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Feedback from In-class Worksheets and Discussion Improves Performance on the Statics Concept Inventory*

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The Statics Concept Inventory (SCI) is used to evaluate students' conceptual understanding in introductory mechanics courses. Previous studies have shown that although performance on the SCI improves at the end of a course, performance is often still unsatisfactory with scores well below 100%. In this study, we sought to determine if providing feedback on conceptual topics through in-class worksheets and discussion would improve students' performance on the SCI. To test this hypothesis, we designed eight multiple-choice worksheets, each inspired by a different topic on the SCI, for use during an introductory mechanics course. In order to evaluate the impact of the worksheets on SCI performance, we divided the eight worksheets into two groups and each group of worksheets was deployed in a different offering of the course. Each worksheet was completed at the end of a class period and, at the beginning of the next class period, the instructor led a discussion of the results and common misconceptions on each worksheet. Students took the SCI at the beginning and end of the course and the change in SCI scores for topics with and without worksheets were compared. Results from both course offerings indicated that the in-class worksheets were effective at improving performance on the SCI, as SCI scores improved significantly more for topics that had worksheets than the topics that did not have worksheets. Furthermore, overall SCI performance at the end of each course was greater than in previous courses. These results suggest that a quick and easy-to-implement addition to the curriculum using in-class worksheets and next-class discussion were effective at providing feedback on conceptual topics, exposing misconceptions, and improving performance on the SCI. The worksheets developed as part of this study are available on-line for other instructors to use (http://del.stanford.edu). The SCI is also free to use and can be found at cihub.org.

Keywords: concept inventory; statics, assessment; feedback; conceptual understanding

1. Introduction

Concept inventories are a useful tool to evaluate students' understanding of important concepts and identify common misconceptions [1–3]. Traditionally, concept inventories have been given as a test at the beginning and/or end of a course. At the beginning of a course, results from a concept inventory such as the Statics Concept Inventory (SCI) can be used by instructors to evaluate students' prior knowledge. At the end of a course, instructors often use the results as a summative assessment to evaluate their teaching, assess student performance, and/or modify material for future courses. However, prior research has suggested that concept inventories can similarly be used to provide students with formative assessment during a course [4, 5]. By providing timely feedback, identifying misconceptions, and serving as a platform for discussion, using concept inventories for formative assessment may help students further improve their conceptual understanding. The aim of this study was to determine if integrating questions inspired by the SCI into the classroom via in-class worksheets and discussion improves student comprehension of statics concepts.

Providing timely feedback through formative assessment has been emphasized as important for student learning [4, 6, 7]. Previous studies have shown that feedback can be especially effective at addressing misconceptions [8]. Hattie and Timperley (2007) found that feedback is most powerful when it provides cues that students can use to identify and recognize faulty interpretations and structure future learning [4]. Applied to conceptual understanding, feedback should help students identify and recognize their own misconceptions and provide examples that can be used to reinforce new concepts. In physics, incorporating conceptual problems into the classroom has been important for improving performance on the Force Concept Inventory (FCI). Crouch and Mazur (2001) demonstrated that short ConcepTests used daily in class contributed to improvements on the FCI [9]. These tests consisted of single, multiple-choice conceptual questions that probed students' understanding and served as a foundation for in-class discussion. FCI scores improved from a normalized gain of 0.23 to 0.49 with ConcepTests and peer instruction methods. These results indicate that ConcepTests can provide valuable feedback to improve students' conceptual understanding in physics.

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Inspired by the FCI, the Statics Concept Inventory (SCI) was designed to evaluate student's conceptual understanding in nine topics covered in most introductory statics and mechanics courses [3]. Previous studies have shown that student performance improves on the SCI at the end of a course [10]; however, performance is often well below 100% with average scores between 43% and 76% [10, 11]. These results suggest that students' have lingering misconceptions and that better strategies are needed to correct misconceptions during the course.

The SCI has traditionally been used to evaluate performance at the beginning and end of a course. Steif and colleagues (2005, 2007) have suggested that using the SCI for in-class activities to diagnose misconceptions may improve conceptual understanding [3, 12]. Previous surveys have indicated that students *believe* that in-class conceptual quizzes [13, 14] and review sessions that incorporate conceptual questions [15] can improve conceptual understanding. For example, Steif and Hansen (2006) offered a review session before the final exam that covered five concepts from the SCI in which the students had performed poorly [15]. A survey revealed that the students believed the review session helped them develop better understanding of the concepts and would help them do better on the final exam; however, the impact of conceptual questions on SCI scores has not been evaluated. More recently Brose and Kautz (2011) implemented weekly worksheets focused on the static equivalence topic of the SCI which included a series of qualitative questions and tasks. They found that static equivalence scores on the SCI improved, although overall performance on the SCI remained below 50% at the end of the course [11].

Extending methods such as ConcepTests, in-class discussions, or worksheets to statics courses may further improve student performance and conceptual understanding. Statics is a foundational engineering subject; identifying and correcting statics misconceptions at an early stage is critical for students' future success [16]. The aim of our study was to design a curricular feedback loop that could improve conceptual understanding and to evaluate the efficacy of these methods in improving performance on the SCI. To this end, we designed eight multiple-choice, in-class worksheets, each of which was inspired by a topic on the SCI. To test the efficacy of the worksheets, we implemented the worksheets over two consecutive offerings of an introductory statics course. The first four worksheets were implemented during the fall offering of the course, and the other four worksheets were implemented during the winter offering. Worksheets covered a single topic and were distributed and collected at the end of a class period, with feedback and discussion occurring at the beginning of the next class period. We compared improvement on the SCI at the end of each course offering for the topics with and without worksheets. We also compared improvement on the SCI at the end of each course offering with improvement on the SCI in previous offerings. Results of this study suggest that providing feedback using in-class worksheets and subsequent classroom discussion can significantly improve performance on the SCI.

2. Methods

2.1 Course Structure

This study was implemented in two courses offerings (fall 2011 and winter 2012) of a ten-week long introductory statics course taught at a private suburban university. Each course was taught by the same lead instructor who has over 20 years of experience teaching statics and introductory mechanics. The instructor had used the SCI at the end of previous courses. Each course consisted of 75 students (Table 1) with similar demographics and educational backgrounds. The majority of the students were sophomore or junior engineering students. In each course, there were two students who were retaking the course; for all other students, the course typically represented their first exposure to statics and solid mechanics within the engineering curriculum and, for some, to engineering in general. The course met for two hours, two times per week and consisted of a mix of lecture, problem solving, and laboratory activities. Approval to perform this study was received by the institution's review board for human subjects' research.

2.2 Statics concept inventory (SCI)

The previously developed SCI [3, 10] consists of nine topics: (1) static equivalence, (2) static equilibrium,

Table 1. Course characteristics

	N	Completed SCI* N (%)	Year freshman/sophomore/junior/senior
Course A (Fall 2011)	75	65 (87%)	2/46/15/2
Course B (Winter 2012)	75	50 (67%)	7/37/3/3

* Students completing the SCI at both the beginning and end of the course.

(3) roller joints, (4) drawing forces on separated bodies (free body diagrams), (5) pin-in-slot joints, (6) Newton's 3rd law, (7) loads at surfaces with negligible friction (negligible friction), (8) representing loads at connections (representing unknown loads), and (9) limits on friction force. For each topic, the SCI includes three multiple-choice questions designed to test conceptual understanding and identify common misconceptions. The individual SCI topics have also previously been shown to be valid and reliable [15]. The ten-week course involved in this study did not cover topic (9) limits on friction force, so we excluded this topic from the study.

The students completed the SCI at the beginning and end of the course as part of the first and last homework assignments. Completion of the SCI, but not the score on the SCI, was incorporated into each student's grade. In Course A, 87% of students completed the SCI at the beginning and end of the course; however, in Course B a lower percentage, 67%, completed the SCI at the beginning and end of the course.

The students completed the SCI on-line at www.cihub.org, a free on-line repository for concept inventories. Completing the SCI on-line minimizes the amount of class time required and gives the students flexibility in when and how long they take to complete the inventory; however, this flexibility also reduces our knowledge of the conditions under which the SCI was completed. After completing the SCI, the students received a summary of their overall score, their score for each topic, and a brief description of each topic.

2.3 Worksheet intervention

We developed eight in-class, paper-based worksheets to provide the students with feedback on their conceptual understanding of core statics topics. Each worksheet consisted of two or three multiple choice questions inspired by a topic on the SCI (see sample question in Fig. 1) and was designed to take roughly five minutes to complete. The worksheets were developed with a team of engineering students and faculty familiar with the course material and the SCI; however, the instructor for the course was not involved in the worksheet development to avoid "teaching to the test." Each worksheet was designed to provide examples of conceptual questions similar in format, but not identical, to the SCI that could serve as a framework for evaluating students' understanding, providing the instructor with quantitative feedback, and facilitating in-class discussion of common misconceptions. For example, Fig. 1 shows an example of a question from the static equivalence topic which is similar to questions on the SCI and evaluates three common misconceptions. On this worksheet, the most common misconception was option (B), moving a couple changes the moment that it exerts. This insight helped the instructor guide the follow-up discussion. The overarching goal of these worksheets was to provide a quick and effective method for providing feedback on conceptual topics throughout the course.

The worksheets were distributed, completed individually, and collected in-class. To provide feedback, the results were compiled and shared at the beginning of the next class, followed by a discussion of common misconceptions. The total time to implement each worksheet was approximately 15 minutes—5 minutes for students to complete the worksheet and 10 minutes of discussion in the following class. Classes met on Tuesday and Thursday, so a minimum of 48 hours passed between when the students completed the worksheet and the in-class discussion. For the first course offering, Course A, worksheets were deployed for the static equivalence, static equilibrium, roller joints, and free body diagram topics, and for the second course offering, Course B, worksheets were deployed for the pin-in-slot joints, negligible friction, Newton's 3rd law, and representing unknown loads topics. This division of topics was chosen such that the two groups of topics had similar levels of difficulty, as based upon performance on the SCI at the end of two previous courses (fall 2008 and fall 2010). The order and timing of the worksheets were designed to align with the syllabus of the course

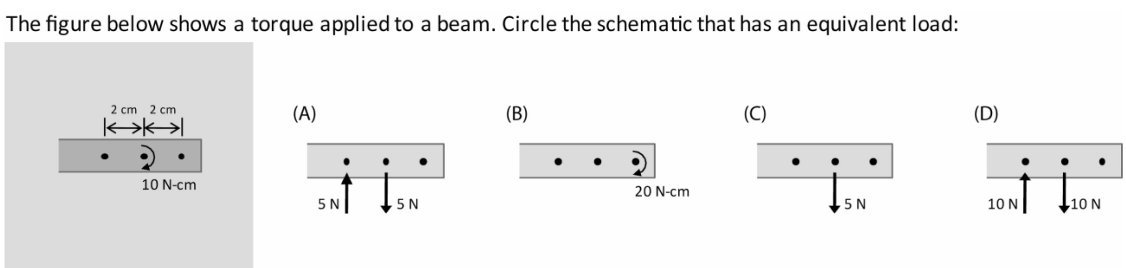

Fig. 1. Sample worksheet question inspired by the static equivalence topic of the SCI. The correct answer is (A) while the alternative answers correspond to common misconceptions including: (B) moving a torque changes the magnitude, (C) a single force can replace a torque, and (C) miscalculation of equivalent couple.

Table 2. Deployment of SCI and worksheets during 10-week course

Week	Course A	Course B
1	**Statics Concept Inventory**	**Statics Concept Inventory**
2	A1) Static equivalence	
3	A2) Static equilibrium	
4		B1) Pin-in-slot joint
5	A3) Roller joint	B2) Negligible friction
6		
7	A4) Free body diagrams	B3) Newton's 3rd Law
8		B4) Representing unknown loads
9		
10	**Statics Concept Inventory**	**Statics Concept Inventory**

(Table 2) such that the worksheets were provided after each topic had been covered.

2.4 Analysis

To determine if the worksheets improved outcomes on the SCI, we compared the change in SCI scores for the topics with and without worksheets. For each student, we calculated the average change in SCI scores for each topic between the beginning and end of the course. We then calculated the average change in each student's responses for the topics with worksheets and for the topics without worksheets. The change in scores for the topics with and without worksheets was compared using the Mann-Whitney U-Test, the non-parametric equivalent of the two independent sample t-test. By testing four topics in Course A and the other four topics in Course B, we were also able to determine if changes in SCI scores were repeatable and independent of which topics had worksheets in each course.

Average scores on the SCI were compared for the beginning of Course A and Course B and for the end of Course A and Course B. The scores on the SCI at the end of Courses A and B were also compared with scores from two previous course offerings taught by the same instructor (previous course offerings did not take the SCI at the beginning of the course). We conducted these analyses using the non-parametric Wilcoxon Signed Rank Test. Finally, we calculated the Spearman's rank correlation coefficients between the SCI scores at the beginning and end of the course for all topics, and between the topics with and without worksheets. The cut-off significance level for all hypothesis testing was defined as 0.05.

2.5 Study limitations

An important limitation of this study is that we measured conceptual understanding by performance on the SCI while the in-class worksheets were also inspired by the SCI. As such, the worksheets may have helped students develop greater familiarity with questions on the SCI, rather than improving their underlying conceptual understanding. Additionally, after completing the study, we evaluated the Cronbach's alpha for the questions on each worksheet and the alpha values were generally low and variable between topics (Table 3). This variability suggests that the worksheets may have covered multiple concepts within each topic and could be improved in the future by adding more questions or focusing the concepts included on each worksheet.

Table 3. Cronbach's alpha of worksheets

Topic	alpha
Static equivalence	0.16
Static equilibrium	0.38
Roller joint	0.73
Free body diagrams	0.73
Pin-in-slot joint	0.42
Negligible friction	0.37
Newton's 3rd law	0.42
Representing unknown loads	0.64

The worksheets were also tested at a single, highly selective institution and implemented by a single instructor. The instructor included in this study leads an interactive and engaging classroom that includes hands-on activities and peer instruction methods. These methods have previously been found to improve performance on concept inventories [17, 19, 20] and may confound the results of this study. The SCI scores at the end of Course A, Course B, and previous course offerings by this instructor were also higher than average scores reported in the literature. Additional research is needed to assess the effectiveness of worksheets in different classroom and university environments.

3. Results

3.1 SCI beginning of course

The average scores, based on a scale of 1–100, at the beginning of the courses were $23 \pm 13\%$ for Course A and $27 \pm 13\%$ for Course B, respectively – slightly better than chance (20% for questions with five choices; see Column A of Fig. 2). There was no statistically significant difference in the scores at the beginning of Course A and Course B. In both courses, the students performed significantly better than chance on the roller joints and pin-in-slot joints topics at the beginning of the course ($p < 0.001$ for both) which may reflect prior knowledge from prerequisite physics courses. The students performed significantly worse than chance on the negligible friction questions ($p = 0.001$) which may reflect strong underlying misconceptions from previous courses or personal experience.

3.2 SCI end of course

Students' performance on the SCI at the end of both

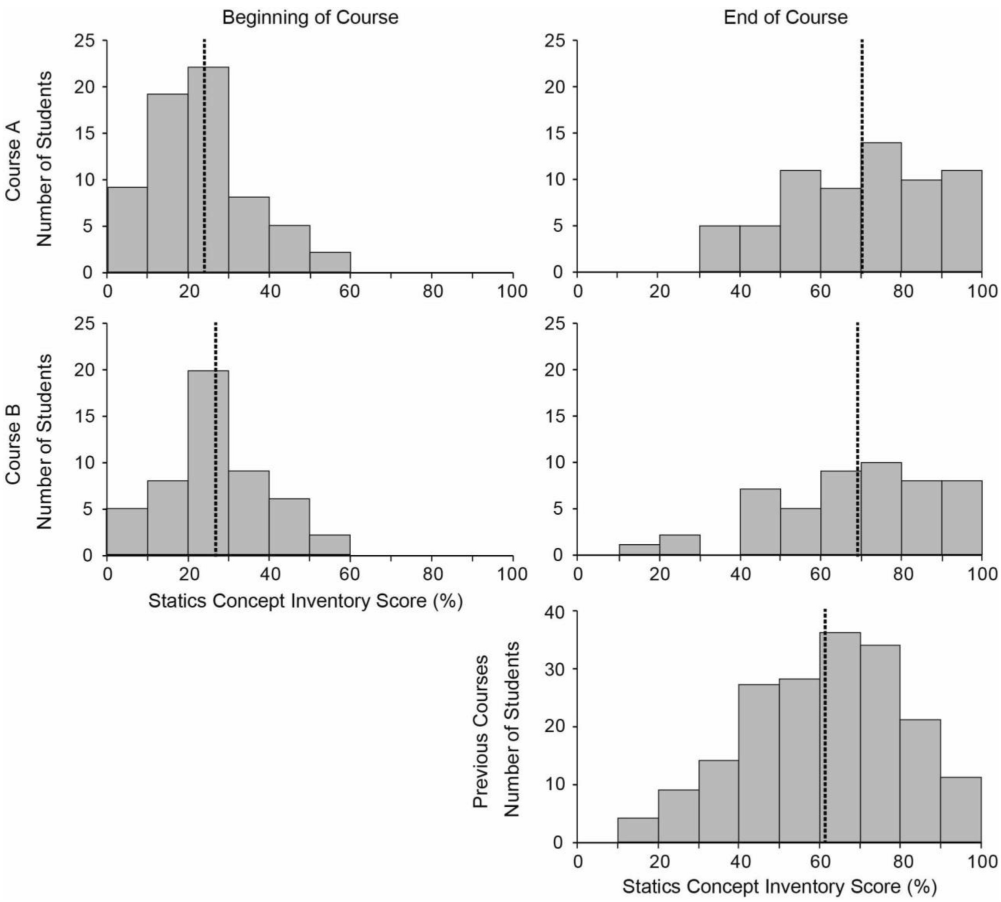

Fig. 2. Histogram of students' performance on the SCI at the beginning (left) and the end (right) of the course for Courses A and B, and (bottom right Fig.) at the end of previous courses. The dotted line indicates the average for each course. The average SCI score at the beginning of Courses A and B were 23 ± 13% and 27 ± 13%, respectively. At the end of the course, the average SCI score was 70 ± 18% for Course A and 69 ± 19% for Course B compared to 61 ± 19% in previous courses.

courses was significantly better than in previous offerings ($p < 0.001$), with an average score at the end of the course of 70 ± 18% in Course A and 69 ± 19% in Course B, as compared to 61 ± 19% in previous courses (see Column B of Fig. 2). There was no significant difference between the final scores for Course A and Course B, and performance on all topics was significantly better than chance at the end of the course.

3.3 Change in SCI scores

At the end of both course offerings, performance on the SCI improved more for the topics with worksheets than the topics without worksheets (Fig. 3A). In Course A, performance on the topics with worksheets improved by 52 percentage points versus 42 percentage points for the topics without worksheets ($p = 0.002$), while in Course B performance on the topics with worksheets improved by 46 percentage points versus 38 percentage points for the topics without worksheets ($p = 0.019$). Based upon these changes, the effect size for the worksheets as determined by Cohen's d was 3.9 for Course A and 2.8 for Course B.

3.4 Comparison of worksheet scores and SCI scores

Scores on the in-class worksheets were significantly better than performance on the SCI at the beginning of the course for all eight topics (Fig. 3B), suggesting that the students had increased their knowledge on each topic during the course in the time before each worksheet was implemented. It is also instructive to look at differences between worksheet scores and final SCI topic scores. At the end of Course A, performance on the SCI was significantly better than the worksheet scores for three out of four of the topics; however, scores on the static equilibrium topic at the end of the course were significantly lower than on the worksheet. At the end of Course B, scores on the SCI were significantly better than worksheet scores for two of the topics (the pin-in-slot and negligible friction topics), but did not change significantly from the worksheet scores for

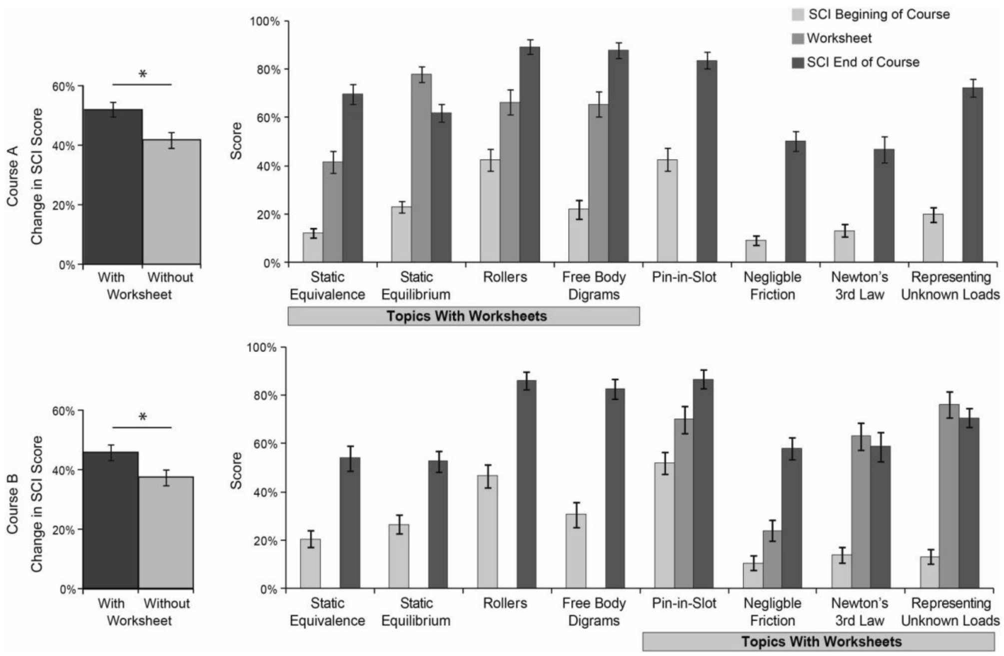

Fig. 3. (Left) Average change in SCI scores at the end of the course for the topics with and without worksheets (*, $p < 0.05$). (Right) Comparison of SCI scores at the beginning and end of the course and worksheet scores for each topic.

the representing unknown loads and Netwon's 3rd law topics. Therefore, on five of the eight topics, students' performance was significantly better on the SCI at the end of the course than on the worksheet, suggesting that for these topics, the in-class worksheet and associated in-class discussion resulted in improved conceptual understanding which was maintained at the end of the course.

3.5 Correlation of beginning and end of course SCI scores

Similar to previous studies [10, 12], scores on the SCI at the end of the course showed a significant, moderate correlation with scores at the start of the course (Spearman's rho = 0.41, $p < 0.001$) and with final course grades (Spearman's rho = 0.48, $p < 0.001$). Although SCI scores on the topics *without* worksheets were correlated (Spearman's rho = 0.48, $p < 0.001$) at the start and end of the course, scores on the topics *with* worksheets were not significantly correlated (Spearman's rho = 0.18, $p > 0.05$). Thus, students who performed better at the beginning of the course were more likely to perform better at the end of the course for the topics without worksheets, but for the topics with worksheets, performance was no longer predicted by performance at the beginning of the course. These results suggest that the worksheets and in-class discussion may have served as an equalizer between higher and lower performing students.

4. Discussion

In-class worksheets and discussion were effective at providing feedback and improving student performance on the SCI at the end of an introductory statics course. This study followed the model set forth by previous researchers of integrating short conceptual questions into an interactive classroom [4, 5, 17]. These results reinforce the positive effects that feedback and discussion of misconceptions can have on student performance and provide a foundation for further development.

These worksheets were easy to implement and took minimal class time for the instructor but produced significant improvements in SCI performance. The overall amount of in-class time spent on the worksheets was about 15 minutes per worksheet—5 minutes for the students to complete the worksheet and 10 minutes to discuss the worksheet at the beginning of the next class—for a total of approximately one hour over the entire course. The performance gains for such a small investment of time were significant, but the time commitment was far less than the one-third to one-half of class time used by Crouch and Mazur on ConcepTests [5, 9].

We also found that the correlation between SCI scores at the beginning and end of each course was significantly reduced for topics with worksheets versus topics without worksheets. This result suggests that the worksheets helped all students, but especially those who had lower scores at the beginning of the course. Higher performing students may not need worksheets as much to guide their self-evaluation of misconceptions, but the extra guidance provided by the worksheets and discussion may help lower performing students' realize and correct their misconceptions. Larger gains for lower performing students have also been reported from other instructional techniques such as cooperation and collaborative learning models [18].

Although overall performance improved on the SCI, there are still opportunities for further refinement and improvement. The scores on the SCI for three topics (static equilibrium, representing unknown loads, and Newton's 3rd law) did not improve between the worksheet and the SCI at the end of the course. Although scores on all three of these topics were higher on the worksheet than on the SCI at the beginning of the course, there were no further improvements after the in-class discussion. These results could be due to a variety of factors such as persistent misconceptions that were not overcome by the in-class discussion, confusion later in the course after additional material had been covered, or insufficient practice to retain concepts till the end of the course. Revisiting these topics through multiple worksheets [11], providing iterative feedback [21], or implementing hands-on demonstrations [19] may help students further improve performance on these topics. For example, the worksheets included in this study could be paired with open-ended problem-solving or hands-on activities to examine transfer to new situations. The work of Parikh (2011) gives examples of such hands-on problems in heat transfer which may guide development for similar activities in statics [24].

Determining the optimal amount of time between when students complete a worksheet and when they receive feedback could also increase the gains from in-class worksheets. Previous studies have suggested that timing is a critical component that impacts the efficacy of feedback [4, 7, 22]. In our study, there was a delay of at least 48 hours between when the students completed the worksheets and received feedback in the next class. However, immediate and iterative feedback has been suggested to enhance the impact of feedback [21]. Integrating worksheets into think-pair-share exercises with in-class response systems such as clickers or flashcards may further improve student's performance on the SCI [14, 23]. Chen and colleagues (2010) implemented clickers and flashcards in a statics course and found that both of these methods were equally effective in improving scores on in-class quizzes [23]. Testing if rapid feedback using clickers or flashcards produce greater improvements in SCI scores is a promising avenue for further research and will help optimize the use of feedback to improve conceptual understanding.

The effect of in-class worksheets and other instructional methods should also be tested with multiple instruments for evaluating conceptual understanding. Our study suggests that in-class worksheets improved performance on the SCI; however, a stronger link between transferable conceptual knowledge and SCI performance would further enhance our instructional methods. There was a moderate correlation between the Cronbach's alpha calculated for each worksheet and the final SCI score for the corresponding topic. Although the correlation was not statistically significant (Spearman's rho = 0.71, $p = 0.06$), this finding suggests that improving the content and reliability of the worksheets might improve student performance on the SCI. Including more questions, integrating other activities, and evaluating conceptual understanding with additional tools beyond the SCI may further improve our ability to enhance students' conceptual understanding.

To facilitate further development of the methods and ideas presented in this study, we have made the worksheets and other materials freely available on-line (http://del.stanford.edu) for other instructors, researchers, and students to use. The SCI is also freely available for instructors to use (www.cihub.org) [12].

5. Conclusion

We determined that a quick and easy-to-implement method integrating conceptual questions, feedback, and classroom discussion improves performance on the SCI. In-class worksheets and next-class discussion inspired by the SCI significantly improved performance on the SCI at the end of the course. We have made the worksheets and other material developed as part of this study freely available on-line for other instructors and researchers to use. Our aim with this study and future work is to develop student- and instructor-friendly methods that will efficiently improve student comprehension of core engineering knowledge.

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