ACTIVE LEARNING AND JUST-IN-TIME TEACHING

In a Material and Energy Balances Course

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Material and energy balances are used daily by most practicing chemical engineers across a wide range of job duties and industries. Due to the foundational nature, the material and energy balances course is usually delivered first in the chemical engineering curriculum. The literature includes numerous papers on the importance of the course, the difficulty of the course and its concepts, and high fail rate (*i.e.*, reputation as a "weed out" course).[1-7] Here, 21st century tools and techniques add to the established learning tools and have led to improved outcomes for the course.

Felder and Rousseau's textbook[8] is widely adopted for the course and defines the structure and course topics covered. While the concepts covered in the course have not dramatically changed recently, how the course is delivered has been altered by the availability of technology. A very recent survey[4] on how the course is taught elucidates numerous trends for the course. One clear evolution of the course delivery is the widespread use of software tools such as Excel (spreadsheets), Matlab (advanced mathematics), and many others. Although not covered in the survey, course-specific tools have also been developed.

Online homework from Sapling Learning has supplemented or replaced traditional problem sets out of the textbook for some instructors of a material and energy balances course.[6,9] Features of this tool include personalized problems (*i.e.*, same problem statement with different numbers), multiple attempts for the students to work until the problem is completed correctly, hints and tutorials available in real time, and real-time grading and class statistics. In addition, the rolling numbers on each problem make creating a solutions manual for all variations difficult. Therefore, the online homework dramatically decreases a common concern about the course, namely cheating through the availability of downloadable solutions manuals.[4,10] Another tool designed to improve students' problem-solving skills is open source educational software called ChemProV.[4,11] ChemProV is a chemical process visualizer that helps students learn material balances through the construction of process flow diagrams. This scaffolded software tool led to statistically significant improvement in problem-solving accuracy when dynamic feedback was built into the tool. Overall, a critical aspect of the Sapling homework and ChemProV are the immediate feedback mechanisms.

Leveraging technology to provide real-time feedback to students, both inside and outside of class, has spurred an instructional approach called just-in-time teaching (JITT).[12-14] The most widely used form of JITT centers on the use of clickers.[13,15-17] More than a decade ago, a group of physics faculty created assignments due before every class to minimize the ebb and flow or cramming throughout a semester. Not only did the faculty have a large amount of data on the students' learning and misconceptions, the faculty could improvise within the current class period and address the students' knowledge gaps. A more recent treatise covering JITT across disciplines[12] presents a number of techniques and settings to collect learning information from students' responses. The common theme is to stop regularly (within a class period or several times per week) so students and the instructor can assess what has been learned. Numerous platforms to interact and collect learning data exist (*e.g.*, clickers, pen-based technologies, course-management systems, and concept warehouses and inventories).

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Overall, delivering courses to students who are digital natives (*e.g.*, References 18-20) can involve numerous active -learning techniques and technology[21] to keep the activity level in the room high, independent of class size. Three main sections of this work include teaching in a large class environment (>100 students), homework and JITT response, and assessment. Course surveys and grades provide two assessment tools in evaluating the effectiveness of these various techniques.

COURSE OVERVIEW

At the Colorado School of Mines (CSM), the chemical engineering curricula (*i.e.*, for accredited degrees in chemical engineering and chemical and biochemical engineering) begin with a course in material and energy balances, which is delivered in the spring of the sophomore semester. The placement in the curriculum is one term later than many schools.[4] About 80% of the students in the course have completed a core sophomore-level thermodynamics course that covers a number of energy balance concepts. The course format is three 50-minute class meetings per week at 8 a.m. in a single, large classroom, with an enrollment of more than 150 students in 2011 and 2012 (Table 1). The course had been taught with multiple sections and instructors (including the author) during 2009 and 2010. A number of reasons for moving to a single section are outlined in this manuscript (*e.g.*, technology such as online homework, creating a small class within a large class). Larger sections are becoming more common for this course in recent years,[4] and a number of different approaches can be employed without overwhelming the instructor or "weeding out" large numbers of students. While traditional graduate student teaching assistants have not been available for the single primary instructor setting, a group of three or four senior undergraduates assist the instructor in the classroom as well as in grading homework and quizzes. Grade point averages are on a 4.0 scale and are consistent with those reported earlier.[3]

The course's content follows the textbook by Felder and Rousseau,[8] which is used in ~85% of chemical engineering programs.[4] To mitigate the course's cost to the students, the textbook was a suggested resource in 2011 and 2012 (especially the ~\$50 ebook version from Wiley compared to >\$200 hard cover book at the university bookstore). Once the textbook's solutions manual is available, the utility of the book as a whole decreases dramatically, in the author's opinion. Most students, however, have access to a version of the textbook. While no formal handouts or alternative textbook are used, all notes written by the instructor during class are scanned and posted. The primary "textbook" cost is for the Sapling's online homework (~\$35/student). The course can be divided into three main areas, namely the classroom environment, homework, and assessment of learning. All three components play a critical role in the delivery of the course.

TABLE 1
Class statistics of material and energy balances class at the Colorado School of Mines. Statistics do not include students withdrawing from the course.

Year	no. of students	Average GPA	%C or better	Sections	Primary Instructors
2012	142	2.39	80	1	1
2011	147	2.50	82	1	1
2010	156	2.38	79	3	3
2009	96	2.04	69	2	2

CLASSROOM ENVIRONMENT

An active-learning classroom is created using peer-to-peer instruction, YouTube videos with course-related problems,[22-24] and JITT feedback from the previous assignment. The majority of class time centers on activity by the students, applying learning-by-doing to the course. In addition, work implementing a small class within a large class was instituted to engage a larger number of students during each class period.

Providing structure in peer-to-peer instruction exercises improves focus and decreases the number of students "waiting to be taught" by a lecturing professor.[17,25] The teacher-centered instruction (*i.e.*, lecture) is limited to two or three 5-10 minute blocks per 50-minute class period. Groups of three students are formed at the beginning of the semester and usually maintained throughout the term. Students have self-selected their groups in recent years. Sitting in groups of three provides a format to randomly assign three roles when working on examples. The roles are leader, questioner, and scribe. The leader takes the lead, does the talking to initiate problem solving, and outlines the steps to complete the problem. The questioner listens to the leader and asks questions if something is unclear or seems incorrect. The scribe's role is to write key steps to the solution for the group and share the solution with the group during or after class. The group work time varies from 2 minutes for concept questions and simpler tasks such as drawing and labeling process flow diagrams to 10 minutes for writing and solving multiple balances. A timer is projected to keep students on task for these periods, however if student use of electronic devices with games or text messages starts to increase, the time is cut off and refocused on the next segment of the class. The roles are randomly rotated by a set of cards used by the instructor (*e.g.*, tallest-leader, shortest-scribe).

With groups working diligently during 40 to 75% of the class time, the instructors use this time to actively engage a number of groups. At least one instructor for every 40 to 50 students is needed to engage the groups in a large class setting. Faculty, graduate students, or senior undergraduate students can fill this role as secondary instructors during group activities. Having a diversity of instructors,

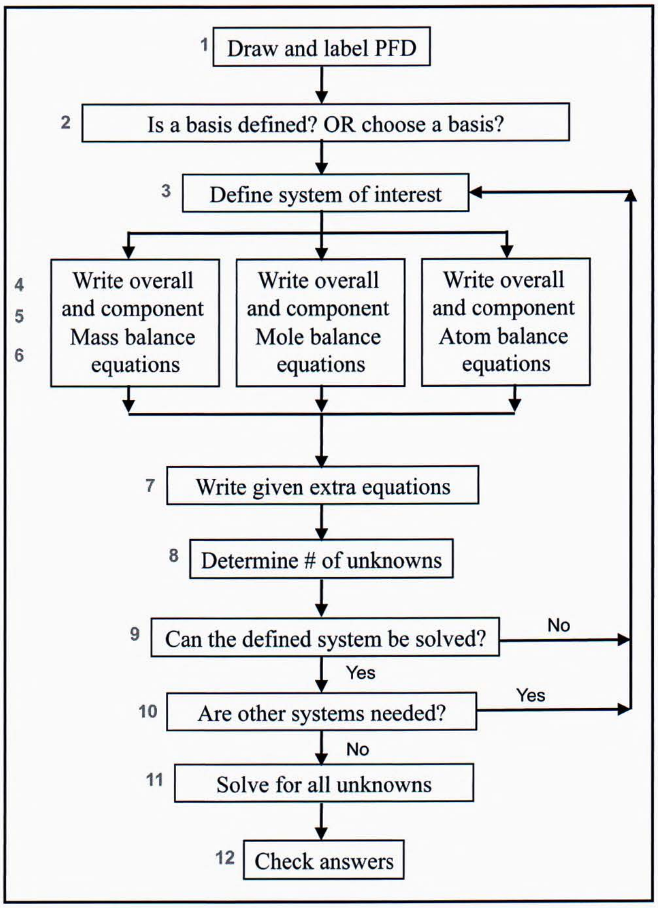

Figure 1. *A 12-step method for solving material balance problems.*

i.e., young/old, male/female, etc., can help build relationships with the students and appropriately represents the future work environment. The idea of using secondary instructors in large classes is not new and has been implemented successfully in 1,000 student sections with improved learning.[26] For the material and energy balances course in 2011 and 2012, three instructors alternated walking the front, middle, and back of the room depending on the day of the class (Monday, Wednesday, or Friday). Since students normally sit in the same general areas, each instructor had the opportunity to engage all of the students regularly.

The primary focus of the class is on providing basic tools for problem solving related to chemical engineering problems. A basic framework for problem solving in the course is summarized in a 12-step process (Figure 1). The utility of a 12-step method for energy and entropy problems (*i.e.*, first and second law) was recently summarized[27] and provided a linear problem-solving scheme. For more complex material balance problems, specifically multi-unit operations, required decisions and loops are added to the framework. The 12-step process is complementary to evaluating degrees of freedom, which is a point of emphasis in the Felder and Rousseau textbook. Feedback from students on the 12 steps (done with anonymous notecards near the middle of the semester) finds the steps useful but not critical to students learning the new material.

A final active-learning component used in the classroom is YouTube Fridays. Several papers have been published on this topic providing the details and feedback on this technique.[22-24] Briefly, students select videos from the Internet and write a course-related problem based on the events of the video (a collection of videos is available[28]). Most course topics have been covered by these problems over the past few years including multiple units, reaction-recycle systems, and vapor-liquid equilibrium. Therefore, selecting the most interesting and challenging YouTube problems to replace the "tried and true" textbook examples increases the energy level in the room. At this point, the examples are not restricted to Fridays since the database of problems has grown steadily in recent years. Groups of three students create one YouTube problem as a project during the semester. Overall, the integration of visuals is an established technique to increase learning, and the sense of personalization of the course engages a large number of digitally native students.[18-20]

HOMEWORK

Three homework assignments per week instill hard work and persistence. One assignment is due each Monday, Wednesday, or Friday class period except for exam days (*i.e.*, 13 assignments of each type of homework are due over the course of a semester). The delivery, length, and content of the assignments vary by assignment type. Short multiple-choice quizzes, personalized online homework, and a traditional "textbook" homework are the three types whose utility will be detailed here.

Instructor-written multiple-choice quizzes are delivered within the course management software (*i.e.*, Blackboard in this case). The content was developed over one semester with updating each semester to avoid the solutions being passed down from the previous year's students. The quizzes ask five to 10 questions per week covering vocabulary, basic calculations (*e.g.*, stoichiometric coefficients, vapor pressure), and concept questions. Adapting pieces of textbook examples or homework is one type of problem. For adding "bio" content, the BioEMB database[29] contains a wealth of full-length problems that can be simplified for this format (Figure 2). Performing atom balances on non-integer stoichiometry (*e.g.*, yeast in Figure 2) emphasizes the universality of the atom balance vs. balancing reaction stoichiometry by inspection. Overall, these quizzes primarily cover material at the remember and understand levels of Bloom's taxonomy.

For developing skills such as applying and analyzing (levels 3 and 4 of Bloom's taxonomy), personalized online homework and handwritten homework fill the role. The initial experiment with Sapling Learning's personalized online homework was published previously.[6] In summary, the students using Sapling earned consistently and statistically significant higher quiz and exam scores, leading to a much lower fail rate for the course compared to students only completing textbook homework. The improved student achievement related to online homework led to adoption of this technology for the two more recent offerings of the course. Most of the online homework problems are as rigorous as the textbook (*e.g.*, multiple units, multiple-part problems). The personalization of the problems comes from rolling numbers within the problem statement. Thus, the concepts and problem-solving skills are the same from student to student but the numerical answers are different. Students were allowed to work in groups on the online homework, but each student needed to apply the correct balances to his or her set of numbers. No data was collected to quantify how many students worked in groups for any of the homework types. Most of the Sapling problems include hints to help students start or to correct errors. Also, some of the problems include full tutorial problems covering the similar concepts before attempting the problem for a grade.

A yeast ($CH_{1.66}N_{0.13}O_{0.40}$) is growing aerobically on arabinose ($C_5H_{10}O_5$) and ammonium hydroxide (NH_4OH) with a respiratory quotient (e/b) of 1.4. The reaction is:

a $C_5H_{10}O_5$ + b O_2 + c NH_4OH --> d $CH_{1.66}N_{0.13}O_{0.40}$ + e CO_2 + f H_2O

Assume 1 mole of yeast as the basis. What is e?

- ○ 0.853
- ○ 0.299
- ○ 0.974
- ○ 0.411

Figure 2. *Example of a multiple-choice quiz problem based on content in the BioEMB.*

Problem sets done with paper and pencil are the third type of homework. Each year fewer problems are taken from the textbook to minimize the amount of rote copying of the solutions manual, which was discussed earlier. Alternate problems and solutions exist without a huge time commitment by the instructor or teaching assistants. Textbook problems with different numbers require work beyond copying the solutions manual. Rolling numbers is trivial in simpler cases (*e.g.*, non-reacting systems) and strongly constrained in others (*e.g.*, vapor-liquid equilibrium). Other sources include problems from other textbooks, the BioEMB database, and old quiz and exam questions. Doing some problems with pencil and paper each week is the best way to simulate quiz and exam situations for the students. While final numeric answers are given on some of the paper homework problems, focus in grading is placed on the problem-solving technique and correct balances, which is also how exams are graded.

While traditional textbook homework is graded within a week of completion (by undergraduate graders in this case), the short quizzes and online homework allow for just-in-time feedback. Both Blackboard's course management software and Sapling's online homework instantly tabulate individual and aggregate grades for evaluation. Both systems tabulate class averages for each problem while Sapling also produces a matrix with varying colors to represent the number of attempts the students needed on a specific problem. On Sapling, the average score is not always the best representation of the class's performance. Students who do not persist to the correct answer receive no credit for the problem (a very small fraction of the class). Distinguishing between the class needing several attempts on average to complete a problem and a low average skewed by a number of students giving up or not attempting a problem is data available for the instructor's professional judgment.

Two of the three class meetings begin by addressing one or more sticking points from the most recent homework assignment (due two hours before class begins). The JITT exercises last from 2 to 10 minutes. For example, a short lecture reviews and reinforces unclear concepts identified in the homework. Alternatively, active problem solving has included re-doing the most difficult problem in their groups, isolating one part of a problem for discussion and resolution, or assigning another problem covering the concept as the problem with the low score. Overall, online tools provide feedback to the instructor instantly that can help keep the students focused on the most important topics in the course. The JITT exercises need additional prep time for the instructor, which is not very difficult if the instructor has taught the course before. The assessment of the JITT exercises and homework is included in the next section.

ASSESSMENT

Homework, quizzes, and exams contribute to the grades earned by students in the class. In addition, formal and informal student surveys provide a second perspective on the multiple homework format and JITT. First, the grades for the three types of homework are aggregated into a single portion of the course graded (~15%). The average grades for homework are generally high (~90%) for the students who complete all of the problems. Next, in-class quizzes—approximately 10—given over the course of a semester provide a means to simulate the exam environment with a problem similar to exam problems. These quizzes take 10 minutes for vocabulary to 25 minutes for longer problems such as reaction with recycle problems. Some quizzes are announced while others are not, to encourage consistent studying of the course material (*i.e.*, avoid cramming before exams). On average, the students earn ~75% on the quizzes. While the majority of the students' effort for the class is on homework and the 10 quizzes, exams make up the majority of the student's course grade.

The timing and frequency of major exams are especially important in the material and energy balances course. As pointed out previously,[2] the course starts out deceptively simple (*e.g.*, units, density) and quickly builds into multi-unit problems that do not always have an obvious place to start solving. During the previous four years, either two or three preliminary exams preceded a cumulative final exam. In years using the two-exam format, students covered the first four chapters of Felder and Rousseau before the first preliminary exam and the first eight chapters before the second preliminary exam. At the time, the logic of covering four chapters of material and then giving an exam seemed correct and in line with the previous deliveries of the course. In 2009, however, more than 75% of the class earned less than 60 out of 100 and a number of students dropped the course as a result. The main feedback from the students was that the difficulty of the material, specifically reaction-recycle problems, was greater than other sophomore-year courses (*e.g.*, math or chemistry). It was decided that overwhelming students in their first exam in their chosen major is not the best way to encourage students to enjoy the chemical engineering profession.

Further, the two-exam format with so many low scores required a curve, and students thought their grades were somewhat arbitrary. Thus, the next year (2010) the three-exam format was adopted and the distribution of material changed. The first preliminary exam covered the first three chapters (*i.e.*, no reacting systems), the second preliminary exam emphasized reaction systems and vapor liquid equilibrium (Chapters 4 through 6), and the final preliminary exam focused on energy balances (Chapters 7 through 9).

All exams are cumulative but emphasize the most recent material. In 2010, it turned out that the first exam provided a false sense of confidence, *i.e.*, an exam without reacting systems was trivial (over 91% average). The parsing of the second and third exam materials gave sensible averages (mid 60s to mid 70s). Therefore, as a further refinement in 2011 the additional material was covered before the first exam, namely single-unit reacting systems (the first part of Chapter 4). The results for 2011 and 2012 showed this new timing for the first exam as optimal with averages of 78 and 74, respectively. While a fraction of the class still earns a failing score on the first exam, the exam is representative of the rigor of the rest of the course and curriculum. As a side note, the ABET continuous improvement forms were used as a way to build this knowledge related to the exam scores.

Overall, course grades and the number of students earning a C or higher in the course have improved in recent years (Table 1). While the author's university teaching evaluations have fallen below the university average for the large course sections the last two years, student learning has improved by another metric. The number of students failing chemical engineering courses the next semester, namely thermodynamics and fluid mechanics, decreased to a four-year low after the Fall 2011 semester (the most recently available data). While course grades are not a standardized metric for engineering education researchers, trends can demonstrate the utility of the teaching strategies discussed earlier.

Online homework was shown to have a significant impact on student achievement when two control sections of the course were compared to one using online homework from Sapling Learning in addition to textbook homework.[6] The success of the online homework in 2010 led to its universal adoption during the past two offerings. Grades, although an incomplete metric, show a measurable improvement since the adoption of online homework for the course (Table 2). In addition to the dramatic shrinking of students earning an F grade in the course, the percentage of students withdrawing from the course also decreased (*i.e.*, from 7.5% to 6.5% of the total enrollment). The results are statistically significant ($p<0.0001$) and consistent with respect to a higher percentage of students earning the C or higher grade needed to enroll in the junior courses. In addition, student surveys beyond the university course evaluations provide insights into which techniques the students feel are helpful.

Three student surveys have been administered during the last two offerings of the course, *i.e.*, online homework, just-in-time teaching, and YouTube Fridays. YouTube survey results are covered elsewhere.[22-24] Surveys related to online homework show a number of interesting trends. During its first introduction in 2010, the students preferred the textbook homework (Table 3), with respect to their perception of gaining understanding and "liking." Online homework and Sapling Learning were unfamiliar to most of the students in 2010, outside of freshman physics (*i.e.*, LON-capa[30]); however,

TABLE 2
Grades earned when using online homework or not during the last four years.

Condition and Years[1]	% students earning grade					Average course GPA	no. of students	%C or better
	A	B	C	D	F			
With Online Homework	23	29	30	12	5.5	2.52	345	82
Without Online Homework	17	20	33	12	17	2.08	196	70

1 With Online Homework occurred for some students in 2010 and all students in 2011 and 2012. Without Online Homework occurred for all students in 2009 and some students in 2010.

TABLE 3 Student survey responses to four questions related to online homework.			
% Strongly Agree/Agree	2010	2011	2012
Online homework helps me understand the course concepts and topics.	85	96	95
Textbook homework helps me understand the course concepts and topics.	92	84	92
I like doing Online homeworks.	50	75	60
I like doing Textbook homeworks.	65	42	52
Note: n=52 students for 2010, 134 students for 2011, and 123 students for 2012			

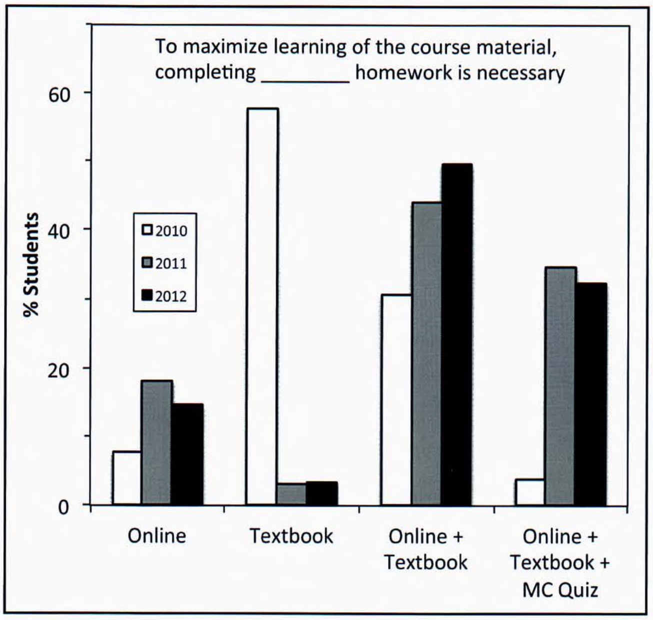

Figure 3. *Students' preferences on homework type(s) over the last three years. The n-values for each year are included with Table 3.*

online homework is becoming a more standard tool with use in organic chemistry, mechanics, and other courses across campus during the last few years. In the two subsequent years, students scored online homework higher than textbook homework on both questions. The category "understanding course concepts from online homework" received almost unanimous response during 2011 and 2012.

Another survey question probed the homework type or types that students perceived help them learn the course material. Textbook homework as a singular homework type received a majority of the responses in 2010, but has garnered only 3% of the response in the two most recent offerings.

To summarize, both familiarity with online homework and a smaller number of glitches with the online homework system likely led to the very favorable survey results over the last two years. Additionally, the vast majority (~80%) students in 2011 and 2012 believe that multiple types of homework help maximize their learning.

The final student survey probed the students' feedback on just-in-time teaching. As discussed earlier, multiple-choice quizzes and online homework provided immediate results to the instructor, which were acted upon to adjust the course content to the current group of students. Responses from 2011 and 2012 were averaged since the students responded with the same level of agreement (*i.e.*, within 3%). First, the immediate feedback from the homework resonated with the majority of the students (Figure 3). The students agreed that the JITT process gave them a means to be an active participant in class and was an effective use of class time. Students clearly understand that the instructor is aware of their strengths and weaknesses as well as not just delivering the same lecture as every previous year. The instructor taking class time to address students' concerns and deficiencies in real time (*i.e.*, not just in the exam review weeks later) is appreciated. Finally, more than 86% of students liked reexamining difficult course material during the JITT exercises (see Figure 4, next page). Focusing class time on the most important material has always been an instructor's prerogative, but now the instructor determines some of that important material from the responses of the students via online tools. The compromise on using class time for JITT exercises has been removing some introductory lecture material from class (*e.g.*, definitions). Overall, implementing JITT should become more common as more online tools are developed and available to faculty.

CONCLUSION

A number of techniques for delivery of a material and energy balances course have been explored and several items optimized over the last four years teaching the course. First, student engagement is achieved even at large class sizes by using multiple instructors—corroborating findings in other, non-engineering disciplines. Active-learning techniques, including short problem-solving periods in teams, problems based on YouTube videos, and JITT exercises, keep students' attention by varying the activity every 10 to 15 minutes. Next, a move away from textbook-based homework was necessary to avoid rote copying of the solutions manual that is available via a simple web search.

A combination of homework types has proven successful in engaging students several times per week in the course material. The implementation of Sapling Learning's online homework has allowed self-directed and personalized problem solving as well as the ability to deliver just-in-time feedback to the class (*i.e.*, only hours after students complete the assignment). Traditional paper and pencil homework and multiple-choice quizzes round out the homework assignments each week, and the quizzes also allow JITT feedback. Overall, JITT exercises received positive feedback from student surveys.

Individual exams and surveys provided assessment of the changes to the course. Timing of the first of three preliminary exams is critical to provide a fair assessment and minimize the students withdrawing from the course and likely changing majors. Student surveys show a strong preference (~80%) for multiple types of homework, especially online homework, to maximize their learning. In total, more active and self-directed tools with immediate feedback are needed to enhance the engineering education community in the near future.

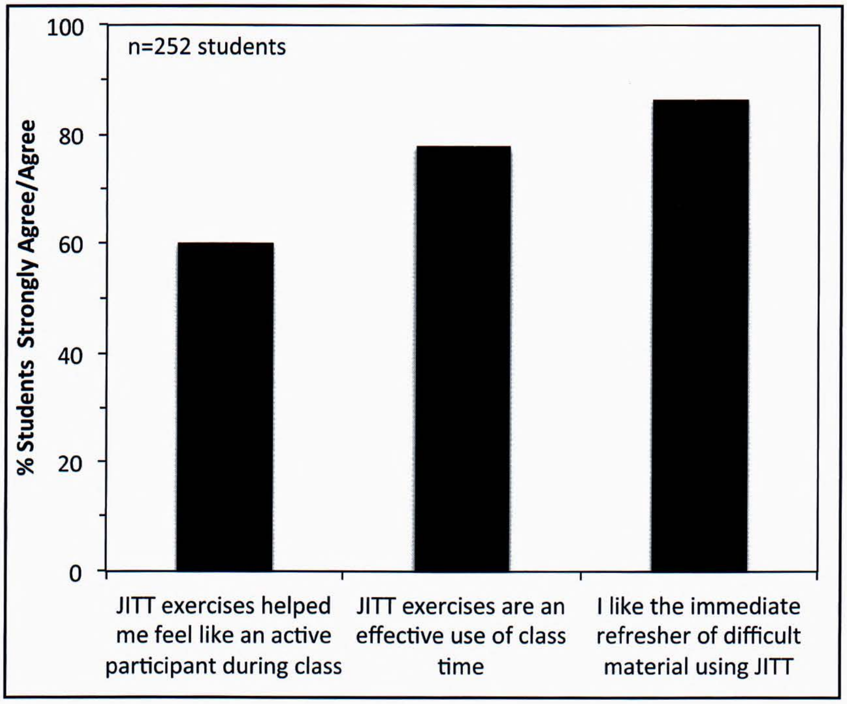

***Figure 4.** Percentage of students who responded "agree" or "strongly agree" to three statements related to Just-In-Time Teaching exercises. Data are averages from 2011 and 2012.*

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