Advances in Engineering Education

SPRING 2017

Effectiveness of Just In Time Teaching on Student Achievement in an Introductory Thermodynamics Course

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ABSTRACT

The utility of Just-In-Time-Teaching (JITT) is compared across course topics and groups of students not receiving JITT exercises in class. JITT feedback incorporated various active learning exercises based on students' performance on online homework problems from Sapling Learning. With over 200 students in two sections participating in the sophomore level introductory thermodynamics course, student performance was evaluated on in-class quiz and exam problems. Student performance covering a specific course topic subsequently reinforced by a JITT exercise was found to be measurably higher (>9%) than a control group who did not receive the JITT review. Overall, comparing student achievement across five topics covered by JITT compared with five different course topics not covered by JITT did show small positive outcomes. The improvements after using JITT exercises included a higher median and 3rd quartile scores, so JITT may be beneficial to mid-performing students. Overall, student feedback on the JITT reviews showed that over 85% of the students thought the JITT exercises were helpful for engagement and a good use of class time.

Key words: Just-in-time-teaching, thermodynamics, Sapling Learning

INTRODUCTION

Active learning encompasses a large set of pedagogies that engage students in the classroom [1-3]. Recently, the integration of technology with active learning has provided educators with quantifiable data sets on the effectiveness of different active learning techniques. For example, students responding via electronic clickers improved in their conceptual understanding in sciences and engineering [2,4-6]. In this work, the technology is an outside of the classroom online homework platform that provides the instructors data to complete just-in-time-teaching exercises related to difficulties in the homework.

Just-In-Time-Teaching (JITT) defines a set of active learning pedagogies [7,8]. JITT can be used to clarify new concepts and eliminate misconceptions by linking work students do prior to class with classroom exercises, explanations, and lectures. Developed to engage students in class and provide real time feedback [8], the use of JITT has spread to many diverse disciplines; however, few engineering applications have been published [7,9].

In general, JITT builds cognitive and metacognitive skills using a number of established learning principles, which will be briefly summarized here. JITT provides a flexible, but structured mechanism for the students to complete work, usually outside of class, that provides the instructor feedback on learning gaps. Then the instructor can use class time to provide feedback through additional student-centered activities. A number of examples tying research on learning [10-12] to the suite of JITT techniques can be found in the books and journals [7-9,13-15]. For example, presenting the aggregate student responses to the class, a misconception may be identified for the majority of the class. Then an exercise can be completed to repair the misconception while simultaneously building the students' metacognitive skills [16-18]. Overall, many new technologies can provide instructors with real time data to identify learning gaps and instruction can then focus on building a more complete understanding of the subject, which has been applied across a range of teaching styles, courses, and learning environments [7].

In order to deliver just-in-time teaching, data must be collected to measure the understanding of the students on recent material. While a growing body of literature involves concept questions and clicker-based responses [2-6,16,19-23], online homework provided the quantitative assessment in this study [24,25]. The authors worked with Sapling Learning© to implement over 150 new problems for the introductory thermodynamics course. While numerous online homework tools exist for basic science courses, such as freshman chemistry or physics (see any major publisher), the availability for engineering courses is much more limited. Having experience teaching the thermodynamics course over many years, the authors had a collection of problems that they had authored and uploaded using Sapling's authoring environment. The authoring process is beyond the scope of this work, but the salient features of the online homework environment will be detailed next.

Our implementation of JITT has students completing online homework using Sapling Learning. Online problems are graded as they are completed so that the student gets immediate feedback and the instructors can track the overall class success and/or problem areas before the class meets. Instructors reviewed assignments approximately 2 hours prior to class and developed problems to be presented as in-class exercises or mini-lectures. Students, working in groups of 2 or 3, then worked the in-class problem followed by an instructor explanation and solution. Key concepts were emphasized and explained, and common misconceptions and errors were noted and corrected. This paper discusses using real time online homework data with JITT to improve student achievement on quizzes and exams.

METHODOLOGY

Several features of online homework provide an advantage over traditional paper homework from a textbook (Figure 1). First, the problems contain rolling numbers or choices so each student has a slightly different set of problems. Rolling the numbers helps to avoid the usage of "textbook" solution manuals and their availability to students has been discussed in recent years [9,26]. Rolling numbers are easy to implement for algorithm problems, but changing numeric values is more challenging when physical properties are needed. Implementing at least three sets of numbers for problems involving tabular data (i.e., steam tables) provided enough variation with the goal of discouraging students from copying answers from other students. Having rolling numbers on exams has led to a number of academic dishonesty cases in the authors' experience. By having students work on their own numerical solution, the focus is more on problem solving and learning than on getting the correct answer, which adheres to the authors' teaching philosophy.

Next, the problems contain hints to help the students complete the problems without synchronous intervention by the instructor(s). Hints are normally viewed after an unsuccessful attempt to answer the question. While unsuccessful attempts lead to a small penalty (10% per attempt in our implementation), multiple attempts encourage persistence and likely improves learning [25]. Finally, the problems are automatically graded so both the student and instructor receive immediate feedback. Figure 1 shows a screen shot of a typical Sapling problem and illustrates which of the numbers are changed for the individual student.

With the online homework being graded as students complete each problem, the instructor can monitor both individual and the class's progress and success. One week between assigning the homework and its due date allowed the instructors to report the percentage of students starting the first problem to the class two to five days before the due date. Reporting the percent of students starting the homework during a class period served as a nice reminder to not wait until the last day to start, but this reporting process was not examined in detail.

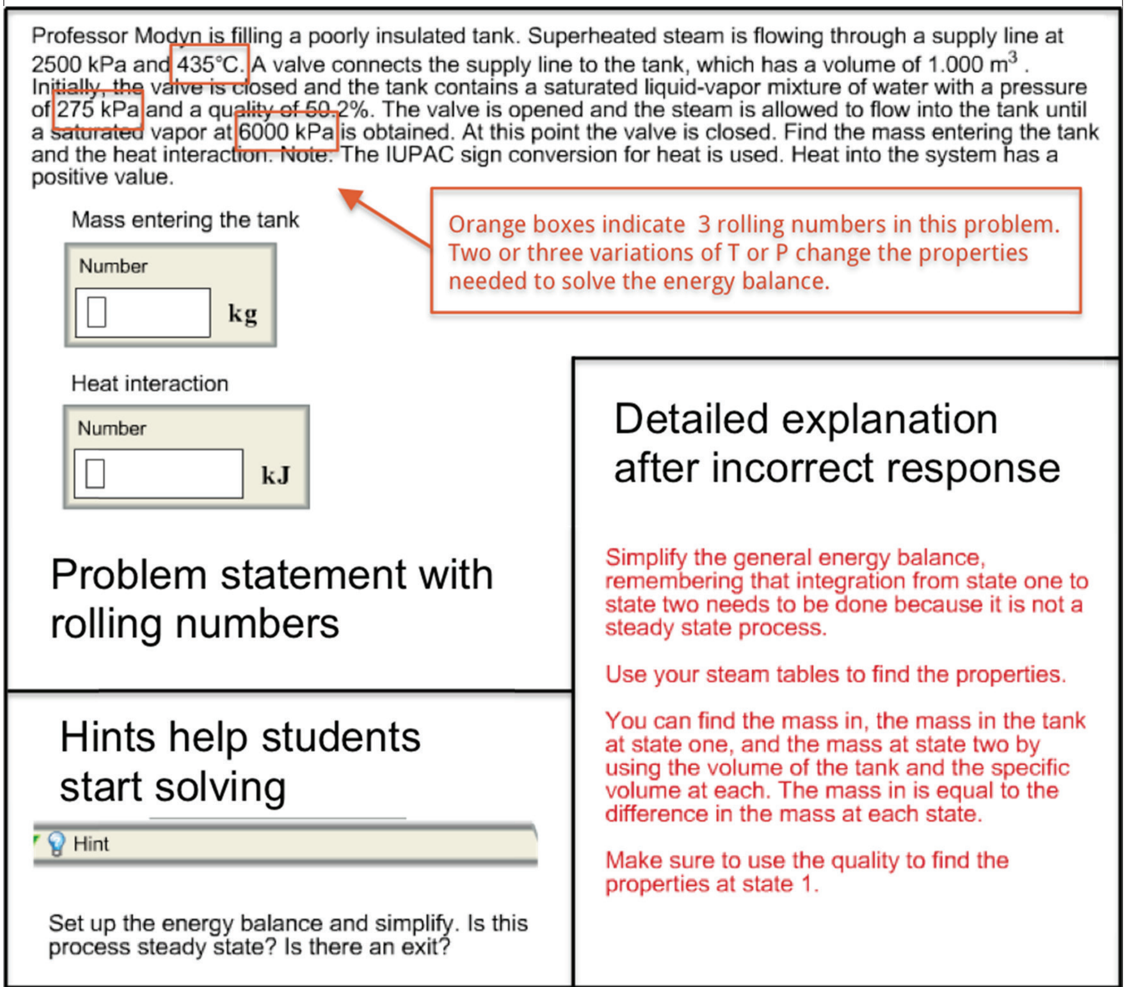

Figure 1. Three screenshots of a tank filling problem from a thermodynamics course on Sapling Learning. The problem statement contains rolling numbers (top), hints (bottom left), and feedback for incorrect answers (bottom right).

The Sapling grade system presents two qualitative assessments of the students' success as well as quantitative data. First, a color-coded horizontal bar graph for each question can be viewed in the activity editor (Figure 2). Specifically, the size of the green bar correlates with the percent of students correctly solving the problem, orange signifies the percentage of students answering incorrectly, and white represents the fraction of the class that did not attempt the problem. Second, the grade book summarizes the success on each column with a single color (e.g., slightly different shades of green in Figure 2) as well as a colored box for each question and individual student. Quickly scanning the colored grid for the entire class can help an instructor determine individual or groups

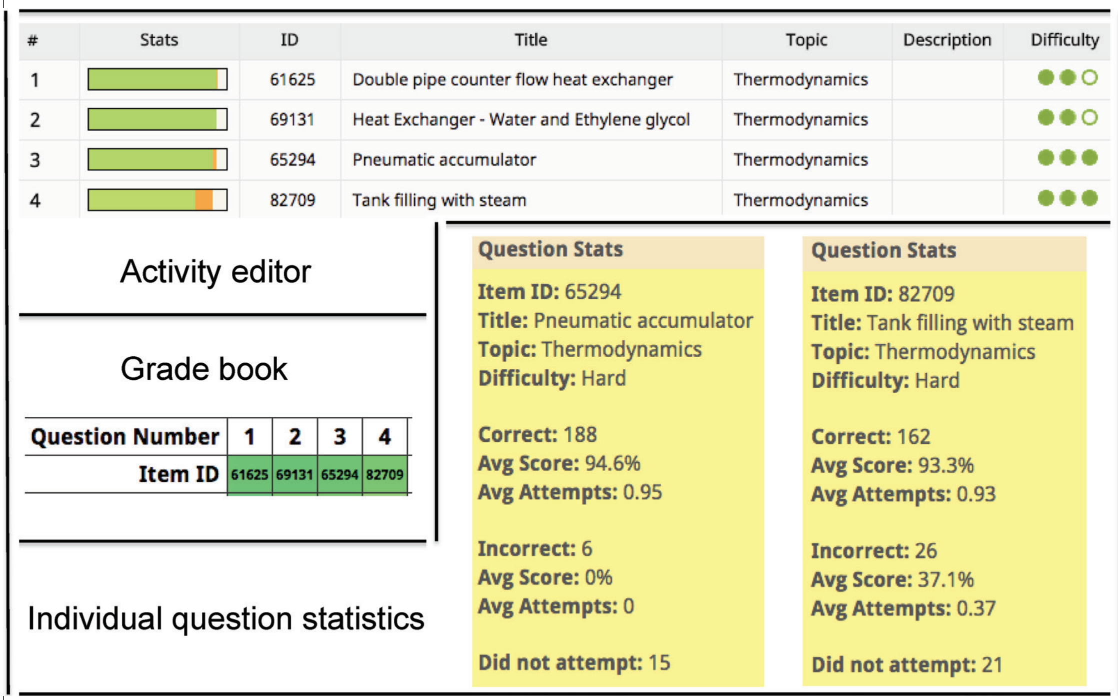

Figure 2. Screenshots of the assessment of homework problems in Sapling Learning. The activity editor shows progress of the class under stats (top). The grade book gives a color coded summary (middle left), and the individual question statistics quantify correct, incorrect, and did not attempt (bottom). Two questions (65294 and 82709) appear in all three sections of the figure.

of students who are attempting incorrectly compared to students who did not attempt some or all of the questions. The professional judgment of the instructors is needed to identify individual student's struggles beyond the qualitative colors. Overall, scanning the grade book's colors is singularly qualitative compared to the more descriptive multi-color bars from the activity editor. Following this qualitative observation, the quantitative data on the problems of interest can be examined.

The quantitative data for online homework problems are the most informative (below right of Figure 2), especially for data-driven engineering professors. The Sapling grade system tallies the number of students earning the correct or incorrect answers for the entire problem and the percentage earned by each group. For the two questions presented in the figure, a similar green color is observed in the grade book while the performance on problem 82709 is measurably lower than 65294 when examining the quantitative question statistics. From using the Sapling system for several years [9], the number of incorrect responses is the best indicator of a problem that the students struggled with. Thus, using quantitation question statistics from the online homework, JITT exercises can focus on the most difficult concepts on recent course material, which will be discussed later.

RESULTS

Course logistics

The Introduction to Thermodynamics course was delivered during the 2014 Fall semester at the Colorado School of Mines. The course number was CBEN210 so the material is considered sophomore undergraduate level. The major concepts covered in the course included: demonstrating a logical and rigorous problem solving ability, computing thermodynamic properties of pure fluids - such as water/steam, and solving steady state and transient processes using the first and second laws of thermodynamics.

While 67% of the students were of sophomore standing when taking the course, junior (25%) and senior (8%) students also enrolled. The diversity in class standing is a result of the students' different majors: 30% chemical engineering (ChE), 32% chemical and biochemical engineering (CBE), 20% engineering physics, 8% civil engineering, and 10% other engineering or science majors. The ChE and CBE students use this thermodynamics course as pre- or co-requisite for another sophomore course (material and energy balances) while the civil and physics students have less need for the course to complete their degrees. Some analysis comparing ChE/CBE students with the other majors was completed. Applying JITT affected all majors in a similar manner, so the results and discussion will focus on the JITT/No JITT comparison.

The three authors delivered two sections of the course in parallel during the Fall 2014 semester. The large section enrolled 161 students with Professors Liberatore and Vestal co-teaching. Professor Morrish taught the small section with 51 students. The large section met Monday, Wednesday, and Friday from 8:00 to 8:50am while the small section met for 75 minutes on Tuesdays and Tuesdays starting at 12:30pm. The three instructors met weekly to keep the content delivered each week in sync. The average GPA for each section before the semester was calculated and found to be statistically equivalent (+/- 0.02 points).

Both sections employed the same active learning strategies: short periods of lecture, usually 15 minutes or less, were interspersed with examples. Generally, examples were worked in groups of 2 or 3 with the instructor or instructors walking the room to answer questions and provide encouragement. The large section included 4 total instructors with two graduate student teaching assistants helping the two professors during most class periods. Thus, the student to instructor ratio was ~ 40:1 in the large section and ~ 50:1 in the small section. Creating the small classroom within a large classroom has been documented elsewhere [9,27]. In addition, a number of examples throughout the semester employed YouTube videos. The YouTube pedagogy has been published previously [28-30], and the YouTube problems were the same for both sections. Overall, the teaching styles and examples were similar between the two sections, and therefore, the presentation of Just-In-Time-Teaching examples could serve as a basis to compare the two sections.

The instructors' response using JITT took a number of forms. The JITT exercise is completed at the beginning of class, and the response includes some lecture related to the troublesome concept followed by active problem solving. Generally, the JITT problems were a variation of the homework problem with the lowest 'score' (problem response data was discussed earlier). Short answer or sketching diagrams were completed with neighboring students so the results could be discussed and refined. Longer problems, similar in length to a homework problem, were also given and took 10 to 15 minutes of the class period. Some of the problems were based on YouTube videos and problems written by students in previous semesters as published elsewhere [28-30]. Overall, the amount of class time was budgeted relative to the success, or lack thereof, on the just completed homework.

Student Achievement

To illustrate the JITT technique, the steps and results pertaining to one course concept, tank filling, will be presented first and followed by the overall outcomes from the semester long application of JITT. Tank filling can be a challenging problem type for students due to the system being both open and transient. Each section of the course worked an example tank filling problem that applied the 1st Law of Thermodynamics in class. Then the students were assigned two problems covering the topic on their homework. One of the tank filling questions was presented earlier in Figure 1.

Tank filling using a real fluid (water) was identified as the most difficult problem on the homework set and provided the basis for the JITT example during the following class period. However, as a control, only the large section completed the JITT tank filling example; whereas the material was not reiterated in class for the small section. During the class period following the JITT exercise, all students were given a quiz covering a 1st law energy balance on a tank filling process. The performance for the two sections on the quiz is shown in Figure 3 with the JITT section clearly out scoring the section not receiving JITT by over 25%. Some disparity between the two average scores could be due to a difference in the actual quiz problem. Since the quiz was given on two separate days, the question was slightly different between the two sections to discourage cheating. Both versions of the quiz awarded 8/10 points for the exact same energy and mass balance formulas, but the large section's tank filling problem used water as the fluid while the small section's quiz used an ideal gas as the fluid. While the variation in quiz content could account for up to 20% of the difference

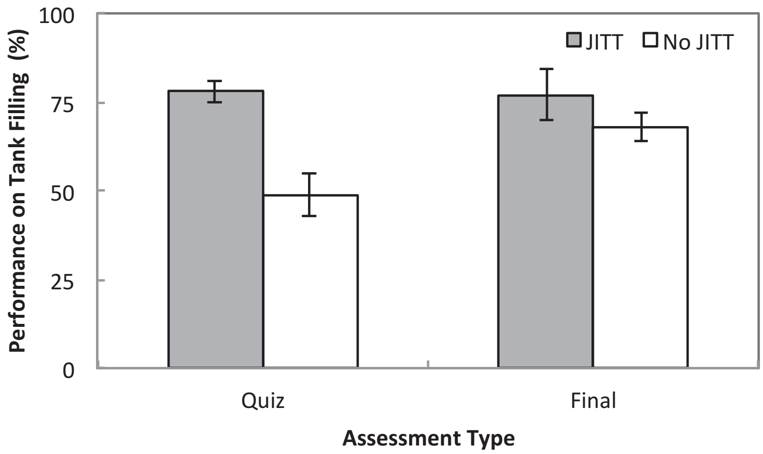

Figure 3. Average performance on tank filling assessment for both a quiz and a final exam problem. The different bar shading represents sections that were given JITT and those that were not (No JITT). The error bars represent 95% confidence intervals.

between JITT and non-JITT students, the data would still show a statistically significant performance improvement when utilizing a JITT review.

To eliminate variability between sections as a differentiating factor, the same experiment was conducted a second time just before the final exam with only the smaller section given a JITT exercise on tank filling. There was a significant span of 7 weeks between the quiz and final exam. Again, the group that received the JITT review scored higher than the section without the JITT feedback. In this case, the final exam problem was exactly the same for all students (all exam questions contained the same problem statements with three different sets of numbers to dramatically reduce the chance of cheating). Certainly, it is intuitive that providing students with extra practice on a topic can improve understanding. However, the added benefit of the JITT approach is in identifying and strategically targeting the most challenging concepts. We believe that extra time spent in class reiterating this identified material will pay dividends on student achievement. These results given in Figure 3 substantiate that JITT methodology can provide measureable increases in student performance on a topic.

Now, the application of JITT throughout the semester and its impact on student achievement will be examined. In this case, the topics were presented similarly in both sections. Table 1 shows a list of the five topics covered using JITT and the five topics covered without using JITT. Because this study was conducted with a single group of students, the topics could not be the exact same for both JITT and No JITT. However, we specifically chose concepts spanning the entire semester and

Table 1. Comparison of Sapling homework average to the average on a similar quiz or exam problem for JITT and No JITT topics. The ± values represents the 95% confidence interval for exam/quiz scores. Standard deviations are not tabulated in the Sapling platform and consequently confidence intervals for HW% could not be calculated.

Topic	HW%	quiz/exam%
JITT		
Gauge pressure, fluid head	74.3	65.0 ± 3.5
Steam quality/interpolation	82.9	71.2 ± 3.4
1st Law piston/cylinder two-step	72.9	77.6 ± 3.4
1st Law nozzle	77.8	85.0 ± 2.3
1st Law turbine	74.3	87.6 ± 2.4
No JITT		
Ideal Gas Law and unit conversion	77.2	80.0 ± 3.4
1st Law piston/cylinder single-step	87.8	87.0 ± 2.1
1st Law rigid tank	88.5	68.0 ± 4.4
Carnot refrigerator	83.7	89.0 ± 2.3
Closed, reversible piston/cylinder	79.4	66.0 ± 3.6

which we believe are representative of the full course. Although some variability due to differing topics is unavoidable, in total the overall data represents nearly 2000 data points making comparisons between the two cases reasonable.

Figure 4 below shows summary statistics of performance on exams and quizzes for three scenarios: a) topics covered by JITT b) topics not covered by JITT and c) overall comparisons of the two. For the box plots, the middle line of the box represents the median score with the bottom and top edges showing the first and third quartiles, respectively. For example, a third quartile score of 85% indicates that 75% of the students scored 85% or less on the quiz or exam problem. The whiskers display the maximum and minimum scores achieved. Each box represents all students that were assessed, typically 180 or more.

In all instances, the top quartile whisker is shorter than the bottom quartile whisker indicating score distributions were not normal. This result is expected given a forced maximum of 100%. Figure 4c provides side-by-side comparisons of overall performance on all topics covered by JITT versus No JITT. The mean quiz/exam scores were nearly identical at 77.5 ± 2.5% for JITT and 78.1 ± 2.9% for No JITT. However, the JITT data did show a higher median value of 83.1% compared to 80.8% for no JITT. The 3rd quartile was 95.5% for JITT and 93.0% for No JITT whereas the 1st quartile values were nearly equivalent at 67.3% and 67.8%, respectively.

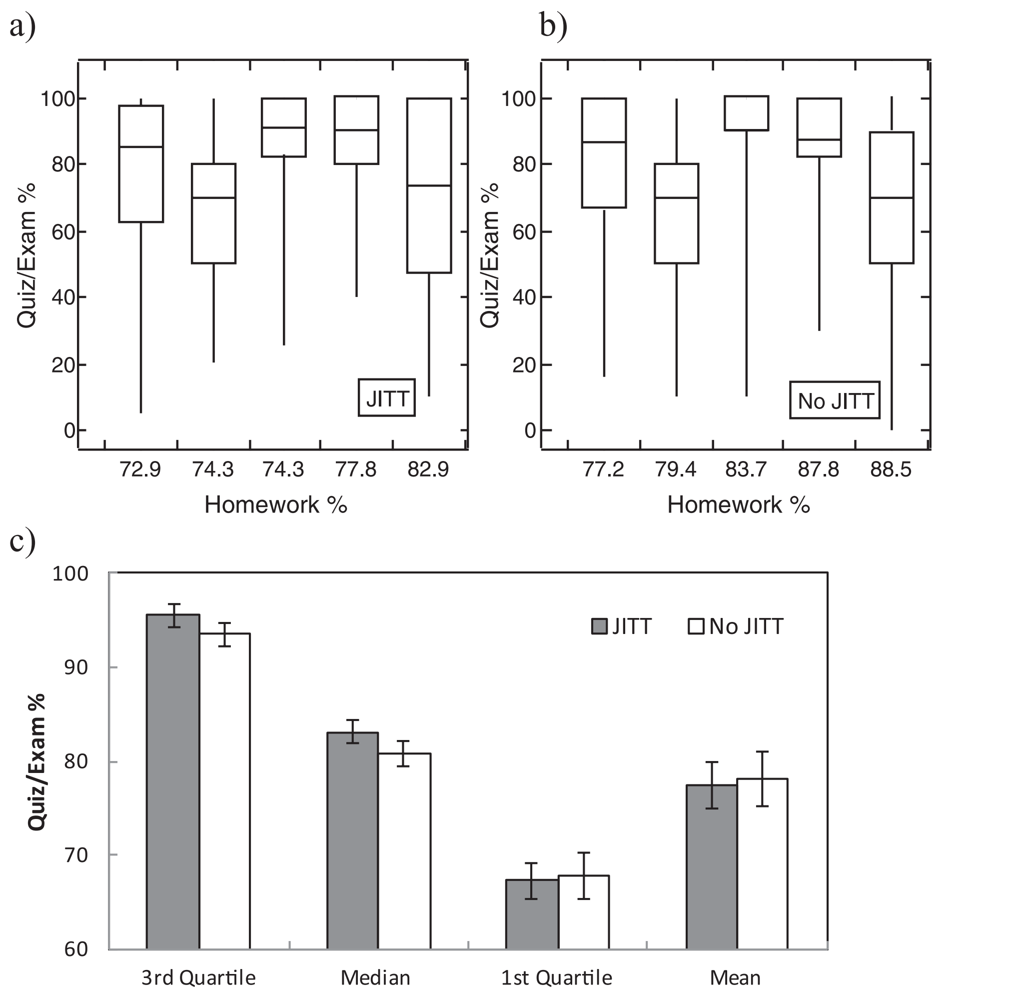

Figure 4. Summary exam/quiz performance statistics for a) topics covered by JITT b) topics not covered by JITT (No JITT) and c) Overall statistical comparisons between the two. The error bars represent 95% confidence intervals.

This data suggests that while average performance for all students was not impacted by JITT, inclusion of the technique could help shift the mid-performing students upward as indicated by the increased median and 3rd quartile scores. While individual students were not tracked to see if JITT shifted students to a higher quartile on any single assignment or over the course of the semester. the average performance provides an aggregated comparison over a sizable number of students. One possible explanation is that these mid-performing students gain more benefit from repetition of challenging material via JITT than the high or low performing students. This result could translate to more B's and fewer C's in a course.

The exam/quiz performance box plots in Figure 4a and b are provided as a function of the Sapling homework score on the corresponding topic, though in this work no trend between the two was observed. In general, a topic that is challenging on the homework would also be so during assessment. But given a data set of only ten topics, this relationship is blurred by varying degrees of difficulty of the exam and quiz problems. Trends between assessment and homework performance could emerge with a larger number of topics to compare.

Student Surveys

An end of semester survey collected students' opinions on various aspects of the course. Four questions were asked about the JITT exercises (Figure 5). Over 65% of the class thought the amount

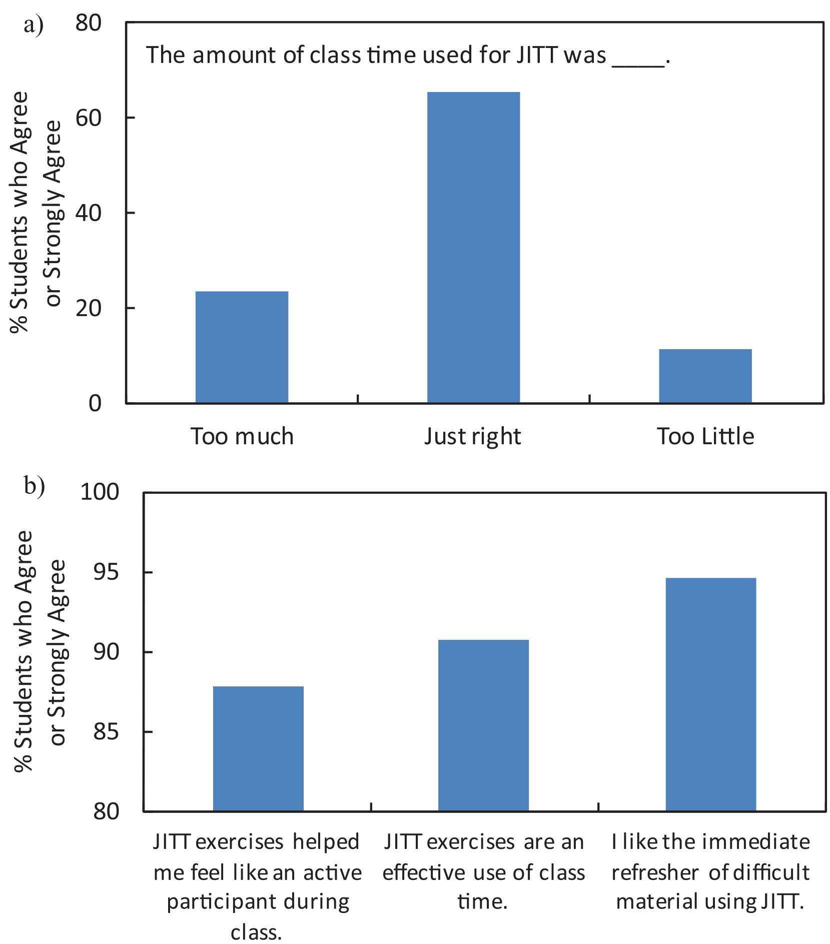

Figure 5. Student responses to survey questions (n=183 students). a) the amount of class time used for JITT versus three choices. b) percentage of students agreeing or strongly agreeing with three statements related to JITT.

of class time devoted to JITT was appropriate with a small fraction wanting more feedback (~11%). The other three questions returned overwhelming positive response for: 1. Feeling like an active participant in the class, 2. Effectively using class time, and 3. Liking the review of the most difficult homework concepts. Overall, the survey results are consistent with other studies [7,9], and JITT provides an opportunity for engagement. Engagement using technology is a widely studied topic [15,31] and the results presented here add to this growing dialogue.

CONCLUSIONS

An approach using online homework to guide Just-In-Time-Teaching exercises in an Introduction to Engineering Thermodynamics course found differences in student performance. The online homework platform provided immediate feedback to students and revealed problematic concepts for the class as a whole. Once identified, these challenging topics were reiterated during the class period following homework submission. The impact of using the JITT exercises on student achievement was then evaluated using in class quizzes and exams. With about 200 students in the course, student performance on a topic covered by a JITT exercise was found to be measurably higher (> 9.0%) than a control group who did not receive the next-day review. While less definitive, comparison of student achievement on a series of topics covered by JITT versus those not covered (No JITT) did show positive outcomes of the approach. The average median and 3rd quartile scores were higher for JITT topics. These results may indicate that the immediate topical review is more helpful for the mid-performing students. Overall, student feedback on JITT exercises was highly favorable with over 85% of students responding that JITT exercises were helpful for engagement and a good use of class time.

ACKNOWLEDGMENTS

The authors thank Katie Houlihan and Jake Newsom for compiling the survey data.

DISCLAIMER

The authors did not receive compensation or royalties from Sapling Learning as part of completing this work. However, future use of thermodynamics online homework problems may financially benefit the authors.

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