AC 2011-736: IMPROVED STUDENT ACHIEVEMENT IN MATERIAL AND ENERGY BALANCES USING PERSONALIZED ONLINE HOMEWORK

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Improved student achievement in Material and Energy Balances using personalized online homework

Abstract

Personalized, online homework was used to supplement textbook homework, quizzes, and exams for one section of a course in material and energy balances. The use of online homework during the Spring 2010 semester is summarized here and detailed by Liberatore in [1], and additional results from Spring 2011 will be included in the presentation. The objective of this study was to test the hypothesis that students using personalized, online homework earned better grades in the course. The online homework system asks the same questions of each student while changing one or more numeric values in the problem statement. A comparison of performance on common quizzes, exams, and final course grades between students using the textbook and online homeworks versus students completing textbook homework and simple, multiple choice reading quizzes showed a statistically significant increase in achievement for the students using online homework. Of note, 91% of the students using online homework achieved C or better as their final course grade compared with 72% of the students in the control group. Student evaluations show that 66% of the students prefer textbook homework in combination with online homework to maximize learning of the course material.

Introduction

"Digital natives" is a term describing the majority of students in higher education today [2-5]. 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 [5]. Technology in the classroom is one way to engage the current generation of students (e.g., clickers, Tablet PCs, YouTube Fridays, etc.) [6-8]. Using technology in a classroom setting is a form of active learning that successfully connects students and learning [9]. Of specific interest here, online homework is an out-of-class technology that challenges students and personalizes the learning experience.

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 using technology. 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 [10]. 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. Overall, 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 author's institution currently enrolls over 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 choices reading quizzes (Blackboard quizzes or BBQ) in the courses 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, online homework are included below and followed by an analysis of the student achievement.

Table 1. Outline of the three sections of Material and Energy Balances

Section	Number of enrolled students	Class time	Hand written 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

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 3 to 6 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 [11]. 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 exceed 75% in recent semesters.

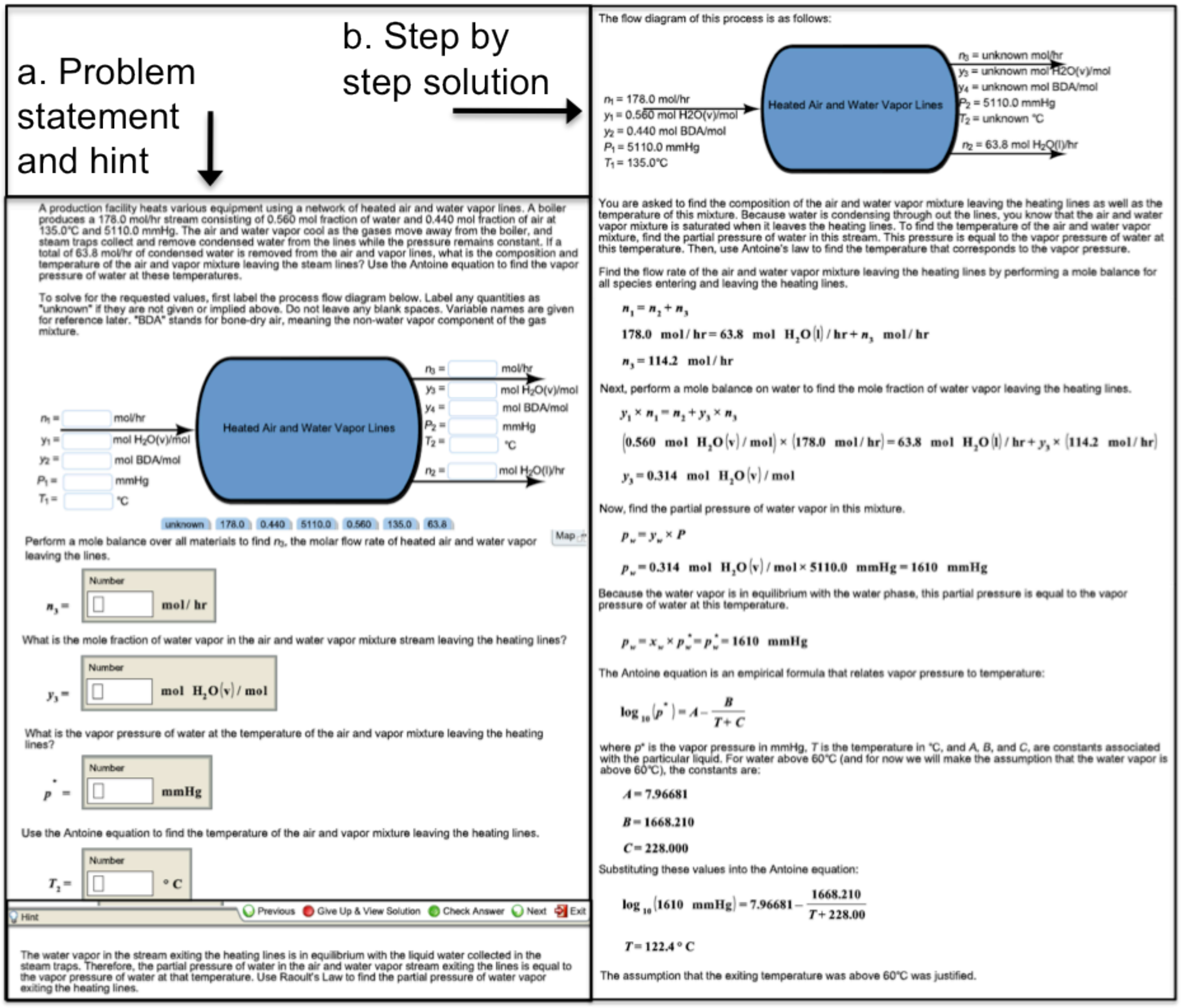
Table 2. Average student achievement for all sections on three types of homework problems

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

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 like 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, etc.). 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 1. One feature (Figure 1a) 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 facilitate problem solving as the student works the problem (Figure 1a, 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 1b). 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 versus textbook homework and the relative difficulty are included in the Evaluation section.



A production facility heats various equipment using a network of heated air and water vapor lines. A boiler produces a 178.0 mol/hr stream consisting of 0.560 mol fraction of water and 0.440 mol fraction of air at 135.0°C and 5110.0 mmHg. The air and water vapor cool as the gases move away from the boiler, and steam traps collect and remove condensed water from the lines while the pressure remains constant. If a total of 63.8 mol/hr of condensed water is removed from the air and vapor lines, what is the composition and temperature of the air and vapor mixture leaving the steam lines? Use the Antoine equation to find the vapor pressure of water at these temperatures.

To solve for the requested values, first label the process flow diagram below. Label any quantities as "unknown" if they are not given or implied above. Do not leave any blank spaces. Variable names are given for reference later. "BDA" stands for bone-dry air, meaning the non-water vapor component of the gas mixture.

n_1 = mol/hr
y_1 = mol $H_2O(v)$/mol
y_2 = mol BDA/mol
P_1 = mmHg
T_1 = °C
n_3 = mol/hr
y_3 = mol $H_2O(v)$/mol
y_4 = mol BDA/mol
P_2 = mmHg
T_2 = °C
n_2 = mol $H_2O(l)$/hr

Perform a mole balance over all materials to find n_3, the molar flow rate of heated air and water vapor leaving the lines.

n_3 = ☐ mol/hr

What is the mole fraction of water vapor in the air and water vapor mixture stream leaving the heating lines?

y_3 = ☐ mol $H_2O(v)$/mol

What is the vapor pressure of water at the temperature of the air and vapor mixture leaving the heating lines?

p^* = ☐ mmHg

Use the Antoine equation to find the temperature of the air and vapor mixture leaving the heating lines.

T_2 = ☐ °C

The water vapor in the stream exiting the heating lines is in equilibrium with the liquid water collected in the steam traps. Therefore, the partial pressure of water in the air and water vapor stream exiting the lines is equal to the vapor pressure of water at that temperature. Use Raoult's Law to find the partial pressure of water vapor exiting the heating lines.

The flow diagram of this process is as follows:

n_1 = 178.0 mol/hr
y_1 = 0.560 mol H2O(v)/mol
y_2 = 0.440 mol BDA/mol
P_1 = 5110.0 mmHg
T_1 = 135.0°C
n_3 = unknown mol/hr
y_3 = unknown mol H2O(v)/mol
y_4 = unknown mol BDA/mol
P_2 = 5110.0 mmHg
T_2 = unknown °C
n_2 = 63.8 mol $H_2O(l)$/hr

You are asked to find the composition of the air and water vapor mixture leaving the heating lines as well as the temperature of this mixture. Because water is condensing through out the lines, you know that the air and water vapor mixture is saturated when it leaves the heating lines. To find the temperature of the air and water vapor mixture, find the partial pressure of water in this stream. This pressure is equal to the vapor pressure of water at this temperature. Then, use Antoine's law to find the temperature that corresponds to the vapor pressure.

Find the flow rate of the air and water vapor mixture leaving the heating lines by performing a mole balance for all species entering and leaving the heating lines.

$$n_1 = n_2 + n_3$$

$$178.0 \text{ mol/hr} = 63.8 \text{ mol } H_2O(l)/\text{hr} + n_3 \text{ mol/hr}$$

$$n_3 = 114.2 \text{ mol/hr}$$

Next, perform a mole balance on water to find the mole fraction of water vapor leaving the heating lines.

$$y_1 \times n_1 = n_2 + y_3 \times n_3$$

$$(0.560 \text{ mol } H_2O(v)/\text{mol}) \times (178.0 \text{ mol/hr}) = 63.8 \text{ mol } H_2O(l)/\text{hr} + y_3 \times (114.2 \text{ mol/hr})$$

$$y_3 = 0.314 \text{ mol } H_2O(v)/\text{mol}$$

Now, find the partial pressure of water vapor in this mixture.

$$p_w = y_w \times P$$

$$p_w = 0.314 \text{ mol } H_2O(v)/\text{mol} \times 5110.0 \text{ mmHg} = 1610 \text{ mmHg}$$

Because the water vapor is in equilibrium with the water phase, this partial pressure is equal to the vapor pressure of water at this temperature.

$$p_w = x_w \times p_w^* = p_w^* = 1610 \text{ mmHg}$$

The Antoine equation is an empirical formula that relates vapor pressure to temperature:

$$\log_{10}(p^*) = A - \frac{B}{T + C}$$

where p^* is the vapor pressure in mmHg, T is the temperature in °C, and A, B, and C, are constants associated with the particular liquid. For water above 60°C (and for now we will make the assumption that the water vapor is above 60°C), the constants are:

$$A = 7.96681$$

$$B = 1668.210$$

$$C = 228.000$$

Substituting these values into the Antoine equation:

$$\log_{10}(1610 \text{ mmHg}) = 7.96681 - \frac{1668.210}{T + 228.00}$$

$$T = 122.4\,°\text{C}$$

The assumption that the exiting temperature was above 60°C was justified.

Figure 1. Screenshots of an example online homework problem (a.) and solution (b.) from Sapling Learning.

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. Student's t-test and degrees of freedom leads to the calculation of cumulative probability [12, 13]. 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 1). 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 3 reaction/recycle problems and 2 vapor-liquid equilibrium questions. 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.

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

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 to 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 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

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.

were cross-correlated with the student's final grade in the course. The responses to ten multiple-choice questions, which allow four levels of response, and three free response questions are summarized.

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 over 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 learning 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.

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

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 were 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 (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.

Acknowledgements

The author acknowledges the Center for Engineering Education and the Department of Chemical Engineering at the author's institution for funding the online homework experiment during the Spring 2010 semester. The Trefny Institute for Educational Innovation at the author's institution also provided financial support to the author to complete this work. The author would like to acknowledge Ron Miller and Keith Neeves for help with manuscript preparation.

Disclaimer

Sapling Learning, who provided the online homework system used in this work, did not compensate the author in any way.

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