ACTIVE LEARNING AND STUDENT PERFORMANCE
in a Material and Energy Balance Course

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Typically the material and energy balance (MEB) course is taught at a freshman or sophomore level. Success in this early course is generally believed to be a metric for future success within the chemical engineering curriculum. However, the complexities and dynamics of the course stem from not only the difficulty of the subject matter, but also from the problem-solving nature of the course, as well as the fact that it is among the first courses that students take within the major.[1]

Like in many engineering programs, a wide range of student needs exists within the Chemical Engineering Department at the University of Louisville (UofL). These students are introduced to structured problem-solving and the development of their chemical engineering skills beginning in this course. Successful outcomes in MEB are measured by the students' ability to comprehend, interpret, and solve applied chemical engineering problems. Within this problem-solving setting, different teaching methods and strategies have been employed. As such, the MEB course is well-suited for active-learning approaches and techniques.

Many researchers have used active-learning approaches in STEM classes.[2-5] Multiple authors have concluded that it must be the student who does the work of learning how to solve problems in order to retain and truly succeed with the course material.[5-8] Freeman, et al. concluded from a large meta-analysis of 225 studies that test scores improved by 6% in active-learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning.[3] This conclusion has been reinforced by other findings in studies involving STEM courses.[9-11]

In this work, we focus on one instructor's (Amos) evolution of the MEB course from a more traditional classroom structure (Course A) to a more student-centric, active one (Course B) over the timespan of five years. In the initial Course A, an approach was used similar to the one used when the instructor was a student. This structure entailed the instructor delivering the lectures and working problems on the board while the students took notes, and although the students were also asked to work problems on the board, they were often ill-prepared to do so. In the redesigned Course B, the majority of problem solving during classtime was carried out in a group or team environment incorporating group problem solving as well as active learning, scaffolding, and peer-led learning. Since technology can facilitate active learning,[12] interactive lectures where both the instructor and students used tablet PCs were used to reinforce the problem-solving concepts inherent in MEB. This combination of interactive lectures and group

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problem solving in an active learning environment is demonstrated as effective in the redesigned course.

In Course B, class lectures and examples were prepared based on the students' current understanding of the topic as well as on responses to reading quizzes taken outside of class time. This just-in-time (JiT) delivery of lectures and example materials has been shown to facilitate classroom learning in MEB,[13] as well as to enhance the time and interactions spent in the classroom and in the problem sessions.[14] The students also worked in a variety of problem-solving teams (grouped both by instructor and by student choice) so that they experienced different team environments.[15] To guide this learning environment, students were asked to complete a variety of assessments and homework assignments in order to promote learning and retention of the material. We detail the experience of transitioning an MEB course from a more traditional instructional approach to one that incorporates active learning, collaborative teamwork, and JiT teaching methods from the perspective of a new instructor.

REFLECTIONS FROM A NEW INSTRUCTOR

When I (D. Amos) started my teaching journey, it had been more than 15 years since I had been in the classroom. I wanted to teach material and energy balances because it was a foundational course at the beginning of the chemical engineering curriculum. Like many new teachers, I set out to impress the students with my knowledge. I learned about all of the new instructional tools (or so I thought) such as Blackboard, clickers, etc. I put together lectures based on the material in the course textbook, *Elementary Principles of Chemical Processes*,[16] and worked through the book's very nice and detailed examples for the students in class. During problem-solving sessions, I worked out problems on the board, demonstrating how to get to the solution, and routinely asked students to come to the board to work problems. I wrote really tough tests thinking that I had covered the material thoroughly. I asked the students, "Do you have any questions?" And most importantly, I believed that regardless of how I presented the information, the students would learn the material.

My students, however, did not necessarily concur with my internal assessment of the course. They came to office hours rarely, wanted more problems worked out, and provided feedback that my tests were not easy to take. I formally made all the standard mistakes inside and outside the classroom, even though they were based on how I learned material as an undergraduate student. However, I also quickly learned and unlearned some of my major mistakes. I learned that students were often too embarrassed and otherwise unwilling to admit that they had a question. I also learned that I had to do simple quick assessments on a weekly or daily basis. Perhaps the biggest revelation was that I did not have to do all the work during lectures, and especially not during problem-solving sessions. In other words, I discovered that not only did students in my class want to learn differently from how past engineering students had learned, but also that no matter how they learned, they needed to be engaged, active learners.[2]

My other main conclusion over this initial period (2010-2011) was that I had to stick with my basic convictions about classrooms teaching and make modifications until I arrived at something that worked well for both myself and my students. For teaching the MEB course, my pedagogical goals evolved into the following: teach the overall problem-solving strategy, emphasize the basics, and ask the students to work lots of problems.[8] In other words, I transitioned to a more active learning format, which has been demonstrated to improve performance and learning.[3] I also rapidly came to believe strongly in teamwork, particularly in forming diverse teams with students of differing strengths, and I frequently assessed what was working in both formal and informal ways.[15] I put together a concept map for the course, routinely shared it with the students, and used it to frame the overall course and lectures. Finally, I worked to be a more reflective teacher in keeping with Brookfield's four lenses of critical reflection.[17] Given these changes, my perception of the student learning over this five-year period was that the students involved in more of an active learning environment both retained and learned the material better when *they* were doing the majority of the problem solving, rather than the other way around.[3,4,12]

STRUCTURING KEY ASSESSMENTS AND PROBLEM SESSIONS

The course gradually transitioned from a traditional teaching format (Course A) with the professor giving lectures and working problems during class time and the students receiving the information and working independently outside of class to solve a single weekly homework assignment, to a more active learning format (Course B) integrating different types of teamwork as detailed in Table 1. During this same time period, the class size increased from 35 (Course A, 2010) to 69 (Course B, 2014) split between two sections. The relevant outcomes that were followed during this course development include the midterm and final exam grades, homework grades, and final course grades.

Although the written feedback collected from the students in 2010-2013 is not analyzed directly in this paper, it was an important part of the transition and course redesign from Course A to Course B, with major changes implemented in 2013 and further developed in 2014. Student feedback clearly indicated that they still wanted the lectures to cover some of the basic concepts needed for the course in addition to problem solving by both the instructor and students. The format of the class was restructured to include more active learning and teamwork coupled with a variety of different homework assessments that included both individual and team-based problem solving.

Weekly Assessments. The dynamics of the environment in which the MEB course is taught are an integral part of the student learning and success in this course. Course A, taught in Year 1 (2010), was a traditional lecture-style course focusing on the textbook information, examples, and concepts. It contained weekly 2-hour problem or recitation sessions that were led by the instructor. The transition to the "new" Course B was an evolution over a 5-year period, and was structured

TABLE 1
The evolution of the material and energy balances class over time (2010 to 2014). The classroom characteristics are from Course A (2010) to Course B (2014).

		YEAR				
	Characteristics	**2010**	**2011**	**2012**	**2013**	**2014**
Lectures (50 min/3x wk)	50-minute lectures closely based on book	X				
	Instructor works some in-text examples from book	X				
	DyKnow instruction used to deliver some material		X			
	DyKnow instruction used to deliver the majority of material			X	X	X
	DyKnow polling used for concept tests		X	X		
	Active learning questions incorporated. Students work in groups of 2-3 on 2-3 activities per lecture.			X	X	X
	Instructor predominately works examples in class along with students				X	X
	Sapling example problems previewed and worked during class				X	X
	"Just in time" delivery of lecture material based on external reading quiz results				X	X
	Dual screens introduced in the classroom				X	X
	Informal polling done in class as needed				X	X
Problem Solving Session (2 hrs, 1x wk)	Instructor works example problems on board	X	X	X		
	Instructor works/sets up problems with students		X	X		
	Students work problems individually and at the board	X	X	X		
	Students work problems in teams of 2 or 3 in problem session using tablet PCs				X	X
	Instructor/TAs available to work problems and assist students	X	X	X		
	Students work only on assigned homework problems	X	X	X		
	Sapling problems worked, but not graded				X	X
	Textbook end-of-chapter problems worked, but not graded				X	X
	Instructor/TAs available to answer questions based on ground rules				X	X
	Instructor/TAs do not work problems on the board				X	X
	Students submit their in-class work to problems as a group through DyKnow					X
Homework (weekly)	Instructor provides weekly formative feedback on students' work submitted in DyKnow					X
	Student works 6-7 HW problems per week	X	X	X		
	Students work 2-4 HW problems per week				X	X
	Reading quizzes assigned and graded on new lecture material prior to being covered in class				X	X
	Students assigned weekly graded Sapling HW (4-5 problems)				X	
	Students assigned weekly graded Sapling HW (2-3 problems)					X
	Students given participation points towards homework grade for problem sessions					X
	Homework format changed to discourage cheating					X

around teaching problem-solving strategies, including setting up and solving problems, as the keys to learning the material. As such, Course B evolved to a semi-flipped classroom that was student-centric with the emphasis on student teamwork. Course B was structured around the idea that active learning, structured problem-solving sessions, and working problems from the beginning to the end would help students avoid the moment of panic that many new learners face when they encounter something new, particularly under typical testing conditions.[18]

Research in engineering education shows that students learn best when they are not allowed to put the subject aside for long periods of time and when their learning experience includes periodic formative assessment and feedback.[8,19] In order to incorporate this idea, there was also a transition from Course A (weekly homework assignments, a weekly 2-hour problem/recitation session, three midterms, and a final exam) to more periodic formative assessments in Course B. The class consisted of three 50-minute lectures and one 2-hour problem-solving session per week throughout the 5-year study. Three different types of weekly assessments were employed in Course B, which were fully implemented in Year 5 (2014): (1) online (Sapling) homework where the students receive real-time feedback as soon as they submit their answers[20, 21]; (2) "paper" or traditional homework assignments where the students work out problems step-by-step and turn these in for a grade; and (3) reading quizzes that require prior reading of the instructor's lecture notes and/or the textbook and taking a quiz. The reading quizzes tested the students' basic understanding of the concepts covered in the reading before the instructor covered each new section in lecture.[20] For the three-lecture-a-week format used in this MEB course, these weekly assessments amounted to an assignment due the day of or immediately prior to each class meeting.

Although the written feedback collected from 2010-13 is not analyzed directly in this study, it was an important part of the transition and course redesign from Course A to Course B, with major changes implemented in 2013 and further developed in 2014. The format of the class was restructured to include more active learning coupled with a variety of different homework assessment types that included both individual and team problem solving. For both the traditional and online homework assignments, students were allowed to work in groups outside of class if they so chose, but each student was required to turn in a unique solution to the problems. Early on from 2010-2013, there were multiple issues with academic integrity in the traditional homework assignments. Instances of compromised homework papers were due not so much to the students working in groups or teams, although some certainly did, but were primarily due to copying from the textbook solution manual, which was readily available to students online. The issue of homework integrity was addressed in a global fashion in Course B (2014) by changing the way the homework assignments were written and delivered. Specifically, the students were given written copies of the homework assignment (available on Blackboard, the UofL learning-management system, for download) with wording and problem numbers changed so that the students could not readily access solutions. The modified homework format coupled with the students working more example problems in the weekly problem sessions greatly improved the students' confidence and responses to their homework questions as determined by the students' homework scores and decreases in overall cases of cheating identified by the instructor/TAs. Although assigned problems were still largely from the course textbook, the number of cases of cheating was greatly decreased. The assessment changes made in the course redesign in transitioning from Course A to Course B became the foundation of the new course as summarized in Table 1.

Use of DyKnow, Interactive Classroom Management Software. DyKnow was first introduced during the lecture part of the course in 2011 and later into the weekly problem sessions in 2014.[22] The DyKnow software allowed the instructor, working from her tablet PC, to present prepared slides and spontaneous notes directly to the students who were connected with their personal laptops and tablets in the classroom. More importantly, the instructor was able to set up and work example problems more efficiently. All students had access to pen-based tablet computers and the DyKnow software platform through a UofL license. In addition, the majority of the students were familiar with DyKnow from earlier freshman-level engineering courses that used the software for instruction. The students were then able to annotate their slides or "panels" as well as take down their own notes in the additional space provided, all of which could be shared directly with the instructor upon request. The students could reference and download these notes later from anywhere with internet access. DyKnow also allowed the students to indicate (in real time) whether or not they understood. The instructor could also use the software for interactive polling of the class, similar to how clickers are used in many classrooms. All of these features were used during both the lecture and the problem sessions.

Problem-Solving Sessions. Beginning in 2014 (Course B), the longer 2.5-hour weekly problem-solving sessions were restructured so that the students worked in assigned groups throughout the class period. The instructor and undergraduate/graduate teaching assistants (TAs) were available for help throughout this session, but only when the students followed the session ground rules. The ground rules required that each student team consult at least three resources (*e.g.*, textbook, Sapling, another student, lecture notes) before asking a question of the instructor or TAs. The ratio of instructor/TAs to students was approximately 1:10. CATME SMARTER Teamwork is a system of secure, web-based tools that enable instructors to implement best practices in managing student teams.[23]

This system tool was used to generate teams based on instructor-specified criteria to account for student gender, cumulative GPA, prerequisite class performance and individual grades on the class midterm exams.[24] The majority of the teams consisted of three students, with teams of two used as needed. Because the teams were changed each week, a short icebreaker activity was used at the beginning of each class to help familiarize the students with each other.[25] Over the course of each weekly session, the student teams would typically solve three to four problems. Approximately half of the problems followed the format of their traditional homework assignments and the remainder were solved in Sapling online. Particularly for the online learning system, this introduction to problem solving in groups, coupled with the session ground rules, helped to alleviate much of the resistance and anxiety that is sometimes encountered with online homework.

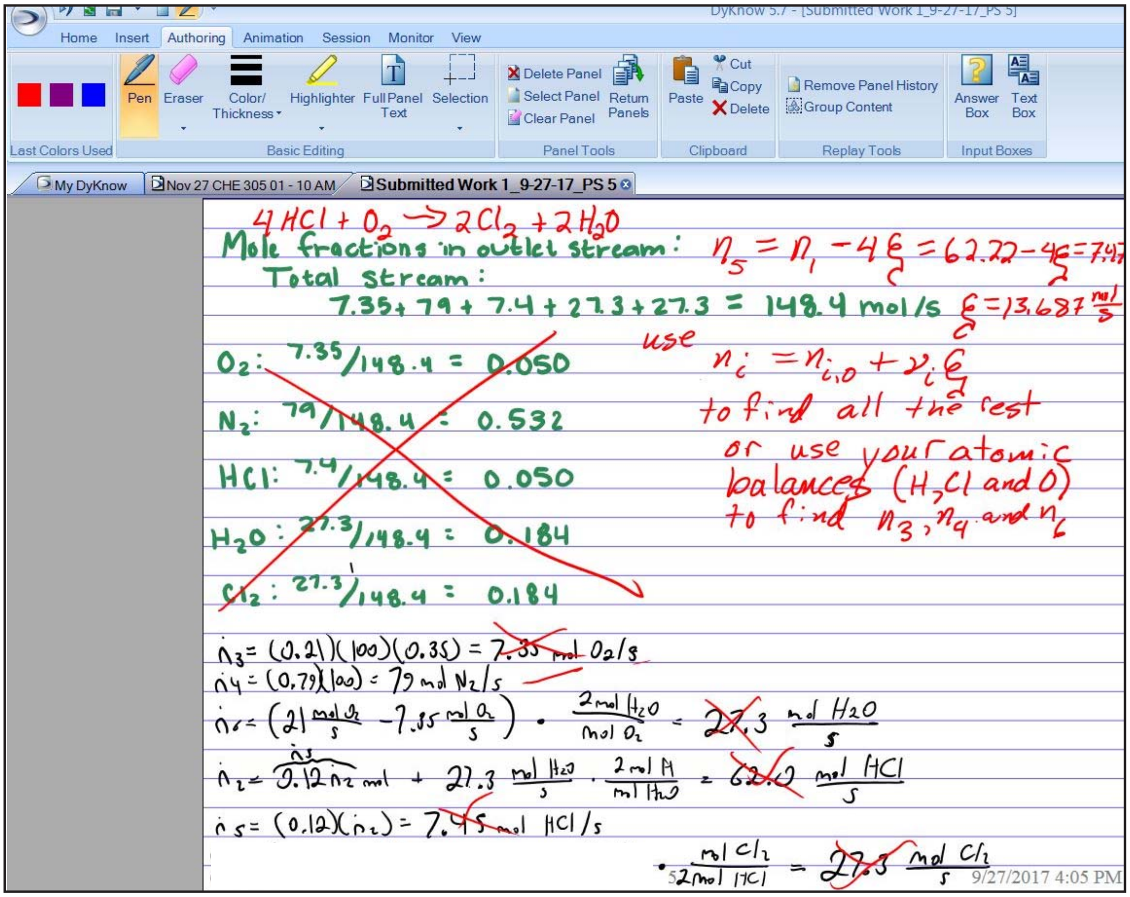

Figure 1. A screenshot of a student DyKnow panel submitted as part of a classroom exercise on a reactive mass balance problem during the weekly problem session. This example shows both student solutions and instructor feedback. Note: in the software, the instructor feedback shows as a different color (red) from the student input on the students' screen.

Students completed their teamwork and solutions in a DyKnow team environment and submitted them electronically to the instructor. The DyKnow interactive classroom software was important for communications among the individual team members because once they were put into groups they could collaborate with their teammates and see what each teammate shared on a single common document in real time. The students in each team were then able to submit a single collaborative copy of their solution as a group and the instructor was able to return it with comments directly to the team with everyone having access to the feedback. As shown in Figure 1, the students' work is annotated in DyKnow by the instructor in a different color ink, typically red, and returned to all students in each group with a single click by the instructor using the "Return Panels" button. Once saved, the submitted panels/slides will appear in the instructor's class folder on the server where they may be assessed and annotated before returning automatically to the student groups whose names appear at the bottom of each panel submitted. The use of DyKnow during these sessions supported the instructor's pedagogical goal of having the students work lots of example problems while allowing for formative assessment. In addition, the technology was used in the classroom to enhance and facilitate both the working of example problems and the way in which feedback on the students' work was communicated as well as subsequent classroom discussions on the "correct" or alternative solutions. As was pointed out by Anderson, et al., the tablet pc technology and the associated classroom interaction system (DyKnow in this study) were used to enhance active learning and instruction in support of the instructional goals.[26] Formative assessments of the teams' solutions reviewed by the instructor were returned to the students on a weekly or biweekly basis throughout the semester. Only participation grades were assigned to the students' work completed during the problem session. Working in teams, coupled with the

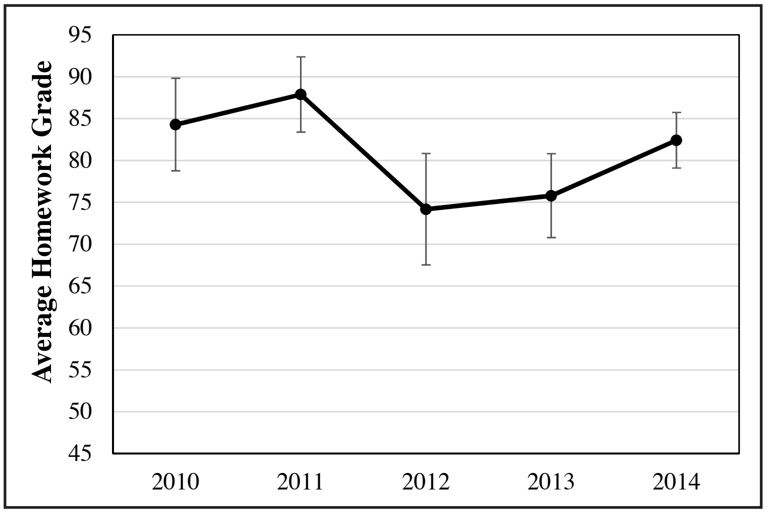

Figure 2. *Data representing the average homework grade percentages for students from 2010 – 2014 by year.*

feedback from the instructor, helped to foster camaraderie, learning, and mastery of the subject.[8,15,19] This teamwork was completed in an overall class size of 69, or approximately 23 groups per week. For larger classes, the feedback might need to be scaled back to fewer problems per week or relying on TAs to provide some of the feedback on the team solutions to the problems. Another possibility would be to implement rubrics assessing the students' progress that could be used for either groups or individuals. The critical idea is to provide formative assessments that contribute to students' mastery of the concepts and the problem-solving approach in general.[6]

Exams. Student performance was measured by periodic formal assessments including three in-class midterm exams and a final cumulative examination. The exams were administered as open book, closed-note exams from 2010-2012 and closed-book, closed-note exams from 2013-2014. When the exams moved to a closed-book format, the students were allowed to prepare a single 8.5" x 11" handwritten equation sheet (front and back) for their use during the exam. Up to one side of this sheet could include example problems. Most students prepared their equation sheets while studying for the exam, and based on student feedback, liked this aspect of the testing procedure. These equation sheets were turned in along with the students' exam solutions. The format of the exams consisted of a section of short-answer, multiple-choice or open-response questions that were worth 15 to 20 percent of the total points. This section was designed to be completed in 5 to 10 minutes. The rest of the midterm exam was composed of multi-part problems that involved setting up and working out the problem in full on the exam paper. Typical elements in this part of the exam could include setting up and drawing a process flowchart, completing a degree of freedom analysis, writing out the mass and/or energy balances, and solving for one or more unknown variables pertinent to the problem. From 2010 to 2012, the exams were written to be taken in 50-60 minutes, but the students were given up to 120 minutes to complete them in order to eliminate time constraints as a major factor in student performance.[2] In 2013-14, due to increasing class size and scheduling constraints, the midterm exam period was limited to 60 minutes. The final exam period remained at 150 minutes for the entire 5-year period. The final exam format was similar to the midterms with the exception that it included three multi-part problems instead of two.

Overall Design of Assessments. The variety of homework and other weekly assessments, including quizzes and the problem sessions, had the advantage of keeping the students working on and practicing the problem-solving techniques that were necessary to be successful in the class. Throughout each of the assignments, as well as in class and during the problem sessions, working through a well-defined solution strategy covered in the course textbook and reinforced in the classroom lectures and notes was emphasized. Mastery of this strategy was linked to the relevant outcomes, in this case the homework and exam grades. Another metric that was followed along with the course outcomes was the cumulative GPA of the incoming students over the 5-year period. The cumulative GPA is that of the students for the semester prior to enrollment in the materials and energy balance course. The cumulative GPAs of students who withdrew from the course were not included in the analysis. The average entering cumulative GPA of the students was 3.3, with the exception of the 2011 class which had a statistically significant higher entering cumulative average GPA (3.6 vs. 3.3).

KEY FINDINGS BASED ON STUDENT PERFORMANCE METRICS AND STUDENT FEEDBACK

The first of the relevant outcomes followed during the course redesign was the homework. The average homework grades for the semester by class year are shown in Figure 2. Notably, average homework grades were similar for 2010, 2011, and 2014, within one another's 95% confidence intervals, and with an average score of 84.2%. For this figure and all other figures, statistically significant differences were measured at an alpha equal to 0.05. The homework performance in 2012 and 2013 was statistically significantly different with an average score of 75% when compared to the other cohort years (2010, 2011, 2014). The average homework grades correlated well with the final exam grades, showing that lower performance on homework assignments is associated with lower performance on the major exams and ultimately the final course grades. Details of what was included as homework assignments are summarized in Table 1. The changes from Course A to Course B included adding an online homework

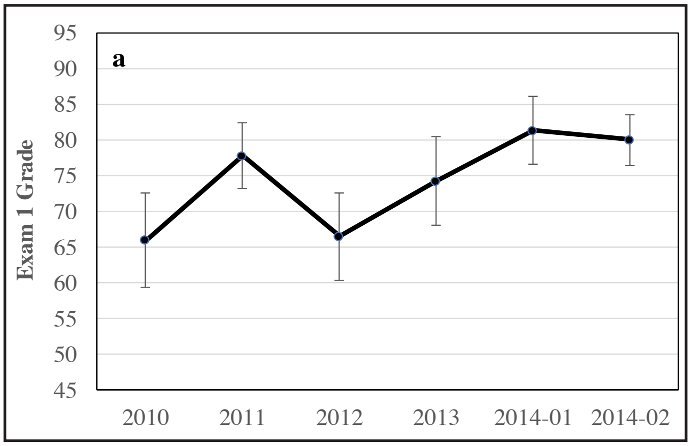

Figure 3a. *Exam 1 grades.*

Figure 3b. *Exam 2 grades.*

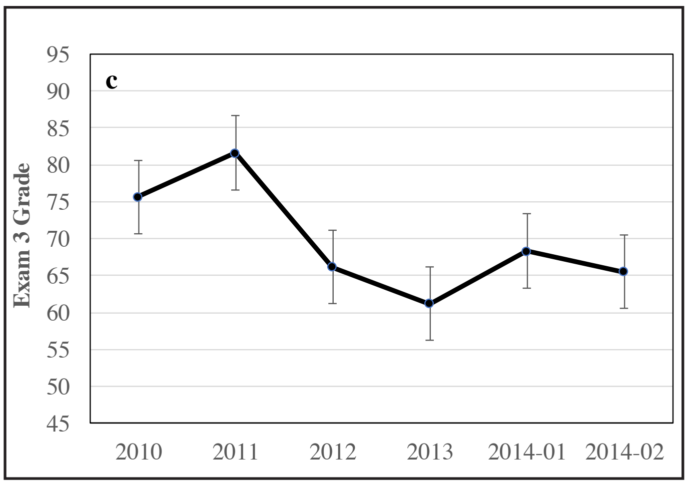

Figure 3c. *Exam 3 grades.*

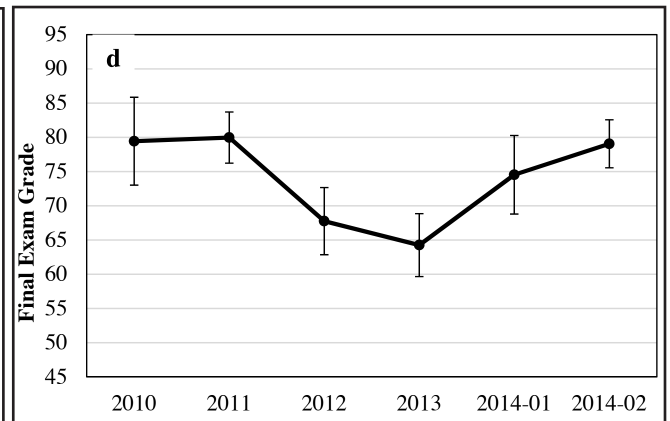

Figure 3d. *Final Exam grades.*

Figures 3. *Average exam grades from 2010 – 2014 with 95% confidence interval bars. Statistically significant differences exist between grades where error bars do not overlap.*

component in 2013 and 2014 offered by Sapling Learning. The online homework was in addition to the more traditional textbook homework assignments that were worked out and turned in for a grade. Although solutions for the traditional homework were not posted, final answers for the problems were available and a limited number of the problems for each assignment were worked out in class. Not surprisingly, student feedback gathered anonymously from 2010-2013 (mid-semester and end-of-semester feedback) indicated that the students wanted less homework. However, closer examination of the homework scores (Figure 2) correlated positively with the final exam grades (Figure 3d) throughout the study duration. Specifically, zero-order correlations were completed to compare the final homework scores to grades on the final comprehensive exam. We found statistically significant correlations between the overall homework score and final exam performance in 2011 ($r = .47$, $p = .007$), 2012 ($r = .60$, $p < .001$), 2013 ($r = .47$, $p < .001$), and section 1 of 2014 ($r = .40$, $p = .017$). The correlations between overall homework score and final exam performance in 2010 ($r = .32$, $p = .065$) and section 2 of 2014 ($r = .30$, $p = .086$) were not significant at the $p < .05$ level. The overall homework grade counted towards 20% of the final course grade.

In addition to the weekly assignments, there were three midterm exams given per semester. The other major assessment for the course was a two-part final that included a traditional exam format where students worked out problems on paper and a second part where they were asked to create an Excel spreadsheet to solve the assigned problems. The traditional final exam was 2.5 hours in length and consisted of three to four longer problems plus a short-answer section similar to the midterm exam format. The second part of the final exam was administered in a UofL computer room on common machines to minimize issues with academic integrity and also lasted 2.5 hours. The combined outcomes for the midterm and final exams are shown in Figures 3. Statistically significant differences exist between grades where error bars set at the 95% confidence intervals do not

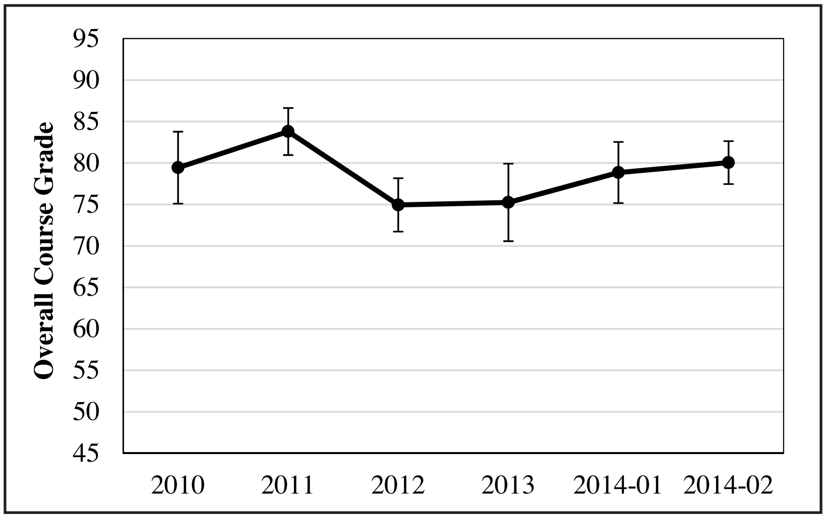

Figure 4. *Average overall course grades from 2010 – 2014 with 95% confidence interval bars*

TABLE 2
Summary of average exam and final course grade percentages in the material and energy balance course with unadjusted exam grades. Fall 2010 to Fall 2014[1]

Year	Class Size	Exam 1	Exam 2	Exam 3	Final Exam	Course Grade
2010	35	66.0[2] (20.0)	56.0[2] (25.5)	75.5 (14.5)	79.0 (18.0)	79.0 (12.5)
2011	33	78.0[2] (13.5)	82.0 (16.5)	81.5 (12.0)	80.0 (10.5)	84.0 (8.0)
2012	47	66.5[2] (21.0)	60.0[2] (20.0)	66.0[2,3] (21.5)	68.0[2] (16.5)	75.0 (11.5)
2013	60	74.0[4] (24.5)	56.0[4] (21.5)	61.0[4,5] (25.0)	64.0[2,5] (17.5)	75.0 (18.0)
2014-01	36	81.0 (14.5)	79.5 (18.0)	68.5[4] (18.5)	74.5 (17.0)	79.0 (11.0)
2014-02	33	80.0 (10.5)	87.0 (11.5)	65.5[4] (16.5)	79.0 (10.0)	80.0 (7.5)

1 Standard deviations for the average grades are shown in parentheses. The exams were graded to within ± 0.5 points out of 100.
2 Raw score is presented, curved grade was used to calculate final score.
3 Exam 3: 32 out of 33 students took the exam. The exam was given in two parts due to some missing data affecting one problem on the exam. The problem that originally had the omission was given as a separate take-home exam (Part 2). The average presented for this exam is for Part 1 (the in-class portion) only.
4 Score after retake exam.
5 Exam 3 and Final Exam: 56 out of 60 students took the exam.

overlap. Exam 1 grades for 2011, 2013, and 2014 are not statistically different from each other (Figure 3a); however, the average Exam 1 grades were lower in 2010 and 2012 and are statistically significantly different ($p < .05$) from 2011 and 2014. For Exam 2 (Figure 3b), 2011 and 2014 are higher than and statistically significantly different from 2010, 2012, and 2013. For the third midterm Exam 3 (Figure 3c), 2010 and 2011 were statistically significantly higher than 2013. In addition, 2011 was statistically significantly higher than 2012 and 2014. Figure 3d shows the traditional (noncomputer) part of the final course exam. This figure shows that the final exam performance was similar for 2010, 2011, and 2014 with an average exam score of 78.2. Final exam scores in 2012 and 2013 were statistically significantly lower than the other years except for 2014-01 based on the 95% confidence intervals with an average final exam grade of 66. In general, the 2011 class performed statistically significantly higher in almost every relevant outcome. Final course grades are shown in Figure 4. Statistically significant differences exist between course grades where error bars do not overlap (2011 & 2012, 2011 & 2013). Overall average course grades for 2010/2014 and 2012/2013 were not statistically significantly different.

A summary of the average final exam and course scores is shown in Table 2 for each course taught from the Fall 2010 (Course A) semester through the Fall 2014 (Course B) semester, which included two sections due to growth in the overall class size. It should be noted that final course grades (Figure 4 and Table 2) reflect curved or replaced grades for the exams indicated. Students who wanted to improve their score had the option to retake a portion, typically one problem, of some exams. The grade on the retake problem was then averaged with the original grade on that problem to determine the exam grade. The overall course grades were very similar for 2010, 2013, and 2014 with an average of 79.4% for 2010 and 2014. However, it should be noted that unlike previous years (2010-2013), in 2014 (which represented the full transition to Course B) due to higher average exam scores, there were no curves used for any of the midterm or final exams and only one, Exam 3, involved a retake of the exam material. The overall course grades were slightly higher (83.8%) and lower (74.4%) in 2011 and 2012-2013, respectively. The averages between 79% and 80% represent a grade of a B- while the lower and higher averages reflect a C and B average, respectively (Figures 3).

In addition, in 2011 and 2014, final exam and course grade averages remained at 75 percent or above as shown in Figure 3d and Figure 4. The distribution of final course grades is shown in Figure 5, which reports the percentages of students receiving each grade. There was considerable growth in the number of students enrolled in the MEB course over the 5-year period from 31 in 2010 to 69 in the combined sections in 2014. In spite of the percentage of students receiving low/failing final course grades of D's and F's, is statistically lower in 2014 (9 percent) than in the two years directly preceding it (2012 [26%] and 2013 [23%], respectively) relative to the 5-year average of 18% based on the 95 percent confidence intervals. However, since the exams taken during this time period were different, it is not possible to compare these performance outcomes directly, even though the difficulty level and format of the exams were similar.

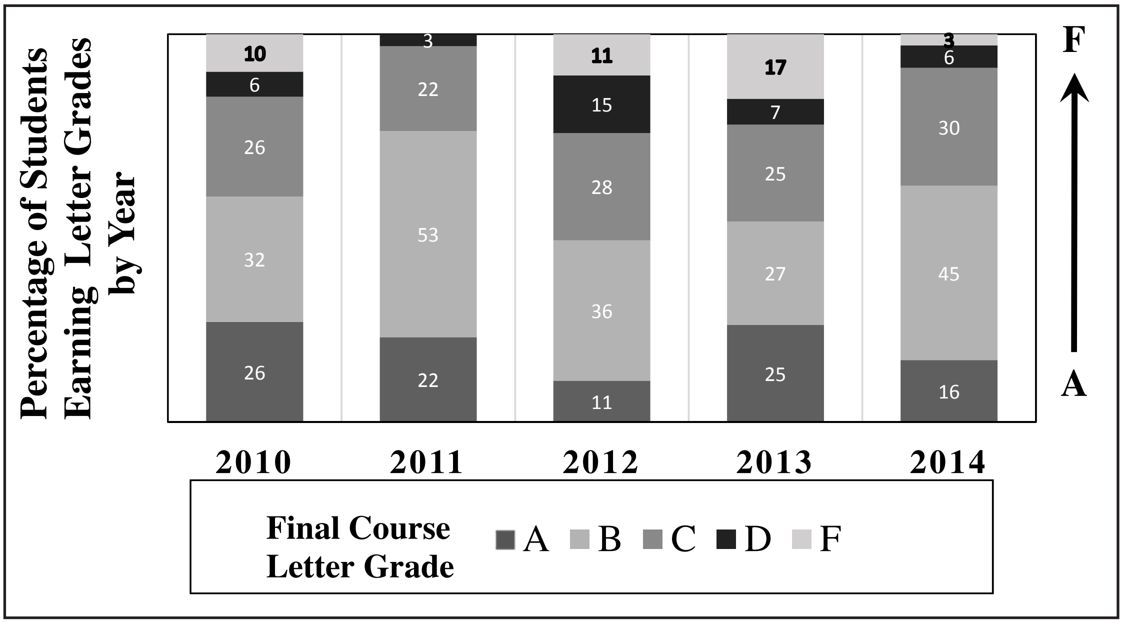

Figure 5. *Overall course letter grades by the percentage of students receiving that grade for each year (2010 – 2014).*

DISCUSSION AND CONCLUSIONS

Overall, the collaboration in teams using DyKnow was well received by the students based on mid- and end-of-the-semester feedback and helped support the active learning, a conclusion also drawn by Anderson, et al. and others.[27] In general, curving of grades is a practice that is generally negatively perceived by students and instructors, particularly those in STEM classes.[11] One marked difference between Course A and Course B in this study is that curving was used in Course A, but was completely eliminated in Course B. The final exam grades showed that the class performance in 2010, 2011, and 2014 was not statistically different, and that low average homework scores correlated with lower performance on the final exam. The conclusion that both the quantity of time spent on homework and the quality of how homework time is used are related to achievement, performance, and retention of students in a course has been shown by other authors particularly for flipped courses or courses involving significant homework or in-class work solving problems.[20, 28] In addition, the 2011 class was associated with higher scores on relevant outcomes, and had a statistically significantly higher average GPA compared to students in other years of the study. Although the influence of technology on the learning outcomes is not analyzed directly, student feedback collected anonymously via Blackboard at the middle and end of the semester in 2014 indicate that the enhanced collaboration and note-taking capabilities were generally viewed positively. The conclusions from the present study show that the number of students failing or receiving a "D" decreased by a factor of two for Course B where active learning was employed compared to the 5-year average performance for the course offering. These conclusions were similar to the conclusions of other authors as discussed earlier. Also there was an overall increase in performance on the final exam and course grades for Course B compared to the previous two years, which was achieved in the absence of any curving. The combination of active-learning methods, technology in lectures, and group problem solving used in this study showed improved overall student learning outcomes including exam scores and overall course grades, even if only modest improvements are observed in the exam scores.

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