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Changing Homework Achievement with Mechanix Pedagogy: Increasing the Efficacy of a Measurement Tool for Construction Majors

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Abstract

In online or large in-person course sections, instructors often adopt an online homework tool to alleviate the burden of grading. While these systems can quickly tell students whether they got a problem correct for a multiple-choice or numeric answer, they are unable to provide feedback on students' free body diagrams. As the process of sketching a free body diagram correctly is a foundational skill to solving engineering problems, the loss of feedback to the students in this area is a detriment to students.

To address the need for rapid feedback on students' free body diagram sketching, the research team developed an online, sketch-recognition system called Mechanix. This system allows students to sketch free body diagrams, including for trusses, and receive instant feedback on their sketches. The sketching feedback is ungraded. After the students have a correct sketch, they are then able to enter in the numeric answers for the problem and submit those for a grade. Thereby, the platform offers the grading convenience of other online homework systems but also helps the students develop their free body diagram sketching skills.

To assess the efficacy of this experimental system, standard concept inventories were administered pre- and post-semester for both experimental and control groups. The unfamiliarity or difficulty of some advanced problems in the Statics Concept Inventory, however, appeared to discourage students, and many would stop putting in any effort after a few problems that were especially challenging to solve. This effect was especially pronounced with the Construction majors versus the Mechanical Engineering majors in the test group. To address this tendency and therefore collect more complete pre- and post-semester concept inventory data, the research group worked on reordering the Statics Concept Inventory questions from more familiar to more challenging, based upon the past performance of the initial students taking the survey. This paper describes the process and results of the effort to reorder this instrument in order to increase Construction student participation and, therefore, the researchers' ability to measure the impact of the Mechanix system.

Introduction

To test the efficacy of any educational intervention, some sort of appropriate measurement system must be employed. Such a measurement system should correlate to the goals of the intervention. For this project, the goal of the investigation was to measure the efficacy of a novel sketch recognition interface in an online homework system. This efficacy was measured multiple ways: homework scores, test questions, and concept inventories. As this novel homework system was being tested in Statics and Statics-based courses, the Statics Concept Inventory (SCI) was selected for pre- and post-semester surveys of the students in both experimental and control groups. When faced with challenging questions on the SCI, some students appear to give up on being able to correctly solve the survey and either stopped or would very quickly enter random answers. By giving up on reading and answering the survey's questions, these students made data collection of the homework intervention's efficacy more difficult. This paper describes the efforts and results of the research team's reordering of the SCI to place the easier questions first in order to increase student responses.

Background

The original issue that this research project aimed to address was students' ability to accurately sketch free body diagrams. A common shortcoming in modern engineering education is producing students with insufficient experience in hand sketching [1]. In addition to being able to graphically communicate with others through hand sketching, engineers also are able to more deeply understand complex engineering topics by sketching them, with the reverse holding true. Kivimäki et al. [2] showed that such a lack of graphical communication skills impedes engineers' ability to reach their full innovation capabilities. The engineering education community is not blind to this shortcoming with multiple reports calling for the strengthening of both sketching and communication skills, such as [3] and [4]. This call must be balanced by the demands for students to learn modern software, such as computer-aided design (CAD), and limitations on the number of hours available to squeeze everything into the curriculum. In this balancing act, some studies have shown that instruction in CAD in lieu of hand drafting has no impact on students' ability to learn engineering concepts [5], while others argue that this option reduces curricular emphasis on hand sketching [6]. Martin-Erro et al. [7] further argue that sketching is a fundamental skill for facilitating creativity and visual thinking. Free body diagrams (FBDs), which are used extensively in both physics and engineering curricula, are often engineering students' most common forms of sketching and are foundational to students' understanding of these courses. While instructors can provide feedback to students on their FBD sketches as a part of grading pen and paper-based homework, this feedback is nonexistent with online homework systems that can only check numerical or multiple-choice answers. Through the use of online homework platforms, therefore, formative feedback on students' FBD sketching is severely limited or even absent.

This research project developed software called Mechanix to address this shortcoming of online homework systems. Mechanix was developed as a web-based software platform that used sketch recognition technology to provide immediate feedback to users. As immediate formative feedback has been shown to facilitate learning [8], Mechanix fills the gap of online homework platforms (and even the time gap of pen and paper homework) by giving formative feedback about FBD sketches. The program provides scaffolded learning to guide students in the right direction without being a step-by-step tutorial. This distinction is beneficial to learners as scaffolded learning, whereby students are given hints [but not the answer] when they make an error [9], is a proven tool to facilitate the learning of complex topics [10]. After students have successfully sketched the FBD for the problem, they are then able to enter in numeric answers, including units, into text boxes. Mechanix is able to evaluate both the numeric answer and unit of measure entered into the same box to provide feedback on whether the students answered correctly.

Two peer-reviewed concept inventories were selected to evaluate the extent to which this new software improved student learning. Concept inventories are especially well developed in the realm of Physics, with the Force Concept Inventory (FCI) being one of the most known of these tools [11]. The FCI evaluates the extent of the taker's knowledge in the area of Newtonian physics [12]. This instrument was selected as one of the study's pre- to post-semester survey assessment tools as Statics and statics-based Structural Analysis courses are based upon physics concepts. There is also a concept inventory called the Statics Concept Inventory (SCI), which was developed to assess knowledge of engineering statics courses [13]. The SCI was the second concept inventory used in the pre- to post-semester survey for this research project and turned out to have different results by university, which also coincided with differing majors, in this study. Specifically, the Construction majors participating in the study through a Structural Analysis course for Construction and Civil Engineering Technology majors that includes structural design, tended to stop taking the survey before completing it at a higher rate than the Mechanical Engineering or Aerospace Engineering majors who were participating in the study through a standard Engineering Statics course. Therefore, this paper presents the research team's efforts to increase the Construction majors' completion and performance on the SCI.

Methods

The SCI was administered as an online pre- and post-semester survey for this research project. Students completed the survey as a homework assignment for class, with the data from students who did not consent to participate in the research study removed prior to analysis. The five universities chosen for the study had been selected to introduce a diversity of student populations in order to look for any impacts based upon this diversity. For instance, the students at Universities 1 and 2 were Mechanical Engineering majors, those at University 4 were Mechanical and Aerospace Engineering majors, and at University 5, the students were a mixture of Construction Science and Management and Civil Engineering Technology majors. From early results, it was evident that the survey itself may have been organized in a detrimental way, with participants losing interest partway through the completion of the survey due to the overall length. Deeper analysis of the subcategories suggests that while some concepts are more difficult than others, students who with low performance at the beginning of instrument may lose motivation earlier into the completion of the survey if they encounter a group of especially unfamiliar or difficult questions. Students who lost motivation early tended to randomly fill out the survey, resulting in an overall lower score than they could possibly achieve if they had not lost motivation early into the completion process.

Graphical analysis of Fall 2019's post-semester sub-score breakdown (Figure 1) for University 1 showed that specific subcategories consistently have a lower score than the other subcategories. It was posited that the questions that were most frequently answered incorrectly were on statics concepts that were not covered in the targeted courses, and therefore, would not show a significant change in understanding from pre- to post-semester or between experimental and control groups. Conversely, the questions most frequently answered correctly were believed to be on the material the students were learning. As such, by placing the questions that would measure the actual impacts of the class first in the instrument, the reordering was believed to be better able to capture the changes in the students' conceptual understanding from pre- to post-semester. Further, because the students had learned the material during class, the questions on these topics may have appeared as easier questions to the students through their familiarity. With an improved instrument, the research team would then be better able to measure any differences between the control and experimental groups.

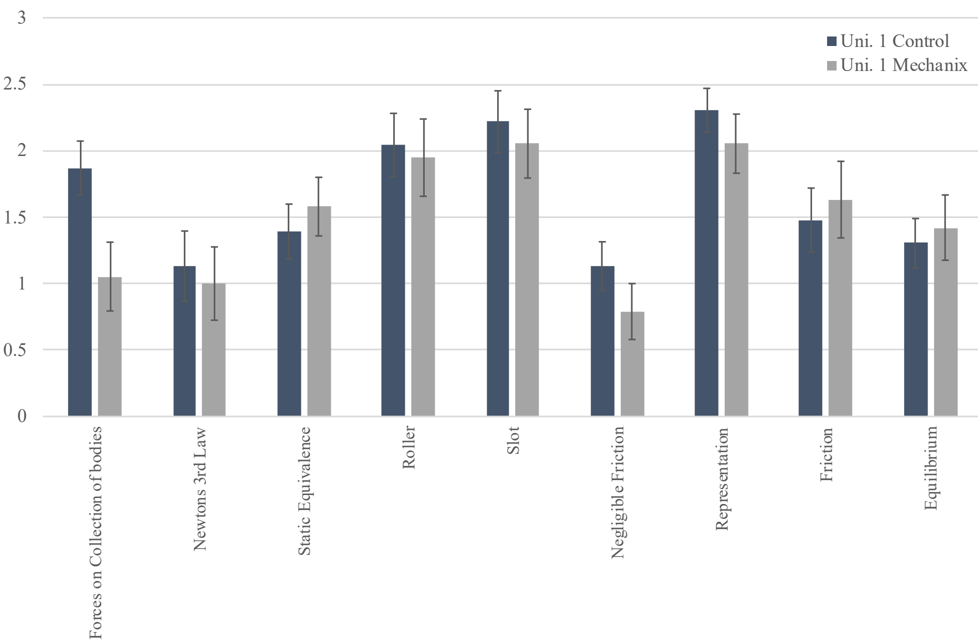

Figure 1: *SCI University 1 Sub-scores Breakdown: By analyzing the breakdown of the sub-scores, it was discovered that some problem types had a significantly higher result than others.*

The breakdown of the subcategories of the Fall 2019 University 1 results (Figure 1) were analyzed using an ANOVA, which used each of the subcategories as factors in the analysis. This quick analysis determined that three subcategories were answered correctly at a higher rate than the other six subcategories, suggesting that the question sets of the three subcategories are were on material covered in class or otherwise seemed easier to the students than others. This analysis also suggested that the SCI may not be an effective instrument if students are only familiar with a few of the topics covered due to the difficult and lengthy nature of the survey. Through focus group interactions with Construction students at University 5, it was determined that they saw little reason in completing the difficult problem sets when it meant a significant investment of time and energy. Due to this determination, the SCI was reordered following an approximation of the ease with which students completed the Concept Inventory subcategories. As students' perception of ease and difficulty were expected to be tied to familiarity with the concepts being analyzed, this reordering to put the "easier" problems earlier was a strategy to put the questions on topics covered in class earlier in the instrument so that meaningful data could be collected on changes in student understanding.

The reordered SCI survey was deployed to all schools following the Fall 2019 semester, except for University 3, which had already completed its participation in the study. The expectation was that students in groups that previously showed lower effort in completing the survey would complete more of the survey before losing their motivation to do their best. Clearly, students answering more questions with good effort would result in the instrument better reflecting the overall understanding of the students.

The reordered SCI was deployed in Spring 2020, Fall 2020, and Spring 2021 semesters. Differences between pre- and post-semester scores as well as between experimental and control groups were analyzed with two-tailed paired or two-sample t-tests, respectively, that assumed unequal variance. The Mechanix software was compared with a control group.

Results & Discussion

Unfortunately, the reordered SCI survey was first deployed during the Spring 2020 semester that featured a mid-semester shift to online instruction due to the COVID-19 pandemic. The impact of the COVID-19 pandemic on this project included a vast decrease in the overall participation rates across all instruments. This trend influenced a decrease in the statistical significance of the collected data points. Although the reordered survey was deployed to multiple schools in Spring 2020, only University 5's Construction students had a statistically significant increase in student performance on the reordered instrument ($t(63)=1.99$, $p= 0.049$). The other schools showed no statistical difference versus the original instrument. Considering the difference in majors, the reordering appeared to be an advantage to Construction majors, whereas the Mechanical Engineering majors were unaffected by the reordering. As there had been a sharp reduction in student participation in Spring 2020, additional semesters of data were collected to ascertain if this trend continued to hold true for a larger population.

There were two main distinctions between the Spring and Fall 2020 semesters, specifically: the difference in the participating population was increased due to more sections being taught by instructors involved in the study in the Fall 2020 semester, as well as the expectation that the passage of time would decrease the effects of COVID-19's effect on participation rates. With the Fall 2020 semester, many students returned to in-person or hybrid instruction rather than the fully online shift that occurred mid-Spring 2020. Allowing class time for the completion of surveys tends to increase participation rates, and therefore it was expected that more data would be collected. Fall 2020 scores were compared to Fall 2019 scores in order to have comparisons between semesters with the most similar instructional style to evaluate the impact of the reordered SCI. These results can be seen in Figure 2, which showed the same trend that was observed in Spring 2020, even with a larger sample size. University 5's Construction majors again benefited from the reordered SCI instrument, whereas the Mechanical Engineering and Aerospace Engineering students at other universities were unaffected by the change.

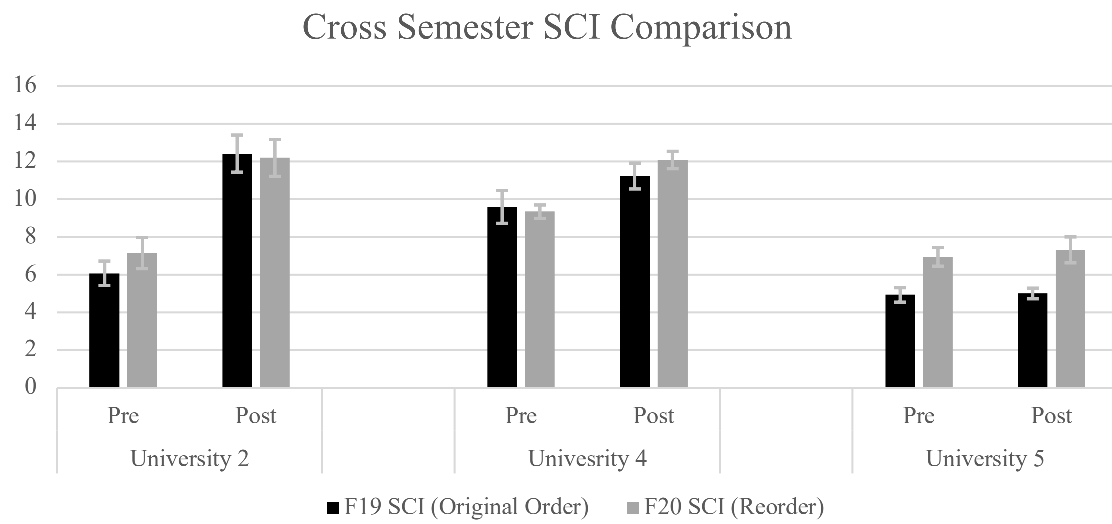

Figure 2: *F19 to F20 SCI Comparison: Within the semester, Universities 2 & 3 showed almost identical scores between the F19 and F20 semesters, but the Construction students at University 5 showed a significant improvement in scores with the reordered instrument..*

The reordered survey had a pronounced effect on the results of the student participants at University 5. While these students still scored slightly lower than the participants at the other universities involved in the study, they performed significantly better than previous participants within the school. A comparison of the Fall 2019 and Fall 2020 semesters shows that participants had increased scores from earlier to later semesters with a statistically significant difference in favor of the reordered data set ($t(91) = 3.11$, p-value=<.001). Further analysis was conducted with a comparison of the Fall 2019 data set and the combined data set of Fall 2020 and Spring 2021. A t-test assuming unequal variance showed growth in both conditions; however, the growth in the Mechanix condition is more significant than the other comparison. Analysis comparing the Post-semester SCI Mechanix conditions through a t-test assuming unequal variance confirms the significance of this data point ($t(91)=3.11$, $p=.0024$), in favor of the reordered SCI survey, and can be seen in Figure 3, with further significance shown in favor of the Mechanix group. These results indicate that the reordered survey did have a positive impact on student completion for Construction majors, meaning either more students had a greater understanding of the topics or more students had higher motivation in completing these surveys with the reordered questions. This trend is reflected in the other schools with Mechanical Engineering and General Engineering students as a trend in favor of the new order, however, the change at the other universities did not have statistical significance. The results at University 5 can be seen in Figure 3.

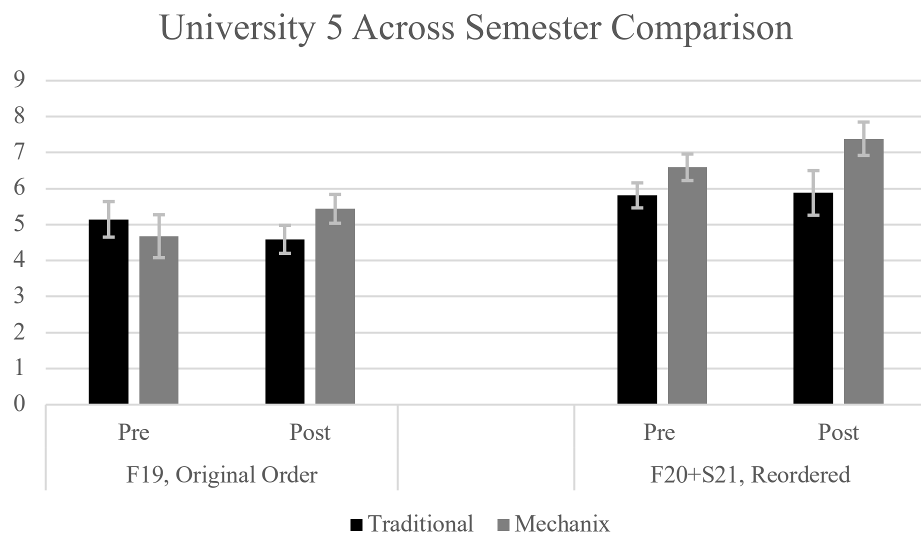

Figure 3: *University 5's SCI Score Comparison: Through the comparison of the F19 (original order) and the combined F20 and S21 data sets (new order) at University 5, it was discovered that the reordered SCI had a significant effect on student performance and understanding of the concepts. This may indicate that the original order may have had a negative impact on student motivation.*

Of note is that the course at University 5 that was involved in the study was not a traditional Statics course, but is instead Structural Analysis for Construction and Civil Engineering Technology majors, which spent over half of its class time on structural beam design in addition to statics concepts such as truss and cable analysis. The lower number of statics topics in the course is a likely contributor to the reason why there were smaller changes from pre- to post-semester performance on the SCI at this university.

Limitations & Future Work

There are a few notable limitations for this work. First, it would be useful to collect data at more universities with a particular focus on non-traditional students, first-generation, and other groups of students who may face extra challenges. We also only evaluated with this survey instrument when assigned as a low-stakes grade. In future work, it may be interesting to evaluate the impact if this assessment is made to be higher stakes, do students put in more effort? In this work, only focus group data was collected instead of using individual interviews or a think-aloud study of the instrument to better understand the behaviors observed. These additional modes of qualitative data collection would shed further light on the effects of re-ordering. The most useful ordering may also depend on the curriculum, since certain related topics may or may not be covered in a given program. Additionally, the reasons for the survey and the benefits to the students may not have been explained well enough or it may be beneficial to illustrate how these abstracted problems can relate to real-world knowledge.

Conclusions

This study showed that the reordered SCI resulted in improved scores in Construction (both Construction Science and Management and Civil Engineering Technology) majors at University 5 in a Structural Analysis course within the construction program. While the Mechanical and

Aerospace Engineering majors in traditional Statics classes at other universities showed a trend towards increased scores, those improvements were not statistically different than the original order of the SCI questions. Future work could collect larger sample sizes in traditional Statics classes. Combining these findings with the focus group revelation that many Construction majors failed to see the point in completing the research surveys, point towards the trend that students who may have lower levels of math preparation, and/or have lower motivation to perform at their best on a research survey persist in taking more of the SCI when the topics that are covered in an undergraduate level Statics course are asked first. To strengthen these findings, the reordered versus original order SCI should be tested in additional construction programs.

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