HIGH TEXTBOOK READING RATES WHEN USING AN INTERACTIVE TEXTBOOK FOR A MATERIAL AND ENERGY BALANCES COURSE

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Engineers are known for being problem solvers, and one problem can have many viable solutions. Textbooks became a standard tool for higher education in the 20th century, and remain a standard method for information dissemination and reference for undergraduate engineering courses. Engineering textbooks explain concepts and define terms and equations. Additionally, worked examples and homework problems are included. Recently, while smartphones and tablets have become relatively inexpensive and multifunctional, the price of textbooks has risen dramatically to more than $200 for a traditional hardcover engineering textbook. Some students opt to use the internet for free rather than add hundreds of dollars of books to growing tuition costs.[1] Simple access to factual information through internet searches has changed how students obtain most of the information found in textbooks.[1]

Textbook selection is normally done by faculty or groups of faculty based on familiarity with content ("did I use that book when I was an undergraduate?"), availability ("can my bookstore get enough copies?"), history ("student surveys didn't mention problems with the book"), and other criteria.[2] However, studies that either quantify student reading rates or relate student learning with textbook usage are lacking, especially for engineering and chemical engineering courses.

Research over more than four decades shows a majority of students ignore textbook readings.[3-8] For example, the 2016 National Survey of Student Engagement surveyed more than 280,000 college and university students and asked how often the student came to class without completing readings. Across many subsets of students—including by year, gender, and engineering majors—the likelihood that students came to class without reading was about 20% for students responding often or very often and consistently more than 70% for students responding sometimes, often, or very often.[4] Another study analyzed reading of more than 900 students across 16 years using an unannounced quiz with survey, which asked whether the students read the assignment as well as evaluated responses to questions about the reading as passing (>50%) or failing.[7] A decreasing amount of reading compliance was found from 80% in the early 1980s to about 20% between 1993 and 1997, which precedes the availability of handheld electronic devices.

Observations that students were not reading textbooks combined with the lack of textbook replacements led instructors to create alternative methods that provide incentives to read the textbook.[9-14] Some alternative methods may be considered

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active learning—the set of techniques that continue to show in single studies and meta-analyses that students learn more through doing.[15-18] For example, reading quizzes have been given either outside of class, *e.g*., using a learning management system, or during class.[18] While frequent assessment and repetition is advantageous for learning, these methods do not address the disconnect between most engineering textbooks and students learning the material for the first time. Felder and Brent go so far as to say "STEM texts are often dense, dry, and almost indecipherable to students who don't already understand much of what they are reading." [18, p. 96-97] Very recently, reflection on textbook material has become available[19] with students contributing comments that are automatically graded using machine learning algorithms.[20]

Steps to modernize textbooks include electronic versions of paper textbooks. Searching the electronic documents, bookmarking, and highlighting are common for e-books read on smartphones and tablets in the early 2010s. Surveys of more than 1,000 college students found that electronic textbooks are accepted or preferred.[21] Interactivity, which can also be considered active learning, is a newer feature still being introduced in textbooks. Supplemental tools, including online homework, have shown learning gains in students who learn using scaffolded problems with small penalties for incorrect answers.[22,23] While these tools are a clear extension of a paper textbook that instructors are comfortable with, fully interactive and low-cost alternatives are starting to become available in engineering. Alternatively, a recent study of more than 600 students across several semesters found a growing majority of digital natives would prefer interactive textbooks to static paper or electronic versions.[24]

Comparing student learning across platforms and technology has evolved over many years.[25,26] Multimedia presentations led to improved test scores compared to students using text-based presentations.[27] Students have also shown preference for the diverse set of resources on the internet compared to a single, text-heavy textbook.[1,27] More recently, interactive web-based content led to statistically significant learning gains compared to static web-based content.[10,12] Animations and interactive simulations are well received by students, and the tracking of mouse movements is being used to identify misconceptions in students.[28-32] Overall, interactive technologies should be developed to leverage the strengths of the digital native[33,34]; however, many faculty authors of educational materials are not natives of the digital age, so creation and adoption of interactive materials may be slow.

Specific to the course of interest here, material and energy balances (MEB) generally introduces students to chemical engineering. The best practices, innovations, and active learning when teaching material and energy balances have been published over many years (*e.g*., References 35, 36). Since course-level details are secondary to the findings of this work, a detailed review of these numerous publications is not provided.

In summary, an interactive textbook may be considered another domain under the guise of active learning. In this paper, the goal is to evaluate usage of a new interactive textbook and related student outcomes. Features of the book, quantitative data on student usage, correlations between usage and grades, and students' feedback will be detailed.

A FULLY INTERACTIVE TEXTBOOK

ZyBooks are full-scale textbook replacements that are viewed, read, and interacted with in a web browser.[37] The author has created what is believed to be the first interactive web book for chemical engineering, titled Material and Energy Balances zyBook. A summary of quantifiable features (Table 1) demonstrates that the interactive web book covers the important content and concepts for a material and energy balances course or related courses.[35] While having access to the internet is required to complete participation, which will be detailed later, a static version can quickly be created (as a pdf file) for offline use and future reference. In addition, appendices are freely available, searchable, and in a form where copying pertinent data to spreadsheets is simple and encouraged (data cannot be copyrighted[38]).

TABLE 1
Feature count of the MEB zyBook as of August 2016

Feature	Number
Sections with content	67
Sections introducing equipment	17
Appendices	12
Animations	>75
Clicks to read whole book	>750
Homework questions	>200
Updates	Regularly

Additional unique features are available. Instructors can order sections to match their syllabus; sections can also be hidden or available without tracking participation. Instructors can add notes or additional content to any section. Students pay less than $50 to access for the semester and can re-subscribe for a small fee (<$20) in future annual increments. Therefore, students can choose to own the book for <$100 for 3 years of undergraduate study (as MEB is often a sophomore course) and have access to the latest animations and features.

The interactive MEB textbook includes many standard features that digitally native students find in e-books and websites. Any HTML5 compliant web browser can be used, so no special software or plug-ins are needed. Easy navigation through a table of contents and searchable index help students quickly refer back to a certain keyword or concept. The book is built on a responsive web template, so a clean, clear interface is available across desktops, laptops, and tablets—with most features also available on smartphones.

Two specific features, namely learning questions and animations, will be detailed below with static, multi-panel figures in an attempt to demonstrate the interactive nature of the book. Both learning questions and animations create incremental units, or chunks, for learners to read and interact with, which is consistent with cognitive load theory. Cognitive load theory[15, 39-41] assumes that working memory has a limited capacity when dealing with new learning. Also, the theory presumes partially independent subcomponents of working memory related to different senses—*e.g.*, visual, touch—that are triggered when participating in the interactive web book.

Learning questions

For decades, homework questions have been included at the end of engineering textbook chapters to test students' comprehension of terms and new problem-solving skills. More recently, quiz questions with instant feedback on whether students are correct or incorrect have been added, usually also at the end of the chapter.[18] In the zyBook, homework sets are built in line with the text from learning questions. Learning questions (Figure 1) go beyond students identifying correct or incorrect answers by providing instantaneous, instructive, and unique feedback for each choice. On the one hand, correct answers elaborate on why the answer was chosen, which may include a few lines of calculation. On the other hand, incorrect responses detail how and why students could have come to an incorrect conclusion and suggest a path to identify the correct answer. Learning questions are scaffolded within a set,[18,42] so simple queries precede more difficult questions.

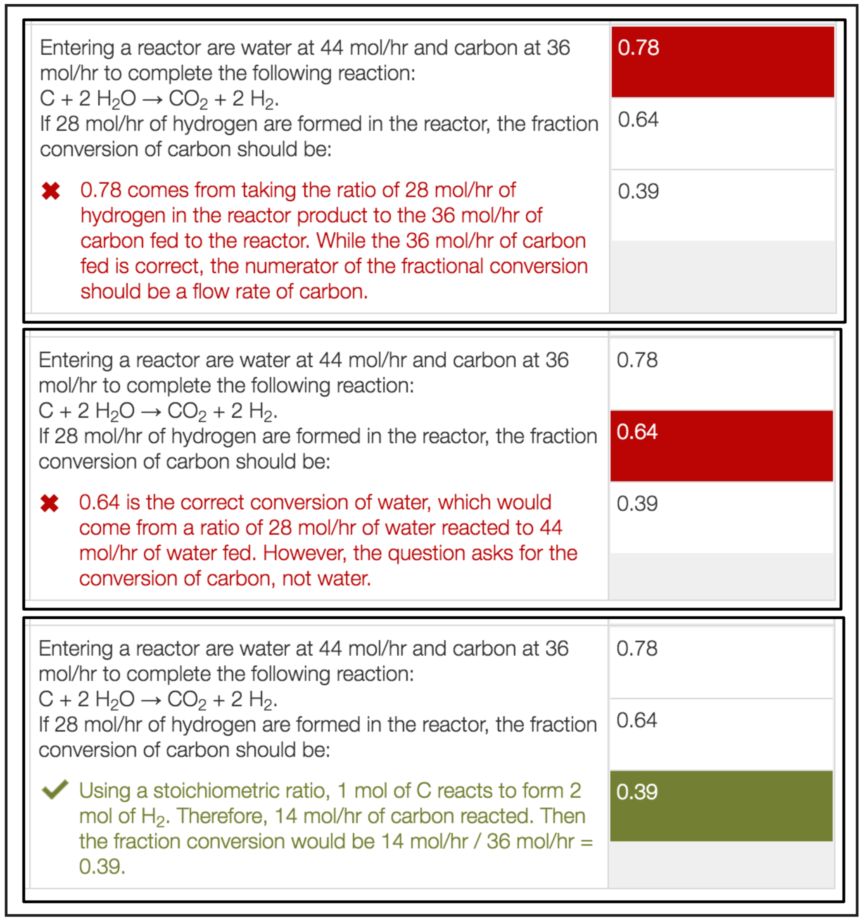


Figure 1. *One multiple-choice learning question related to reacting systems with each answer selected. Each answer includes explanation of the correct or incorrect response.*

Animations

Animations, which appear to be the first of their kind in a chemical engineering textbook, are another feature of the interactive web book. Generally, an animation takes a static image, such as a figure, and builds the text, equations, and diagrams through a small series of steps—usually 3 to 6 steps. Animations are interactive; readers must click to initiate each step, and each step includes animated actions and a text caption. Mixing text and images has been shown to be beneficial for learning.[39] Generally, animations fall into three types, namely: (1) derivations – such as applying simplifications to a general energy balance; (2) figures – such as constructing a phase diagram; and (3) actions occurring in process units – such as separation in a distillation column. Animations and question sets can be reset, so students re-watch to review before quizzes and exams. Students reported watching animations multiple times, which will be discussed later.

While an animation cannot be demonstrated in a static publication, a multi-paneled figure (Figures 2, next page) shows how new concepts can be framed and chunked. Animations begin with clicking the Start button (not shown), and a four -sentence problem statement appears at the top with a caption at the bottom. The second step copies each sentence of the problem statement, and the associated drawing (stream or process units) appears over about 10 seconds. Finally, the drawings assemble into a process flow diagram. Breaking figures into smaller steps would agree with cognitive load theory, introduced earlier, which is difficult to do with a standard textbook where text and figures are assembled in an organized, universal sequence.

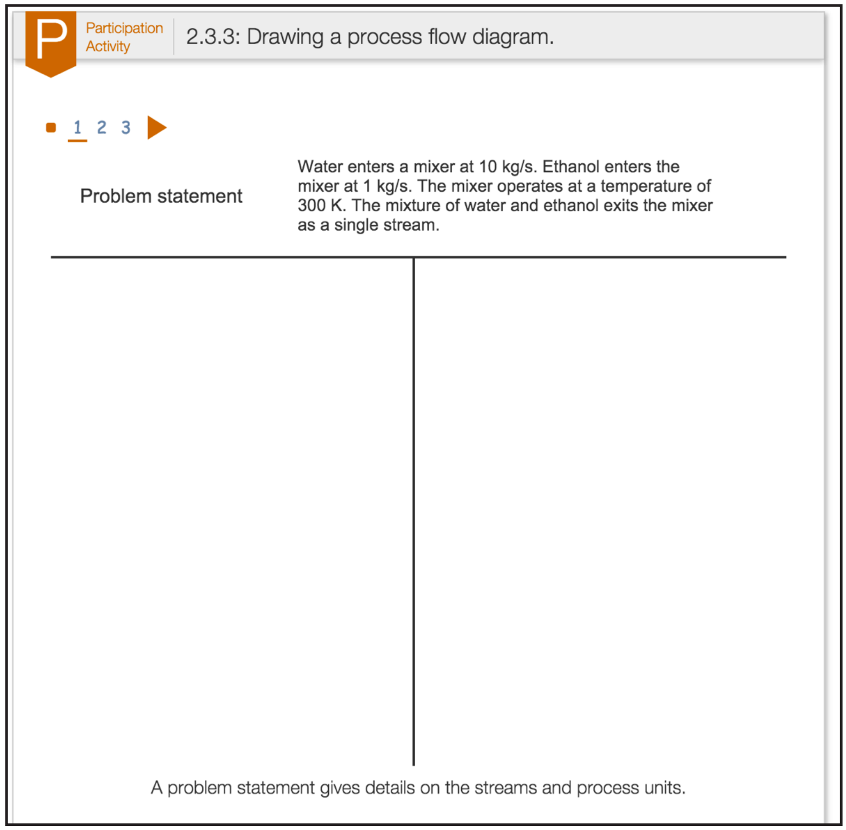
Overall, animations take 30 seconds to 2 minutes to watch. Therefore, the animations are analogous to short video clips used in many flipped classrooms, where the video length is found to be more effective when less than 10 minutes.[43-45]

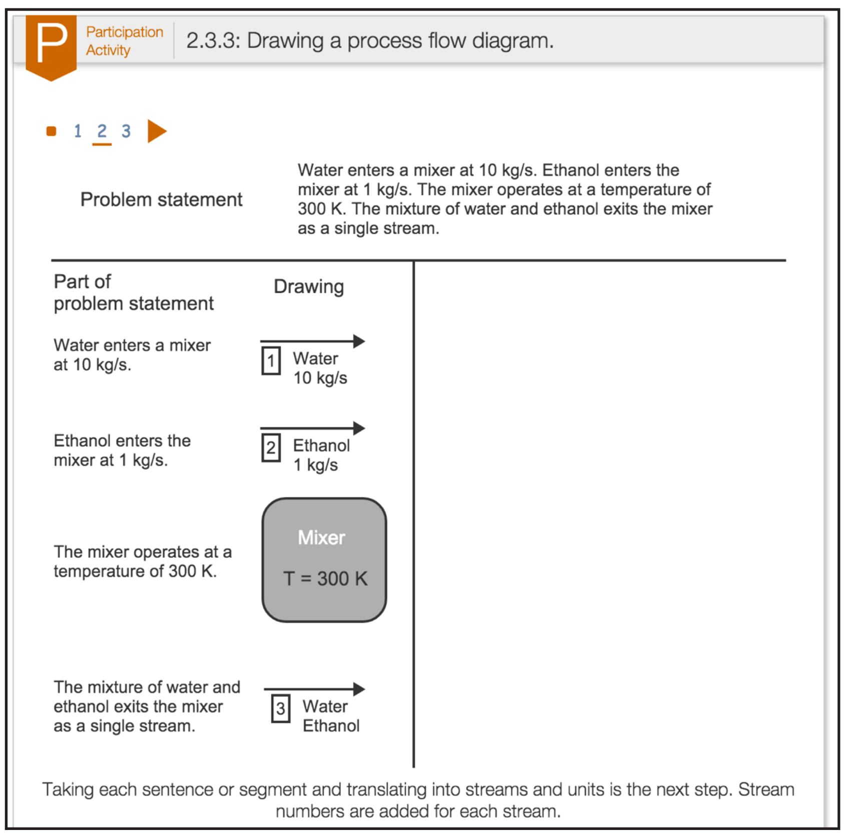
METHODS

The first class to use Material and Energy Balances zyBook was at the University of Toledo during the Spring 2016 semester. The course consisted primarily of freshmen students in their second semester of college. The course is taught earlier than most chemical engineering programs[35] to better prepare students for mandatory co-op experiences, which start as early as spring semester of the sophomore year. Enrollment included 100 students, 60% male and 40% female, after five students withdrew during the semester. Two professors, including the author, attended all classes and alternated leading class time; both professors served as in-class coaches during active-learning segments. Three graduate teaching assistants provided office hours and were additional in-class coaches (see References 36, 46).

The university determined that the findings discussed below are considered program evaluation and not research, since the findings were formulated after the course. Future hypotheses or questions formulated based on these findings will be vetted by the Institutional Review Board. During post-course evaluation, a hypothesis was formulated: Higher rates of textbook reading improve final course grades. The following questions provide a framework to begin testing this hypothesis.

1. *How does student usage of an interactive web book compare to the literature for conventional paper-based textbooks?*
2. *How do web book reading rates correlate to student performance, as aggregated by higher-performing and lower-performing students?*
3. *Do web book reading rates correlate to gender?*
4. *Do students using the interactive web book feel engaged with different features?*





Figures 2, right and facing page. *Three static screenshots of a three-step animation about drawing a process flow diagram.*

RESULTS

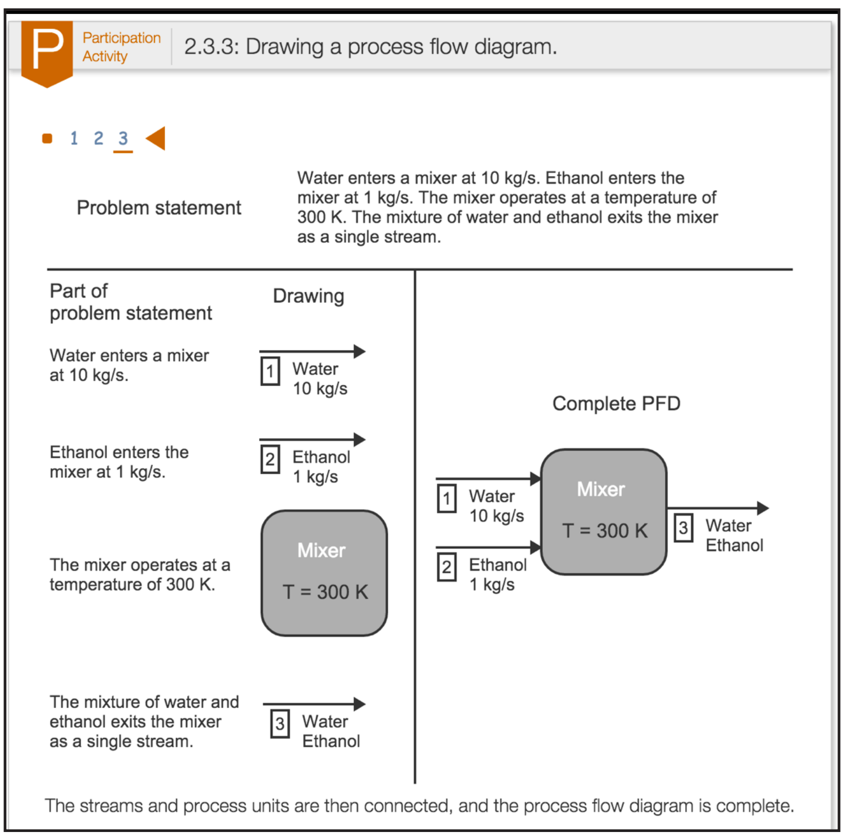
Quantitative usage

Students were assigned readings of one to four sections of the interactive web book before most classes. Due dates for each section can be entered by the instructor directly into the book. In this case, 6% of the total course grade was earned for completing the readings before the due date. A more comprehensive study[11] found as little as 2% of the course grade provided enough incentive for students to read an interactive web book.

Participation grades are earned when clicking correct answers in question sets or viewing each step in an animation. Participation grades are transparent, so students see their score accumulate as they read (similar to gamification of certain engineering courses[47-49]). Clicking incorrect answers does not penalize students, so students come to recognize the detailed feedback on why each answer is correct or incorrect. The effect of students' mindlessly clicking to earn participation grades has been studied by other authors; 73% of students earnestly attempted at least 80% of the problems and only 1% of more than 500 students earnestly attempted less than 20% of the problems.[9] Students mastered the new style of textbook and required reading assignments after a few classes. The first three reading assignments led to 57, 23, and 87% of the class earning 100% participation grades (full data available in Reference 50). Aggregate participation data was shared with students early in the semester to reinforce the importance of reading. While students were provided a second chance to earn a perfect participation score for Chapter 1, consistent participation before a firm due date occurred thereafter.

With 67 sections over eight chapters, the zybook generated a large amount of student participation data. Overall, 87% of the reading for the entire class and semester were completed on time. This high reading rate is very encouraging, compared to less than 30% reading rates reported over several decades.[3-7] Specifically, five of the eight chapters registered at least 85% participation, while the other three chapters garnered 78, 79, and 81% participation. While the number of sections per chapter ranged from four to 16, the number of sections did not correlate with participation. Fluctuations in reading scores by section or chapter were not significant, and likely reflect the uneven and cyclic workload of college students.

Additional analysis found 85% of the sections were read completely (5,686 out of 6,700); on average, a section contained 12 recorded clicks, while longer sections monitor more than 30 clicks. Partial participation occurred in 2.6% of the sections, *i.e.,* 1 to 99% of the participation grade. Finally, 13% of the sections were not attempted before the due date, indicating that students rarely moved on without completing a section they had started. Bugs are a concern with new technology, however, the very small number of partially completed sections and only one complaint that clicks were not recorded confirm that some students' chose to not participate or did not value their grade.



Usage and course grades

Using the quantitative web book participation data, two additional questions relating reading and grades can be examined. Exam scores, quizzes, and homework determined final course grades. Four exams—three midterm exams and one final exam—comprised 70% of the grade, while eight quizzes (out of nine with the lowest score dropped) contributed 10%. The remaining 20% of the grade was allocated as 14% for homework—weekly handwritten and some multiple-choice questions on the learning management system—and the final 6% for participation in the interactive web book.

Since participation grades were high, the effects of conflating web book participation and final grades were small. For example, the average A student earned 5.7% of their final grade from web book participation compared to 5.5% for the average B student. The largest

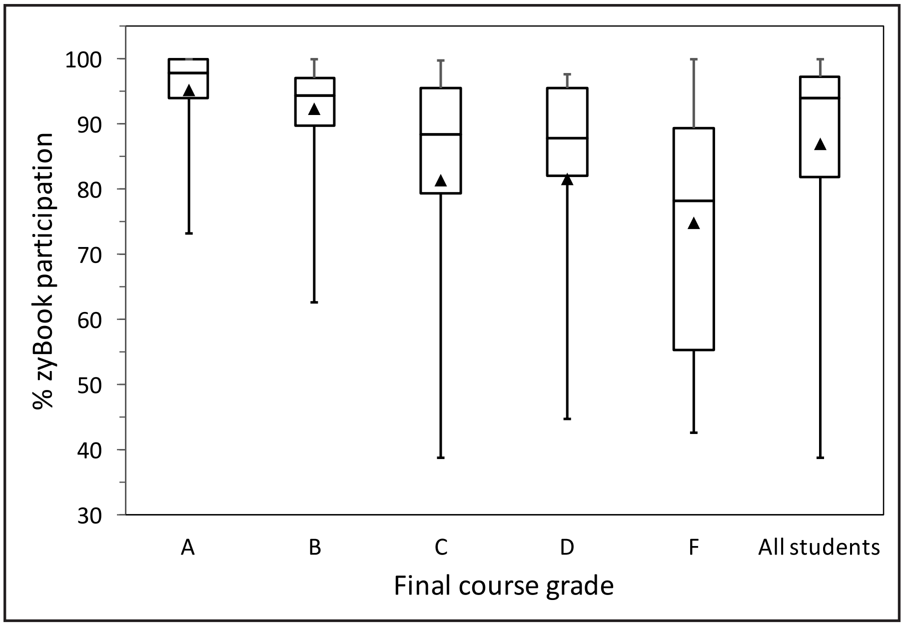


Figure 3. Box-whisker plot comparing interactive web book participation grade to final course grades. Filled triangles represent the mean scores. n=100 students.

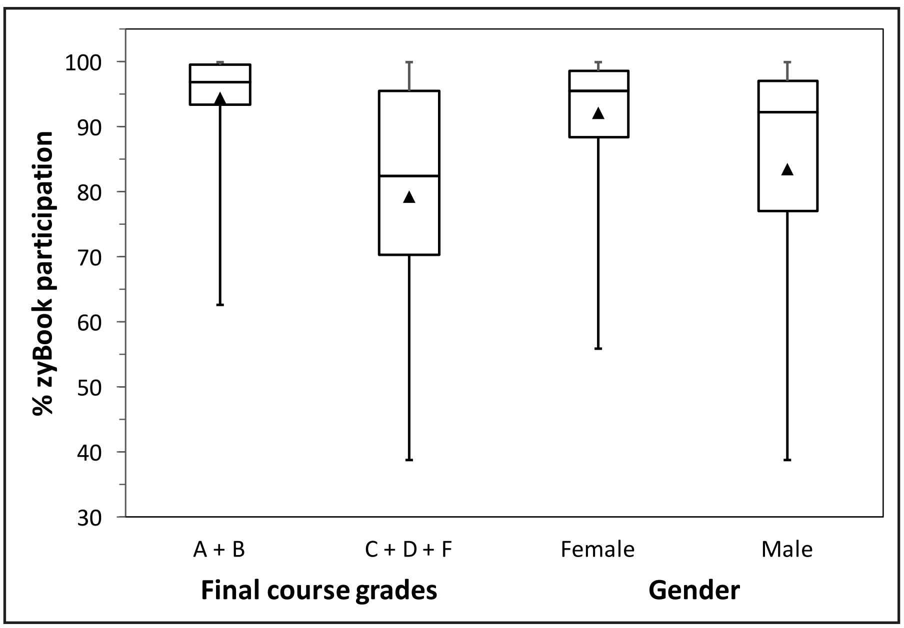


Figure 4. Box whisker plots comparing web book participation and either subsets of the final course grade or gender. Statistically significant differences were found based on final course grades (p<0.001) and gender (p=0.008). n= 50 A+B, 50 C+D+F; 40 female, 60 male students.

change between average web book scores and final grade categories is 0.6%, which is unlikely to alter a student's final letter grade. Students earned simple letter grades—A, B, C, D, and F—without the use of plus/minus grades; the class's grade point average (GPA) was 2.50, which is in line with previously published values for MEB.[36,51] A grade of D is a passing grade for continuing through the curriculum.

Comparing web book participation with final course percentage showed some trends with significant scatter, while grouping students into grade categories allowed for more quantifiable analysis (Figure 3). First, average participation (represented by filled triangles) generally increases with better grades, *i.e.*, A students read more than B students. The largest decrease in average participation comes between B and C students (11%). While C and D students read the same amount, F students read 7% less on average than D students. A linear regression, while not shown, fit average participation versus grade (using A=4, etc.) with an R^2 value of 0.93, so the fit is reasonable. This regression quantified a 5% increase in average participation for each letter grade starting at 75% for F students. While other studies demonstrated weak or no correlation between reading and grades,[14,52] comparisons for engineering textbooks could not be located.

Box-whisker plots provided additional details about the distribution of participation (Figure 3). Median scores for each final grade category (horizontal line dividing the two boxes) were higher than averages in all cases. Since the boxes represent the second and third quartile of students, the distribution of participation for A and B students is much smaller and at higher values than for C, D, and F students. Alternatively, standard deviations for A and B students (7 and 10%, respectively) were significantly smaller than for C, D, and F students (18, 22, and 20%, respectively).

Examining high and low participation in relation to final grades quantified two additional trends. First, at least one student earning an A, B, C, D, and F completely read the interactive web book before the due dates (highest score in the D category was 98% while 100% was earned in the other categories). Therefore, reading the interactive web book cannot guarantee a satisfactory course grade, which is not surprising in the author's opinion. Also, the minimum amount of reading to earn an A in the course was 73%, and A and B students had noticeably higher minimum reading rates than C, D, and F students.

Further categorizing students provided more detail into the relationship between web book participation and final grades. The class was divided exactly in half when grouping A and B versus C, D, and F students (Figure 4). Very small second and third quartile boxes for A and B students showed 76% of these students earned participation grades of 93% or higher, while only 32% of C, D, and F students earned participation scores of 93% or higher. Similarly, the fraction of students with participation grades of 90% or higher, *i.e.*, those earning an A for web book reading, is dramatically different. While 82% of A/B students read 90% of the book, only 36% of C, D, and F students accumulated an A for reading, which tracks assignments without penalties for incorrect answers.

Since interactive web book reading was a participation grade and did not evaluate conceptual knowledge, a null hypothesis could be made that all students should earn the same grade for reading. Comparing 50 A and B students with 50 C, D, and F students using a two-tailed unpaired t-test finds $p < 0.001$, which is statistically significant. Thus, students in the bottom half of the class do complete less reading, which is believed to be quantified for the first time for a chemical engineering textbook.

Finally, participation and final grades were compared with respect to gender. Female students earned higher participation grades on average (92% vs. 83%) with smaller second and third quartiles (Figure 4). Applying a null hypothesis based on gender finds $p = 0.008$, which is statistically significant. Higher participation again mirrored final course grades. Female students earned an average GPA of 2.7±1.4 compared to 2.3±1.4 for the male students ($p = 0.2$). Gender differences and perceived disinterest of female students are discussed related to games and college courses,[53-55] while high reading rates were recorded, regardless of gender. Previously, interactive web content helped lower-achieving students more when comparing scores on pre- and post-reading quizzes,[12] while this data appears to be the first to examine gender and interactive textbook reading. Therefore, two subsets of students, gender and higher/lower final grades, find good agreement with the trend observed for the entire class, and confirm that a correlation between web book participation and final course grades extends to sub-categories of students.

Overall, students' usage of an interactive web book has been quantified directly, possibly for the first time, and usage correlated with students' final course grades. Several caveats should be noted. First, correlation does not imply causation, so these findings should not imply that reading more will result in a higher course grade. Since most students were in their second semester of college, measures—such as pre-term GPA—were not employed to characterize student quality. Due to the limited sample size of 100 students, correlations have not been tested outside of the author's class. Thus, a halo effect[56] may account for some of the findings, especially for self-reported surveys discussed next.

Student surveys

Surveys measuring students' opinions provide some information about engagement. Near the beginning of the semester, informal, anonymous feedback was requested after completing Chapter 1. On index cards, the students responded to three course-related questions. One question stated: "List two things you like about the zyBook." Early in the semester during a material and energy balances course, putting a positive spin on questions has proved successful in encouraging students' feedback.

TABLE 2
Book features that students like (n=100 students)

Feature	Number of students
Interactive	46
Concise/less text	39
Animations	20
Easy to understand/ organized	20
Explains why the answer is wrong	16

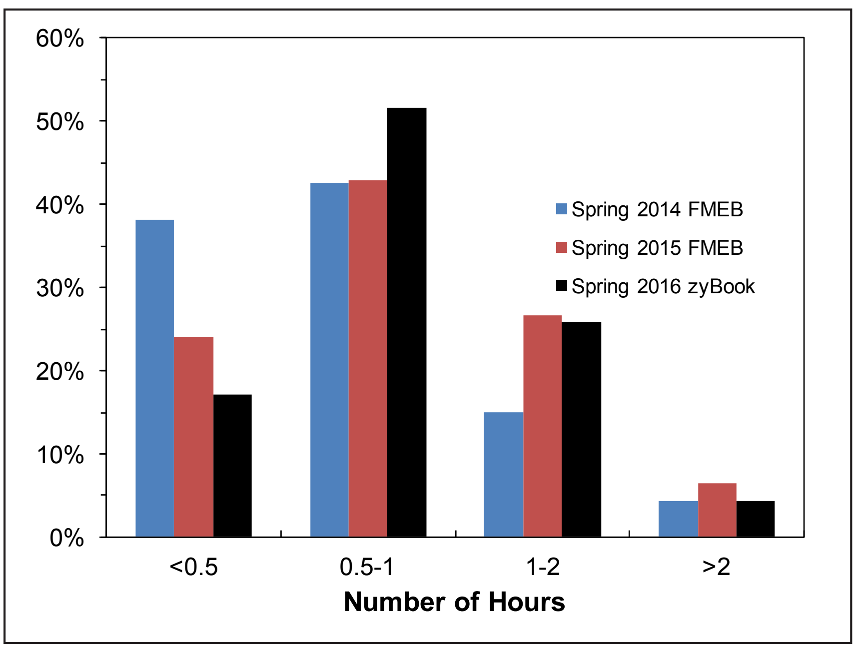
The top five responses garnered at least 16 students' votes (Table 2). Since responses were handwritten without prompts, common ideas were identified and tallied by a work/study student, who was not taking the course. Interactivity and animations resonated strongly with digitally native students. Brevity and lack of large blocks of text were also lauded. Students liked learning questions, which may point to the fact that constructive feedback is lacking in most textbooks and learning materials. Finally, the easy-to-understand/organized nature of a webpage or e-book was mentioned, which speaks to the comfort level digital natives have with digital content.

Overall, many features of the interactive web book gathered high marks from a vast majority of students based on an end-of-semester survey. Options including strongly agree, agree, disagree, and strongly disagree were available for many questions, including "I learned new material from _____ in the zyBook." The two highest scores—defined as students responding agree or strongly agree—were for animations (87%) and reading the text (86%). Three of the four types of question sets—true/false, multiple-choice, and matching—scored well (77 to 83%). Short-answer questions scored lower (66%), which is attributed to the small number of short-answer question sets. Only one feature, external web pages, garnered agreement from less than half of the class (47%). The author infers this response to a lack of interest in going beyond a textbook for learning.

Since animations are new to chemical engineering textbooks, an additional question asked if animations were watched more than once. Overall, 95% of the respondents reported watching at least one animation more than once. More than half of the class (52%) reported watching six or more animations more than once. Repetition has benefits in learning,[40] and students control the speed clicking through each step, which allows each learner to customize time and repetition when learning from animations. More concrete web analytics will put more quantitative data on repetition in the future.

Continuous effort to click though animations and question sets differs from reading words on a page. Therefore, time reading/participating in the interactive web book each week was surveyed. Overall, 52% of the class reported spending 30 to 60 minutes reading per week, 26% reported 60 to 120 minutes, and 4% stated more than 120 minutes. Therefore, time reading the interactive web book is less than the hours of weekly homework assigned in chemical engineering classes. The amount of time is slightly higher than previous electronic books[57,58] used by the author for the course (see Supplemental Figure 1 for comparison).

Additional questions addressed motivation, keeping pace, and overall usefulness. First, points being the only motivation to read the interactive web book was agreed with by 39% of students. Next, 87% of students correlated web book reading with keeping connected with course progress. Finally, students responded to: "Overall, I found the MEB zyBook to be a useful textbook for the course." The response was quite positive with 87% of the students agreeing or strongly agreeing. To put this response in perspective, an earlier electronic textbook written by the author was used in 2014 and 2015,[57,58] and students agreed with the overall usefulness statement at rates of 66% and 73%, respectively.



Supplemental Figure 1. *Fraction of students reporting the time spent reading the electronic textbook each week. (n = 128, 159, and 93 students for 2014, 2015, and 2016, respectively)*

CONCLUSION

In summary, a web-native, interactive textbook was written for and implemented in a material and energy balances course. Several unique features distinguish the book from traditional textbooks. Question sets are scaffolded from easier to more difficult and explain why each answer is correct or incorrect. Animations turn figures into interactive constructions and divide ideas into manageable chunks, which benefits learning based on cognitive load theory. Students receive feedback in real time and accumulate a participation score that instructors can monitor.

Overall, 87% of the zyBook was read across all sections and students in the course. The average zyBook participation grades correlated with final course grades. 82% of A and B students earned at least a 90% participation score, while only 36% of the students earning C, D, and F final course grades earned at least 90%. Examining students by gender found statistically significantly higher participation scores for female students when compared to male students.

Student surveys found strong support for almost all of the zyBook's features, especially the animations. Over 90% of students reported that they viewed at least one animation more than once. Finally, 87% of students found the zyBook to be a useful textbook for the course, which was higher than previous electronic books used for the course.

The availability of textbook reading data allows quantitative determination of whether a textbook should be required when learning engineering content in the 21st century—where factual information is freely available and quickly searchable. Therefore, a meta-analysis in the coming years could establish strong correlations between textbook reading and course grades, which was observed for one course with 100 students in this work.

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NOTES

Some features of the zyBook were previously described in an ASEE proceedings publication.[50] The author may receive royalties from sales of the zyBook. Faculty interested in animations or other interactive features can obtain an examination copy at <zyBooks.com>.

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