems well, especially considering the uniqueness of the assignment. Time spent grading these problems using the rubric doesn't seem atypical when compared to grading traditional problems with partial credit, though it may be a more mentally demanding endeavor. More data is needed, though, before an approximate grading time can be reliably predicted for these problems, which may vary depending on factors like previous grading experience and English language fluency among others. Ongoing studies are being conducted with other TAs who are non-native English speakers, and the grading rubric is still being tuned to facilitate ease and reliability in grading.

Subsequent iterations of this study are currently ongoing at this institution and other partner institutions to see if they yield similar results. The results and feedback from the pilot study discussed here will help to shape these studies going forward. For example, students in recent semesters have been given revised assignment instructions and a copy of the grading rubric,

moves intended to alleviate some frustrations with grading reported by students and TAs. Data will also be collected in the future to examine whether the process problem assignments favor certain demographic groups. Other adjustments will be made based on continued feedback from multiple parties involved in the study.

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Appendix A: Grading Rubric Used for the Process Problem Assignments*

Criteria	Full Credit (2 pts)	Partial Credit (1 pt)	No Credit (0 pts)
Has the student provided sufficient detail that another beginning Statics student could reproduce the approach to the solution?	Identify sequence by which unknowns are being found. Variables used in each equation are identified. Body or particle chosen for FBD is identified (if applicable).	One necessary step is missing or steps are slightly out of order. Variables used are not identified in one equation. Body or particle for FBD not clearly identified.	More than one necessary steps are missing or greatly unordered. Variables used are not identified for multiple equations.
Has the student demonstrated an understanding of what is being done in the solution process?	Approach described is fundamentally sound. Each equation used is described in words, not with algebra.	One error in the approach or distracting extraneous information. One equation described algebraically.	Multiple errors in approach. Multiple equations described algebraically.
Is the description written such that I can understand what the student means?	Description begins with the objective of the problem. Description no longer than ¾ page typed, single-spaced. Pronouns have clear meanings (each sentence is easily understandable).	Description does not begin with the objective of the problem. Description more than ¾ page, but less than 1 page. One or two sentences are not clear.	Description more than one full page typed. More than two sentences are not clear.
Is the description focused on the *approach* to the solution of this problem, not the specific numbers of the solution?	No problem-specific quantities are used in the description. Details are provided about solving this particular problem.	One problem-specific quantity is provided in the description. Description is about how to solve this type of problem in general.	More than one problem-specific quantities are provided in the description.

* Adapted from Hanson and Williams[4]. Note that the score for each criterion is determined based on the lowest scoring row in each. For example, for criterion 2, if the approach is fundamentally sound but there is one equation described algebraically, the score for that criterion would be 1 (partial credit).