Reading analytics and student performance when using an interactive textbook for a material and energy balances course

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Reading and animation usage analytics for an interactive material and energy balances textbook

Abstract

Interactive textbooks provide instant feedback to students as well as to the professor. Previously, features of an interactive textbook from zyBooks for a material and energy balance course were detailed, including scaffolded question sets and animations. While newer features will be presented, quantifying student usage will be central to this contribution. Recent findings showed student reading/participation averaged 87% over the entire interactive web book over the entire semester for a course with 100 students, which far exceeds the less than 30% reading statistic in the literature. Final course grades for students using this zyBook correlated with the average reading scores. Additionally, statistically significant higher textbook reading scores were observed for students earning A and B final course grades compared to C, D, and F final grades as well as female students compared to male students. New data relating final course grades and book reading will be presented. One new feature, challenge activities, are personalized, auto-graded homework with scaffolded questions across 3 to 6 levels per activity. The increasing difficulty was verified by student success rates.

Introduction

Textbooks became a standard tool for higher education, and specifically engineering education, in the 20th century. However, the ubiquity of smart phones, tablets, and laptops has led to multimedia course resources supplanting paper books for some engineering courses. Additionally, very little information is available to answer a fundamental question about a textbook's utility or necessity, namely how many students read their textbooks for engineering courses or any college course?

Over more than four decades research shows a majority of students ignore textbook reading [1-6]. For example, one study used pop quizzes to measure reading compliance and observed decrease from 80% in the early 1980s to about 20% between 1993 and 1997, which precedes the availability of handheld electronic devices [5]. While reading quizzes offer one incentive to read a textbook before class, web-based technologies can quickly and easily tracks usage, e.g., video views, online homework responses, course management system's file downloads, reflective textbook commenting, etc. [7-15]. Student engagement with new technologies does not seems to be a detractor; one recent study found a growing majority of current engineering students, sometimes called digital natives, prefer interactive or electronic textbooks [16, 17]. With detailed data now available, new research questions related to textbook usage can be formulated and tested.

While portable electronics became relatively inexpensive and multifunctional, the price of textbooks rose 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 [18]. Therefore, electronic resources at a lower price, such as the zyBook discussed here, provide another alternative.

Active learning encompasses the techniques that continue to show in single studies and meta-analyses that students learn more through doing [15, 19-21]. Interactivity, which creates learning by doing situations, is a feature of many electronic resources. For example, interactive web-based content led to statistically significant learning gains compared to static web-based content [8, 10]. Overall, interactive technologies are being developed to leverage the strengths of the digital native [22, 23]. Therefore, an interactive textbook, such as the Material and Energy Balances zyBook discussed in this paper, may be considered a tool within the guise of active learning.

The course of interest is material and energy balances (MEB), which 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., [24, 25]). Since course level details are secondary to the findings here, a detailed review of these numerous publications is not provided.

Features of the interactive textbook will be introduced first, followed by a presentation of data generated by students using the book, and finally analysis and conclusions complete this paper.

Materials: An interactive textbook with animations

ZyBooks are full-scale textbook replacements, which are viewed, read, and interacted with in any HTML5 compliant web browser. The lead author created the Material and Energy Balances zyBook whose features are summarized in Table 1. Students pay less than $50 to access for the semester and can re-subscribe for a small fee (<$20) in future annual increments. With so many recorded clicks and attempts made by each student, a large amount of student participation data is being generated. The first class using the textbook was during the Spring 2016 semester, and a paper detailing the reading data has been accepted for publication in Chemical Engineering Education [26].

Table 1. Features of the MEB zyBook as of February 2017.

Feature	Number
Sections with content	67
Appendices	12
Animations	80+
Clicks to read whole book	960+
Homework/example questions	200+
Auto-graded challenge problems	170+
Updates	Regularly

Three unique features will be highlighted here: learning questions, animations, and challenge activities. These features create incremental units, or chunks, for learners to read and interact with, which is consistent with cognitive load theory. Cognitive load theory [19, 27-29] 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, which are triggered when participating in the interactive web book. Alternatively, the cognitive theory of multimedia learning is similar to cognitive load theory [30, 31]. Three components of the cognitive theory of multimedia learning are: 1. the dual-channel assumption, which infers than humans have different channels for processing visual versus verbal signals; 2. The limited capacity assumption, which is very similar to cognitive load theory, and 3.

An active-processing assumption, which requires the user (i.e., students in our case) to be actively engaged with the multimedia. Similarly, other researchers divided neural activity in the cortex devoted to the senses as 25% touch, 25% sound, and 50% vision [28, 32].

Learning questions

For decades, homework questions have been included at the end of engineering textbook chapters, while more recently, online quizzes provide instant feedback, usually asynchronous or outside of the textbook [15]. In the zyBook, learning questions are built in line with the text. Learning questions are multiple choice, true and false, or short answer questions that provide instantaneous, instructive, and unique feedback for each response. While correct answers offer additional details, 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, so simpler queries precede more difficult questions [15].

Challenge activities

Challenge activities test students' learning in a low stakes setting. These challenge activities are a form of online homework. The students are graded for completion of each level of a challenge activity with an activity having 3 to 6 questions of increasing difficulty. Both the completion rate and the number of attempts will be analyzed to infer learning of the material related to animations (as data is being collected during the Spring 2017 semester). The questions are individualized with both rolling numbers and some randomized question content (e.g., balancing a chemical reaction with methane for one student and propane for another student). In Figure 1, a pressure related question varies locations and related atmospheric pressures in different versions of single question.

Animations

Animation is a broad term that encompasses many types of sequences of images. While some animations were created as early as the 17^{th} century, animation became more widely available in the early 20^{th} century with hand-drawn pictures that would be become known as cartoons. From full length movies from Walt Disney to computer generated imagery in three dimensions (e.g.,

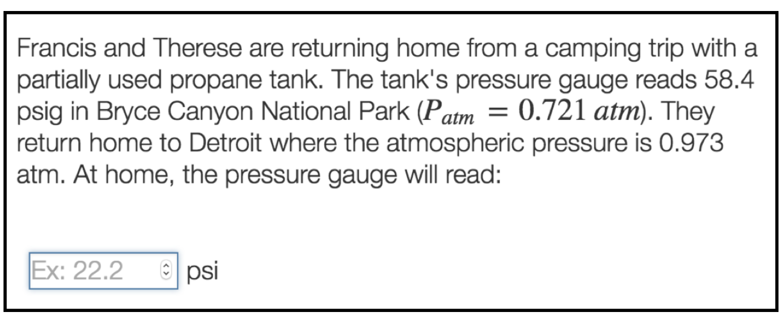

Figure 1. Example of a challenge activity problem in the MEB zyBook.

Pixar films), animation has dramatically evolved. Animation is now readily accessible to both create and view on most personal computing devices using software (e.g., Adobe Flash) or a modern web browser. Animations are being used in both K-12 and higher education. Medical education uses animations for understanding anatomy and biomechanics [33, 34] while sciences are exploring animations as a way to convey molecular level interactions not visible by the human eye [30, 35-44].

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 (Figure 2). Animations are interactive; readers 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 [27]. 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 can be reset, so repetition is easily controlled by the student.

While movements within an animation cannot be demonstrated in a static paper, the multi-paneled figure (Figure 2) shows how new concepts can be framed and chunked. Animations begin with clicking the Start button (not shown), and definition of conversion fades in with a caption. The second step focuses on the scenario of a reactor with a conversion of 0, the third step demonstrates the conversion of A to B in the reactor for intermediate conversions, and the final step visualizes the complete conversion of A to B. Breaking figures into smaller steps would agree with cognitive load theory, 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 [45-47]. A 2017 addition to the animations is 2x speed button, which allows students to shorten the actions and will likely be useful during second or third viewings of an animation.

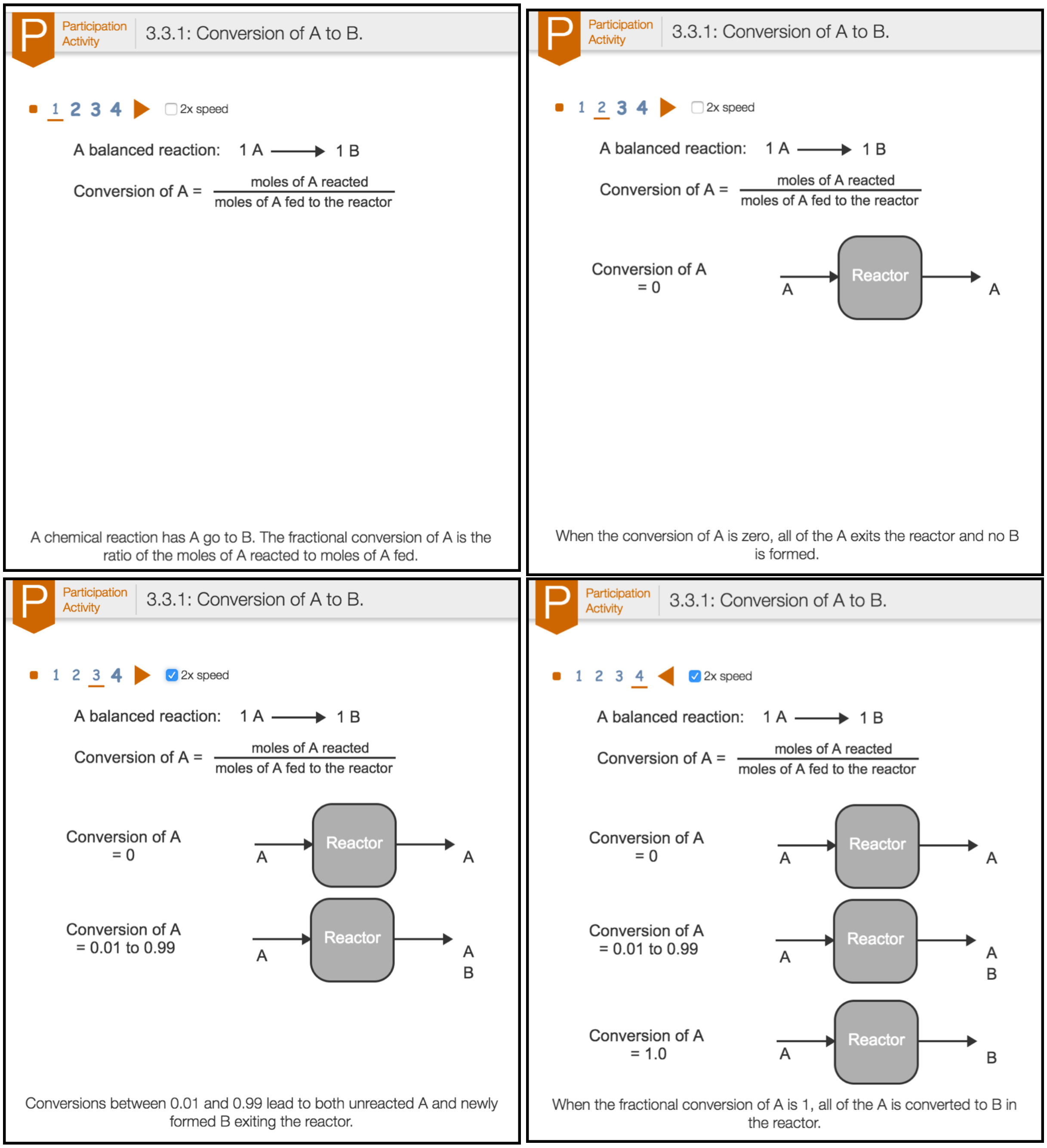

Figure 2. Screenshots of a four-step animation visualizing the concept of conversion. Movement of A and B in and out of the reactor is lost using static images.

Results and discussion

Data from the Material and Energy Balances zyBook was generated at the University of Toledo during Spring semesters of 2016 and 2017. The course consisted primarily of freshman students; the course is taught earlier than most chemical engineering programs [24] to better prepare students for mandatory co-op experiences starting as early as spring semester of the sophomore year. Enrollment was between 90 and 100 students, approximately 60% male and 40% female.

Reading data

Students were assigned readings of one to four sections of the interactive web book before most classes in 2016 and weekly readings of sections in 2017. Reading participation before the due date recorded in the zyBook accounted for 5 or 6% of the total course grade. A more comprehensive study [9] 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 and completing question sets or viewing each step of an animation. Aggregate participation data was shared regularly in class to reinforce the importance of reading. Students see their score accumulate as they read (similar to gamification of certain engineering courses [48-50]). Clicking incorrect answers does not penalize students. Students' mindlessly clicking to earn participation grades has been studied by other authors; one primary finding was 99% of over 500 students were found to be earnestly attempting most of the problems [7].

With 67 sections over 8 chapters, a large amount of reading data is generated. In 2016, 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 [1-5]. For the first three chapters in 2017, an even higher reading rate was observed with the average reading rate of 91% (Table 2). The average reading rates do not tell the whole story; 3rd quartile scores are 100% for these three chapters, i.e., at least 75% of the class are earning a 100% score for the reading participation. Overall, the high reading rates are very encouraging and will be correlated with grades and other metrics in the talk.

Table 2. Reading participation data for three chapters in 2017. n = 92 students.

Chapter	Average	Standard deviation	3rd quartile score
1	91	25	100
2	89	25	100
3	93	19	100

Usage and course grades

Using the quantitative web book participation data, questions relating reading and grades can be examined. Exams and quizzes make up 80% of a student's final grade in the course, and in 2016, 14% was awarded for primarily hand written homework with the final 6% for participation in the interactive web book. Since 2016 participation grades were high, the effects of conflating web book participation and final grades were small (<1%). Students earned simple letter grades – A, B, C, D, and F – without the use of plus/minus grades; the class' grade point average (GPA) was 2.50, which is in line with previously published values [25, 51]. A linear regression fit average participation versus grade (using A=4, etc.) with an R^2 value of 0.93, so the fit is reasonable. This fit quantified a 5% increase in average participation for each letter grade progressing from ~75%

for F students to ~95% for A students. While other studies demonstrated weak or no correlation between reading and grades [12, 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 2nd and 3rd quartile of students, the distribution of participation for A and B students is much smaller and at higher values than C, D, and F students. 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. 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.

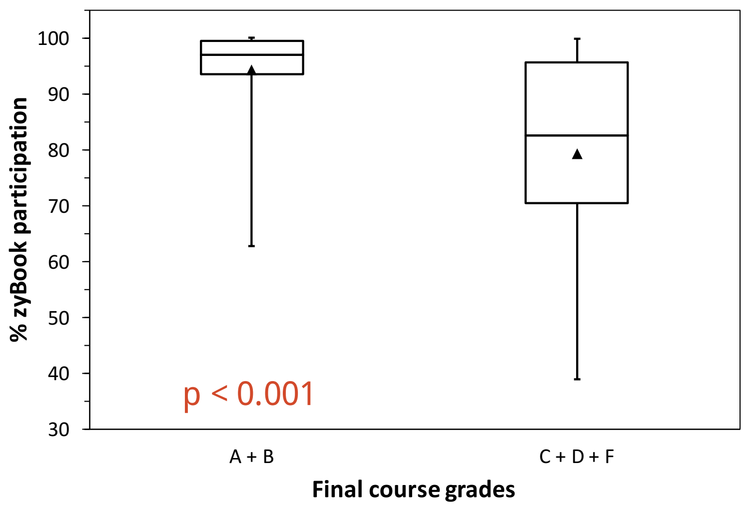

Figure 3. Box whisker plots comparing web book participation and 2016 final course grade. Statistically significant differences were found ($p<0.001$). n= 50 A+B, 50 C+D+F. Adapted from [26].

Overall, students' usage of an interactive web book has been quantified directly and usage correlated with students' final course grades in 2016. However, correlation does not imply causation, so these findings should not imply that reading more will result in a higher course grade. The correlation found in 2016 between reading and course grades is being re-examined in 2017. In addition, since the author of the book is also the instructor, a halo effect [53] may be observed in some of the findings, especially for self-reported surveys.

Challenge activity data

Challenge activity questions are new in 2017 and data are being generated. In the talk, students' success in completing the challenge activities as well as the number of attempts will be quantified and analyzed. Data from over 170 problems will be included in this analysis. Initial results from the first chapters show a clear progression of difficulty from question to question within each challenge activity as the author intended (Figure 4). Comparisons of success between the first and last question of a challenge activity will be analyzed and presented.

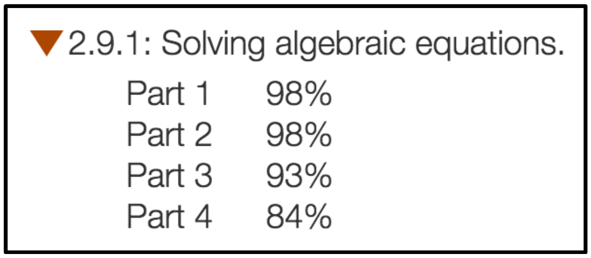

Figure 4. Screen shot from 2017 class showing decreasing success with later questions within a challenge activity. n= 92 students.

Animation usage

In an end of semester survey from 2016 [26], animations were the highest scoring feature that helps students learn with an 87% agreement rate. Another survey 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 6 or more animations more than once. Repetition has benefits in learning [28], 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 are now available to quantify repetition, which will be central to the findings discussed below. One research question is: do students re-watch animations before an exam or randomly throughout the semester.

Conclusion

An important part of successfully solving complex problems – a critical skills in the 21st century workforce [54]. Using visuals to enhance learning is well documented in education and learning science [55, 56] and is extended to engineering education here with interactive exercises and animations. An interactive textbook from zyBooks for a material and energy balance course was detailed, including learning questions, challenge activities, and animations. Quantifying student usage using web analytics student reading participation averaged 87% over the entire interactive web book over the entire semester in 2016 and higher values in 2017. These findings dramatically exceed the 30% or lower reading statistics in the literature. The challenge activities are a new feature similar to online homework with rolling numbers and randomized content within each question. The challenge activities are scaffolded across 3 to 6 problems per activity, which was verified by student success rates.

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Disclaimer

The author may receive royalties from sales of the zyBook detailed in this paper.

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