IMPROVED STUDENT ACHIEVEMENT USING PERSONALIZED ONLINE HOMEWORK

for a Course in Material and Energy Balances

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"Digital natives" is a term describing the majority of students in higher education today.[1-4] These students have had access to computers and the Internet from early in childhood. Being connected to technology is considered normal with Smartphones and iPods always within reach. Educating technology-savvy students necessitates a more dynamic process than the standard lecture-homework-exam paradigm used at most universities during the 20th century.[4] Technology in the classroom is one way to engage the current generation of students (*e.g.*, clickers, Tablet PCs, YouTube Fridays).[5-7] Using technology in a classroom setting is a form of active learning that successfully connects students and learning.[8] Of specific interest here, online homework is an out-of-class technology that challenges students and personalizes the learning experience.

Using a textbook and assigning homework problems from the book is a standard tool in most undergraduate engineering courses. The number of textbook choices for a specific course is limited. The course of interest in this work is Material and Energy Balances where one of two textbooks is usually required.[9, 10] With the limited number of book choices and the free flow of information via the Internet, most students are easily able to obtain textbook solutions manuals. One student informed me that you acquire the solutions manual by "just Googling it." With solutions manual in hand, many students equate copying portions of the solutions manual with learning the problem-solving skills of a chemical engineer. While publishers very regularly print "new" editions of books, problems within textbooks do not engage the digital natives once the solutions manual becomes available.[11]

To overcome the stagnant content from the same textbook problems from year to year, several groups have turned to technology to personalize the homework experience. From faculty to small companies to large publishers, a change in the definition of homework in higher education has begun. The most comprehensive study in the literature evaluated learning gains from online courseware with respect to usage and self-regulation for a statics course.[12] Based on performance on a series of in-class exams, students' learning gains appeared to be more closely related to self-regulated usage (*i.e.*, a student working problems until they feel they have learned the material) than total usage of the online homework environment.

Other groups have initiated online homework projects using a system called LON-CAPA, an abbreviation for Learning Online Network with Computer Assisted Personalized Approach. One group of authors explicitly indicates that the objective of this system is not an online textbook but a mechanism to engage the students in learning the content of the course.[13] The open-source nature of LON-CAPA allows faculty to write problems for use only at their home institution and course or share with the greater community of users.[14] The online homework system detailed in this study is a commercial web-based system from Sapling Learning.[15] Comparisons between commercial systems and open-source tools will be an important exercise as more courses in higher education adopt these types of personalized learning systems. Online homework, based on the improved student achievement reported here, will become a more common tool in the coming years.

IMPLEMENTATION

The undergraduate program in the Department of Chemical Engineering at the Colorado School of Mines currently en-

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rolls more than 500 students. Three sections of the Material and Energy Balances (MEB) course were taught during the Spring 2010 semester. A different professor taught each section, but the students received common homework, quizzes, and exams (Table 1). All three instructors used common lecture materials, and all three instructors scored at or above the university average when rated on their effectiveness as an instructor by the students. The difference between students in section B and the two other "control" sections was the format of their homework assignments, which made up 5% of their semester's grade. The students in section B completed two homework sets each week: the common textbook-based problem set and a personalized online homework. The control sections completed one common textbook-based homework set and short multiple-choice reading quizzes in the course's web environment (Blackboard) each week. In general, the student achievement in the two control sections was indistinguishable (*i.e.*, independent of the instructor). Details on the standard homework, web-based quizzes, and online homework are included below and followed by an analysis of the student achievement.

Students were assigned problems from the textbook (Felder and Rousseau) as homework throughout the semester as is commonly done in chemical engineering courses. The MEB course assigned three to six problems each week to be hand written and handed in as the common homework for all three sections. The students were encouraged to work in groups, but individual hand-written solutions were turned in for credit and graded by teaching assistants. Generally, all of the homework problems were assigned from the textbook with the assumption that the solutions manual was readily available. Some problem sets included modified textbook problems (new numbers), problems written by the instructors, or materials taken from the BioEMB database.[16] Three types of homework sets were assigned: all textbook problems, mix of textbook and alternative problems, and all alternative problems (Table 2). The difference in the overall class averages indicates some level of mindless copying of the solutions manuals. Overall, the textbook problems with accessible solutions give the students a false sense of security as exam averages very rarely exceeded 75% in recent semesters.

One alternative to encourage textbook reading and studying is using multiple-choice quizzes (also called Blackboard quizzes or BBQs) inside of the class's web-based instructional environment. The quizzes examine the students' learning at the lowest levels of Bloom's taxonomy, namely knowledge and comprehension.[17] Many problems test the students on very basic calculations, which will be a small part of a problem on their homework. The length and difficulty of the BBQs is demonstrated in examples related to reacting systems and vapor-liquid equilibrium (Figure 1). Overall, students scored at least 85% on these types of problems throughout a semester. Since these quizzes are due before class, just-in-time learning can be employed by the instructor.[18, 19] As class begins, the questions with the students' responses (percentage) for each answer can be obtained by the instructor (and projected for the class to see). If one or more questions have a low score (usually <80%), this topic is then

Question: $C_6H_6 + 15/2\ O_2 \text{--->} 6\ CO_2 + 3\ H_2O$
1500 mol/s of oxygen and 300 mol/s of benzene are fed into the reactor for combustion. Which is the limiting reagent?
Answers:
- ☐ O_2
- ☐ N_2
- ☐ C_6H_6
- ☐ H_2O

Question: 3 SCMM of "Dry" Colorado air is at 22°C and a pressure of 12.1 psia is blowing in the wind. The partial pressure of the water in the air is 2 mmHg. What is the percent relative humidity?
Answers:
- ☐ 1
- ☐ 5
- ☐ 10
- ☐ 90

Figure 1. *Example questions from multiple-choice reading quizzes.*

TABLE 1
Outline of the Three Sections of Material and Energy Balances

Section	Number of enrolled students	Class time	Handwritten homework	Online homework	Blackboard quizzes
A	51	8 am	Yes	No	Yes
B	57	9 am	Yes	Yes	Optional
C	56	9 am	Yes	No	Yes

TABLE 2
Average Student Achievement for All Sections on Three Types of Homework Problems

Homework problem type	Number of homework sets	Class Average (%)	Standard Deviation (%)
All textbook problems	7	84.9	5.5
Mix of textbook and alternative problems	3	80.8	1.6
All alternative problems	2	70.0	n/a

re-introduced to start the class period. The multiple-choice quizzes ask five to 10 questions per week and take the students 30 minutes or less in most cases. Replacing the multiple-choice quizzes with online homework represented a greater time commitment for the students and required higher levels of Bloom's taxonomy as will be explored in the next section.

A private company, Sapling Learning, provided the online homework system employed in this work. While Sapling has been providing online homework for several years in areas such as chemistry and biology, Fall 2009 was the first time chemical engineering content was available. The questions are organized by chapter and topic to follow the textbook (Felder in this case) and the course syllabus. Sapling provided a Ph.D. chemical engineer as a "Technology T.A." to set up the assignments and assist the instructor. In this case, the Technology T.A. kept the instructor's extra effort required to use the Sapling system to less than 1 hour per week. The content is web-based and each student has an individual login. Sapling creates weekly homework sets based on the topics in the course syllabus. The instructor can then customize the basic problem set (*e.g.*, add/subtract problems, change due date). The questions are personalized for each student by changing at least one of the numbers in the problem statement. Thus, the content and concepts are consistent across the class without obtaining the same numerical answer. Each question allows the student to answer until they obtain the correct solution. A small portion of the grade (5% in this case) is deducted with each incorrect response. For example, a 100-point problem would be award 85 points after 3 incorrect attempts. The problems are accompanied by hints to guide the problem solving. Some problems have step-by-step tutorials that are available after a student enters an incorrect answer. After working the tutorial problem, the student returns to the original problem to complete the solution. Finally, fully annotated solutions are available once the student solves the problem or gives up.

The salient features of the Sapling personalized online system are summarized in Figure 2. One feature (Figure 2a) available on many problems is matching knowns (numbers with units) and unknowns to locations on a process flow diagram (PFD). Here, students click and drag the label to the appropriate location on the PFD. Drawing and labeling a PFD is a critical skill for mastery of the MEB course. PFDs translate words in the problems statements into simple diagrams representing physical processes. Also, hints are available to

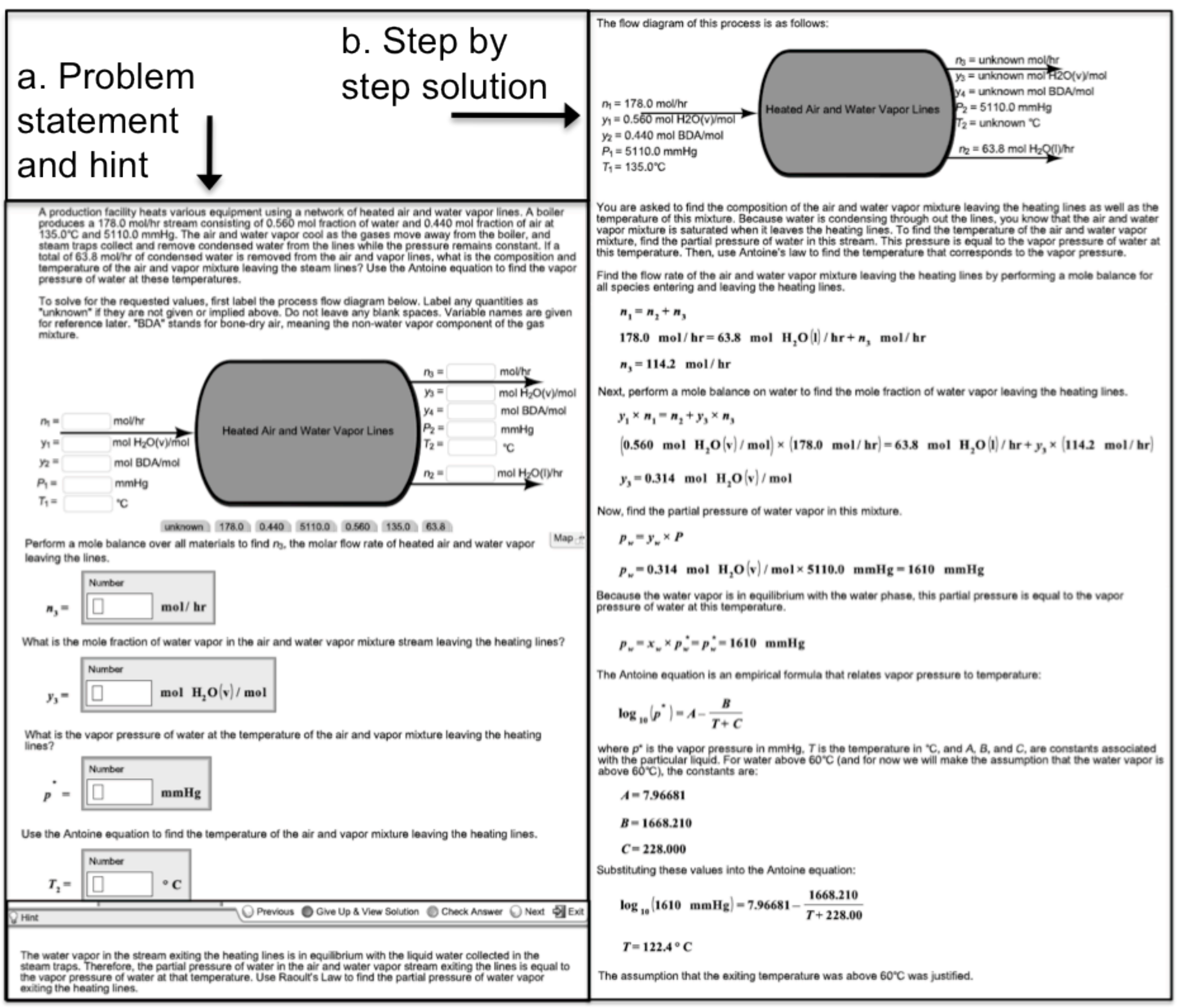

Figure 2. *Screenshots of an example online homework problem (a.) and solution (b.) from Sapling Learning.*

facilitate problem solving as the student works the problem (Figure 2a, bottom). In addition to the hints, correct answers are displayed when the problem is completed correctly or aborted. More importantly, a full explanation of the solution is available for the students to review (Figure 2b). Overall, a simple web-based system provides a framework for guided personalized learning by solving relevant material and energy balance problems. Real-time feedback is available anytime with the online homework system while one-on-one attention during office hours is limited to a few hours each week.

Overall, in the author's opinion, the difficulty of problems from the Sapling system is on par with questions from the Felder textbook, especially for reaction/recycle and vapor-liquid equilibrium problems discussed below. The students' opinion on time needed to complete online vs. textbook homework and the relative difficulty are included in the Evaluation section.

STUDENT ACHIEVEMENT

A series of hypothesis tests to determine the difference between two means quantifies the statistical significance for the students using the online homework compare to the control sections. The hypothesis is that the students using online homework earned the same level of achievement as the control group. Student achievement in the online homework section is considered statistically significant (*i.e.*, disproving the hypothesis) if the cumulative probability (p) is smaller than the baseline p-value. This baseline significance was determined from the cumulative probability based on students' overall grade point average (GPA) before the start of the semester. The online homework section had an average GPA of 3.16±0.54 while the control group's average GPA was 2.95±0.52. Students' t-test and degrees of freedom leads to the calculation of cumulative probability.[20, 21] The p-value for the preterm GPA is 0.0168. The hypothesis testing was applied to quizzes, exams, and final course grades.

Two of the most difficult types of problems in MEB are multi-unit reaction/recycle and vapor- liquid equilibrium (*e.g.*, problems like Figure 2). Two online homework problems on reaction/recycle were completed before an in-class quiz and subsequent exams. One online homework problem using Raoult's law preceded the second midterm. The students' achievement compared to the control sections on three reaction/recycle problems and two vapor-liquid equilibrium questions (Table 3). Four of the five questions analyzed show p values less than the significance of 0.0168. Therefore, student achievement showed statistically significant improvements. The improvement is believed to be strongly related to the additional practice using the rigorous online homework problems. Additional analysis of three midterms and one final exam showed the same statistically significant achievements.

The final course grades also quantify the increased student achievement (Table 4). The section using the online homework earned more A's and as many total A's and B's as the control sections despite having a significantly smaller number of students (56 and 100 for section B and A/C, respectively). The difference in GPA is statistically significant (p=0.0006), which places a very small probability that the hypothesis is true. A secondary metric for the Material and Energy Balances course is the number of students earning a C or better (the minimum criteria to advance in the chemical engineering curriculum). A C or better grade was achieved by 51 of 56 students (91%) in the section using the online homework while over one quarter of students in the control sections did not achieve a satisfactory score in the course. To place these numbers in context, an attrition rate of 25-35% for this course is believed to be "average" based on previous years at the Colorado School of Mines and my conversations with other faculty across the United States who teach the same course. Overall, the additional study time and practice using

TABLE 3
Student Achievement and Cumulative Probability on Quiz and Exam Problems Related to Two Difficult Course Topics

Test – Question type	Online + Textbook Homework section (Ave. % ± St. Dev.)	Textbook Homework + BBQ section (Ave. % ± St. Dev.)	p
Quiz 5 - Reaction with recycle	68±31	50±33	0.0006
Exam 2 - Reaction with recycle	84±13	72±17	0.0022
Final - Reaction with recycle	79±21	69±29	0.0178
Exam 2 – Vapor-liquid equilibrium	80±26	69±29	0.0110
Final - Vapor-liquid equilibrium	77±21	67±25	0.0074

TABLE 4
Overall Grades for the Course

	Number of students earning final grade in the course								
Sections	A	B	C	D	F	W	Average GPA[1,2]	Standard Deviation GPA[1]	%C or better[1]
B	20	15	16	4	1	1	2.93	1.05	91
A & C	17	18	37	15	13	7	2.27	1.24	72

1 Excludes students withdrawing from the course (grade of W).
2 p=0.0006 based on average GPA.

personalized online homework appears to lead to statistically significant improvements in student achievement.

EVALUATION

In addition to analyzing the students' grades on the online homework and in the course, a one-page evaluation about online and textbook homework was given at the end of the semester. The students were required to put their names on the surveys, and the surveys were collected and held by one of the students until after the semester's final grades were posted. Students' identities were cross correlated with the student's final grade in the course. The responses to 10 multiple-choice questions, which allow four levels of response, and three free response questions, are summarized.

TABLE 5
Students' Percentage Responses to Six Survey Statements

Statements	Strongly Agree	Agree	Disagree	Strongly Disagree
Sapling homework helps me understand the course concepts and topics.	38	46	13	2
Felder homework helps me understand the course concepts and topics.	35	58	8	0
The hints and explanations on the Sapling homeworks helped me better understand the course material.	38	40	15	6
I like doing Sapling homeworks.	12	38	37	13
I like doing Felder homeworks.	8	58	29	6
I like doing the combination of Sapling and Felder homeworks.	10	53	25	12

On average, the time needed to complete online homework was ~2 hours and textbook homework was ~2.5 hours. The distribution of average hours worked per week show the vast majority of the students spent 1 to 3 hours of time on each type of homework each week. The aggregate result of the number of hours per week spent working on the combination of online and textbook homework showed a notable trend (Figure 3). The students earning an A for the course put in more time each week on homework than the B students. The B students also put in more time on average than the C/D students. C and D students are grouped due to the small sample size of D students (n=4). The one student receiving an F in the test section did not take the survey (and was frequently absent from class). As an instructor, it was satisfying to learn that the harder-working students earned better grades in the course.

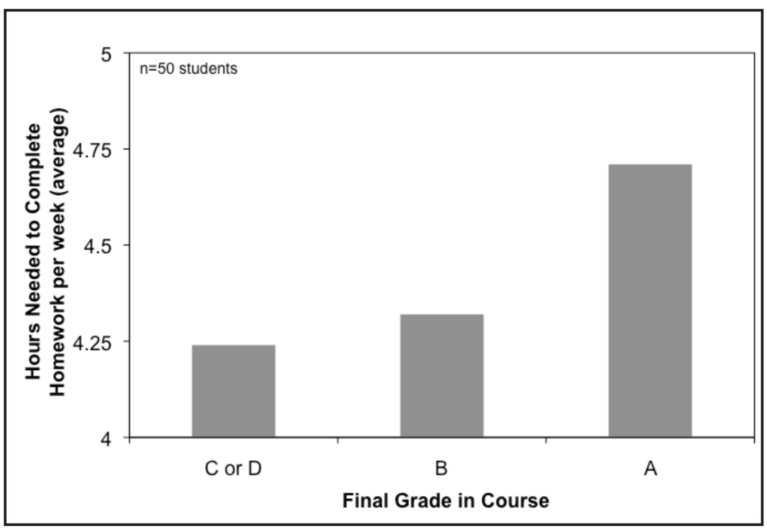

Figure 3. Average time spent completing homework (combination of online and textbook) as a function of final grade in the course. Hours average from survey responses (Survey response=average time: <1=0.5 hr; 1-2=1.5 hr; 2-3=2.5 hr; >3=3.5 hr).

Six questions were ranked strongly agree, agree, disagree, or strongly disagree (Table 5). The first two questions probed the students' perception of learning using online or textbook homework. The vast majority of the students believed they learned the course concepts and topics from both types of homework, with a slightly more positive response for textbook problem sets (84% and 93% agree/strongly agree for online and textbook homework, respectively). Next, the effectiveness of the learning aids (*i.e.*, hints and explanations) of the online homework system was queried. Positive response from more than three quarters of the students (78% strongly agree/agree) verify the additional material was worthwhile from the students' perspective. Three questions asked if the students "like" doing Sapling, Felder, or a combination of both. Overall, the students slightly preferred textbook to online homework. The students who received an A in the course gave a more positive response on all three "like" homework questions compared to the rest of the students. The preference of doing the combination of online and textbook homeworks was similar to doing textbook homework alone. Thus, the student surveys indicated that the additional work needed to complete the combination of online and textbook homework did not alter how much the students liked doing their homework.

Continuing the online/textbook comparisons, the preferred homework method or methods was queried. The question asked, "To maximize learn-

TABLE 6
Samples of Written Comments From Students About Online Homework

They are harder than normal problems, but having hints/explanations/tutorials helped.
I like the fact I could learn the material without too much penalty.
The explanations helped me understand where I was going wrong on the problems.
The Sapling problems helped me to understand the material by offering hints and explanations.
The detailed feedback on the questions I answered wrong helped me understand the concepts much better.
Sapling helps me learn the material a lot more than Blackboard quizzes because we have to work out problems and show our understanding step by step.
By doing Sapling before Felder, the Felder homework became easier.
I liked the hints given. It helped to teach a lesson rather than test a lesson.
As long as we aren't paying for it, I think it is a great idea.
The BBQs I did generally took 30-60 minutes at the most where as the Sapling generally for that week takes two or three times as long.
The step-by-step format of the problem allowed me to establish my concepts better.
Can we get solutions manuals for Sapling?

ing of the course material, completing _____ is necessary." where the choices were Sapling, Felder, Felder+Sapling, Felder+Sapling+BBQ. The majority of the class (66%) believed doing more than one type of homework maximized their learning. Completing only a single homework type showed a strong preference to textbook over online homework (31% for textbook, 4% for online). Doing online homework as the only preparation for in-class quizzes and exams with pencil and paper may be analogous to mastering hitting home runs on a video game and then trying to hit a home run off of a major league pitcher.

The final multiple-choice question collected data on the number of Blackboard quizzes the student completed over the course of the semester (out of 12). More than two-thirds of the class completed two or fewer Blackboard quizzes. The responses confirm the fact that optional assignments are rarely completed.

A free-response question collected the students' ideas on the aspect of online homework that helped them learn, what they would change or improve about the Sapling system, and a space for other comments. The hints and problems with step-by-step walkthrough were mentioned numerous times as helping the students grasp the problem solving (Table 6). Other representative comments reiterate points presented earlier, including taking significantly more time to complete than the Blackboard quizzes. Students wrote that online homework was more difficult than textbook homework, but it is unclear whether this feeling stems from not having the solutions manual when stuck on a problem (see final comment in Table 6). Overall, additional problems requiring step-by-step problem solving appear to make the students feel more prepared for quizzes and exams (based on these written responses).

Finally, the online homework evaluations and the standard university evaluations tallied several students requesting to do online homework as long as they (the students) do not have to pay for it. The cost per student is $34.99, but was discounted because the fee was paid by university funds. The concern about cost is legitimate with textbook prices for the latest version of the Felder text topping $200. If online homework is used in future semesters at the Colorado School of Mines, the cost of online homework will be paid for by the students, likely bundled with the textbook or e-book. The cost of personalized, online homework systems will likely fluctuate as publishers, third-party companies like Sapling, and open-source materials become widely available in the coming years.

CONCLUDING REMARKS

An experiment with personalized online homework with embedded hints and guides to encourage students to learn problem solving was completed. At the beginning of the 21st century, textbook homework problems are becoming less valuable as problems are stagnant (*i.e.*, same year to year) and solution manuals are readily available. Two groups of students were compared. One group completed online homework (with its related problem solving and higher-order thinking) while a second group of students completed simple multiple-choice reading quizzes each week. Statistically significant improvements in student achievement was observed on two of the most difficult course topics, namely reaction with recycle and vapor-liquid equilibrium problems. Final course grades of the section completing the online homework found 91% of the class receive C or better while only 72% of the control group did (a statistically significant result based on a hypothesis test between two means). Finally, student evaluations show that textbook homework is preferred to online homework, but requiring both online and textbook homework was thought to maximize learning by 66% of the section completing online homework. Overall, online homework is a viable technology that can improve student achievement and should be implemented if resources allow.

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