Paper ID #23171

Quantifying Self-guided Repetition Within an Interactive Textbook for a Material and Energy Balances Course

Prof. Matthew W. Liberatore, University of Toledo

Matthew W. Liberatore is a Professor of Chemical Engineering at the University of Toledo. He earned a B.S. degree from the University of Illinois at Chicago and M.S. and Ph.D. degrees from the University of Illinois at Urbana-Champaign, all in chemical engineering. His current research involves the rheology of complex fluids as well as active learning, reverse engineering online videos, and interactive textbooks.

Ms. Katherine Roach

Chemical Engineering Student

Quantifying self-guided repetition within an interactive textbook for a material and energy balances course

Abstract

Interactive technology has quickly integrated into daily lives through handheld electronics and the Internet. Here, an interactive textbook replacement from zyBooks for a material and energy balances course has been used in recent years. While features of the interactive textbook were highlighted previously, including animations replacing figures and question sets in lieu of large blocks of text, student usage will be the focus of this contribution. Similarly, reading analytics have been presented previously with average reading rates of 87 and 93% for 2016 and 2017, respectively (n = 100 in 2016 and 88 in 2017). While these reading rates surpass rates of less than 30% reported for traditional textbooks, new research questions are asked based on large sets of web analytics generated by students using/reading the interactive textbook. First, for one cohort in 2017, almost 8,000 animation views were completed, i.e., all steps were clicked and watched. The utility of an interactive textbook to provide repetition will be explored. Analysis will also be provided for students' attempts and success when completing auto-graded homework problems within randomized numbers and content within the interactive textbook. For the 2017 cohort, over 170 auto-graded questions were assigned to the students generating over 40,000 attempts. New findings related to the types of questions needing the most attempts before correct will be presented. Finally, questions – and the related concepts – will be identified that students completed large numbers of attempts *after* answering the question correctly and earning their grade, i.e., performing self-guided repetition.

Introduction

Textbooks are in many cases the antithesis of active learning. Printed on paper or viewed electronically with text and figures unchanging for years and sometimes decades, textbooks lack the engagement of touch screens and personal electronics. Luckily, new textbooks are being created to be active learning platforms with full interactivity. In addition, student usage and reading rates can thus quantify usefulness and quickly guide further development to improve student learning outcomes.

The dearth of available reading data for higher education students has been discussed in previous contributions in this area recently [1-3], and will not be elaborated upon here. Alternatively, digital classroom technologies provide more data to students and instructors than any previous period in higher education. From downloads of documents, page views in a course management system, or clicker responses in class, the ubiquitous term "big data" applies in most modern higher education classrooms.

Interactivity is central to collecting large data sets. The interactive textbook discussed here is well aligned with learning gains observed with active learning [4-9]. Beyond interactivity is the concept of repetition or focused practice. With student clicks being recorded throughout an interactive textbook, new research questions can be formulated.

Material and energy balances is the topic of the interactive textbook, and the course introduces students to chemical engineering and problem solving. Pedagogical innovations when teaching material and energy balances have been published over many years (e.g., [10, 11]), and specific concepts and context from previous work will be applied in the results presented later.

Features of the interactive textbook are summarized, followed by a primary reading and homework problem success, and finally repetition is quantified before conclusions are presented.

Materials: A fully interactive textbook

ZyBooks builds textbook replacements guided by the concept of less text, more action™. These course materials are read and interacted with in any HTML5 compliant web browser without additional plug-ins or software. This paper's lead author created the Material and Energy Balances zyBook in recent years, whose features have expanded each year (Table 1). Students pay less than $60 to access for the semester and can re-subscribe (<$20) in future annual installments. With over 1,000 recorded interactions made by each student, trends in reading, animation views, and challenge activities can be examined. Data from usage during Spring semesters in 2016, 2017, and 2018 will be included in the talk and paper that expand into new areas compared to previous publications [1, 2].

Table 1. Features of the MEB zyBook as of February 2018.

Feature	Number
Sections with content	80
Animations	100+
Clicks to read whole book	1200+
Homework/example questions	200+
Auto-graded challenge problems	290+

The style of the zyBook's sections and subsection are to divide the material into incremental units, or chunks, for learners to read and interact with, which is consistent with cognitive load theory. A central tenet of cognitive load theory is that working memory has a limited capacity when dealing with new learning [6, 12-14]. In addition to strategically dividing the learning material in the zyBook into chucks, the interactive nature engages both vision and touch; cognitive load theory also presumes partially independent subcomponents of working memory related to different senses. Other cognitive and learning theories have been discussed in previous publications and are not repeated here [1, 2].

Table 2. Features of the MEB zyBook as of February 2018.

Chapter	Title
1	Quantities, units, calculations
2	Material balances
3	Reacting systems
4	Solids, liquid, and gases
5	Multiphase systems
6	Energy balances
7	Reactions and energy balances
8	Transient systems
9	Spreadsheets

Each section of the interactive web book contains a repetitive progression from definition to demonstration to practice to challenge. New concepts are introduced with terms in bold, which are indexed for full searchability. Next, animations demonstrate concepts through a series of about 3 to 6 steps that elaborate on the newly defined concept. Each step in an animation builds upon the previous steps creating the final image, figure, or text. Animations fit into several categories and are not well captured by images in a static paper. Alternatively, a movie is available demonstrating animations within the MEB zyBook on a public website [15]. Animations combine text and images, which has been shown to be beneficial for learning [12]. Three types of animations have been discussed previously, namely derivations, figures, and actions occurring in process units. Since animations take 30 seconds to 2 minutes to watch, the chunking agrees with humans' attention span measured by billions of video watch data compiled by Wistia [16].

The practice and challenge parts of the format include learning questions and online homework. Learning questions are multiple choice, true and false, or matching exercises that provide instantaneous, instructive, and unique feedback. Correct answers provide new depth on a concept, and incorrect answers elaborate how and why the answer is incorrect and suggest a path to finding the correct answer. Both learning questions and challenge activities are scaffolded [9], so easier questions normally precede more difficult questions. The validity of easier questions and harder questions will be compared with student data later in this work.

Results and discussion

Student reading and attempts data from the Material and Energy Balances zyBook were generated at the University of Toledo during Spring semesters of 2016, 2017, and 2018. The course consisted primarily of freshman students with enrollment between 88 and 105 students, approximately 60% male and 40% female.

Reading participation

Students were assigned readings either each class meeting or weekly during three semesters. Only reading participation completed before the due date are presented, and the actual reading rates are slightly higher. Reading participation for 5 or 6% of the total course grade, which provides a small incentive but does not significantly alter final course grades. Another study [17] found as little as 2% of the course grade provided enough incentive for students to read an interactive web book.

Reading participation is earned when clicking and completing question sets or viewing each step of an animation. Clicking incorrect answers does not penalize students or seem to deter students from reading further to find the correct answer. For example, multiple choice questions normally have 3 to 4 responses, so clicking incorrectly does not add significantly to reading time.

Students and instructors (e.g., professor and teaching assistants) see their score accumulate as they read. Class data was shared in real time during several classes, which shows that the instructor values reading and keeping pace with the course material. Students can mindlessly click as fast as possible to earn participation grades, but other authors found 99% of greater than 500 students earnestly attempted problems [18].

Over 160,000 clicks for reading participation were recorded in 2016 and 2017, which can be distilled into reading rate distributions. The mean and median reading rate are very high - 87/94% in 2016, 93/98% in 2017, and 89/100% to date in 2018. Compared to less than 30% reading rates reported over several decades [19-23], fully interactive reading participation appears to engage students. However, mean and median do not represent the distribution created by students. Therefore, box-whisker plots provide greater detail into the reading rate across larger segments of the class.

Combining mean and median with 1st and 3rd quartiles shows the reading participation for the top quarter, half, and three quarters of the class (Figure 1). Therefore, 75% of the class completed 82 and 87% of the reading in 2016 and 2017, respectively. The mean score is measurably lower than the median, which is a result of a small number of students earning very low reading rates. While the top half of readers earned over 94% in 2016 and 2017, how many students earned an A or 90% for reading participation? 59 and 70% of the class earned a reading grade of A for the entire semester in 2016 and 2017, respectively, which can be compared to exam scores where about 14% of the class earned 90%. Therefore, high reading rates are encouraging and but do not guarantee an A on exams, quizzes, or in the course.

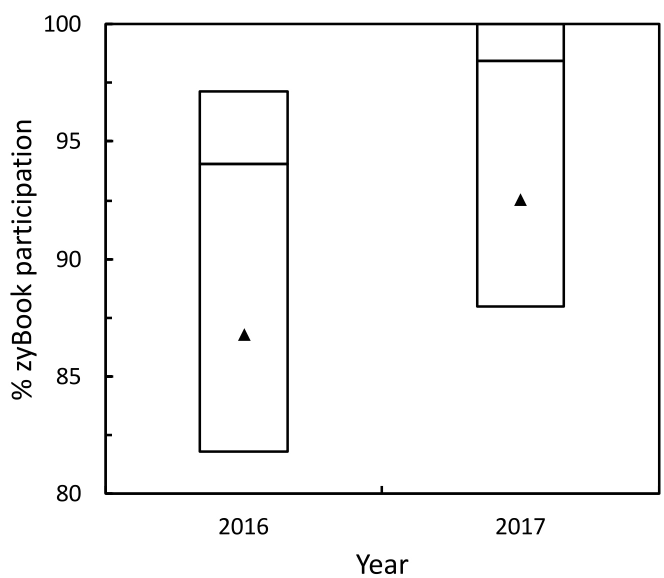


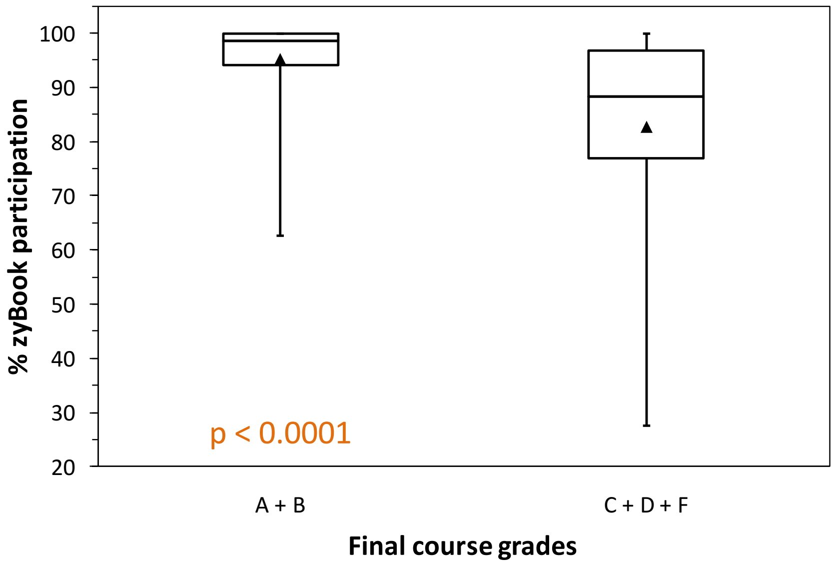
Figure 1. Box whisker plot of zyBook reading participation percentage over 2 years of use.

Reading participation and final course grades

Since individual exams and quizzes make up 80% of a student's final course grade, a comparison between effort (reading participation grade) and mastery (final course grades) may be elucidated (Figure 2). Since reading participation grades were high (i.e., above 75%), the effects of conflating reading participation and final course grades were small (<1%). The overall grade point average for the combined cohort of 188 students (GPA) was 2.49, which is in line with previously published values [11, 24]. A linear regression reasonably fits average reading participation versus grade (using A=4, etc.), which was discussed previously [2], and differs from previous findings where weak or no correlation between reading and grades was found [25, 26].

The combined cohort contained 101 A/B students and 87 C/D/F students while students withdrawing from the course were not included in the plots (Figure 2). Since the whisker dramatically expand the y-axis, a second more focused figure is included to facilitate discussion and analysis. The two groups are extremely statistically significantly different ($p<0.0001$), which can be summarized by a difference in median reading participation (horizontal line dividing the two boxes) of 99 vs 88%, respectively for the A/B and C/D/F groups. The interquartile spacing represents the middle 50% of students in each group is also dramatically different. Interquartile spacing varies only 6% for A/B students (94 to 100%) while C/D/F students exhibit greater variability and lower participation (77 to 97%). While similar statistically significant difference is found with exam scores for these two groups, reading participations requires only effort while exams necessitate mastery of course concepts.

Predicting as well as understanding success has been studied extensively, and on one hand, general consensus states that intelligence/talent/IQ does not strongly correlate with success [27-29]. On the other hand, growth mindset or grit rates effort over talent, which more often leads to success [27, 28]. Therefore, an analogy can be drawn with reading participation in material and energy balances. Effort on assignments, without penalties for incorrect answers or requirement of talent or mastery, correlates strongly with success in mastering course content and earning an A or B in the course.



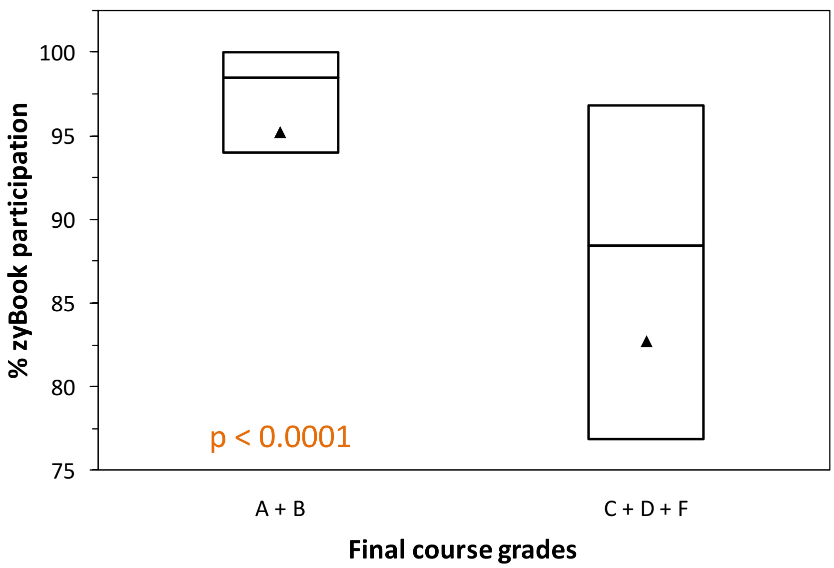


Figure 2. Top. Box whisker plot comparing reading participation and final course grade over two years. Bottom. Box plot with smaller range along y-axis. Statistically significant differences were found ($p<0.0001$). n= 188 students.

Animation views

In an end of semester survey from 2016 [1], students ranked animations the feature of the zyBook that helps them learn (87% agreement); additionally, 95% of the respondents reported watching at least one animation more than once. Since repetition has benefits in learning [13], quantifying the number of animation views can help instructors identify concepts that students are revisiting, which may indicate an attempt to learn or practice one or more concepts.

Web analytics quantified each click related to all of the animations during the Spring 2017 semester. Aggregating the data verifies the students' survey response from 2016, i.e., students re-watch entire animations regularly. Seven chapters of material are covered on the final exam and each chapter's animation view exceeded the number of students in the class. The viewing rate for the entire book was 114%, which encompassed over 7900 complete animation views across 88 students. Chapter 8 on transient systems was only covered on a single quiz the final week of class had a 98% animation viewing rate.

Focusing on the material balances chapters (Figure 3), students watch animations between 108 and 150%. Chapter 3, which covers material balances with chemical reactions, has the highest viewing rate. Three of the top five most watched animations for the entire book were in Chapter 3, and provides insight into concepts that students may find challenging. Here, the most watched animations covered finding excess and limiting reactants, using extent of reaction, and the difference between single pass and overall conversion.

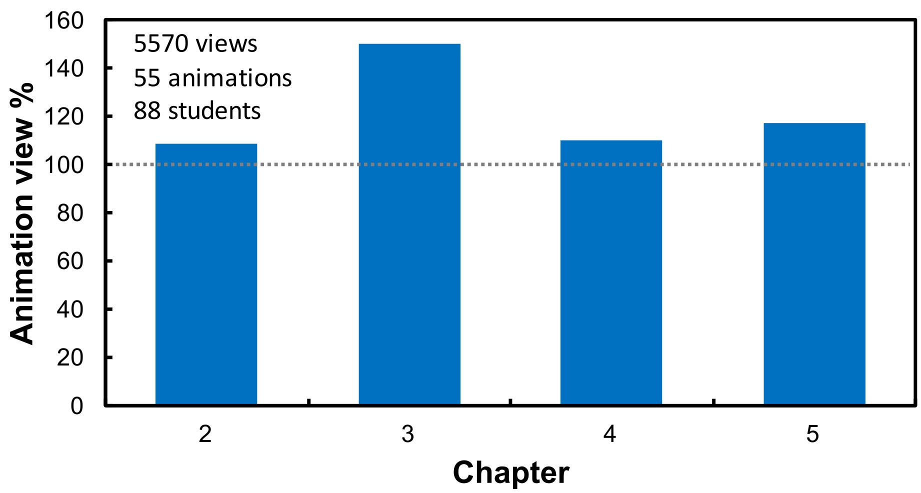


Figure 3. Percentage of students completely watching animations over 4 chapters that included 55 animations.

<u>Challenge activity completion</u>

Challenge activity questions were added in 2017; the fraction of students' completing questions correctly will be presented first with the number of attempts will be quantified in the next section. Students were generally successful when completing over 170 problems within challenge activities (Figure 5). Over 46% of the problems were completed by over 90% of the class and an additional 27% of the problems were successfully solved by 80% of the class. Therefore, about a quarter of the challenge activity problems could be considered difficult for the students.

Continuing the analysis from four material-balance-focused chapters (Figure 5), Chapter 4 and 5 covering multiphase behavior were more difficult than problem solving and material balances with reacting systems in Chapters 2 and 3. Diving deeper into Chapter 3 again, students earned over 80% correct on 20 of the 21 challenge activity levels. The two problems with lower success were the last questions of a challenge activity, which verifies the increasing difficulty when progressing through a challenge exercise that was discussed earlier. First, the last question on balancing reactions provided difficulty when the stoichiometric coefficients of a chemical component contained decimals, e.g., $C_{13.6}H_{25.1}O_{12.4}$. Second, most difficult question related to balancing combustion reactions including excess air. With this granular, real-time data an instructor can go to the next class sections and provide additional focused practice on these difficult concepts, which is normally called just-in-time teaching [30].

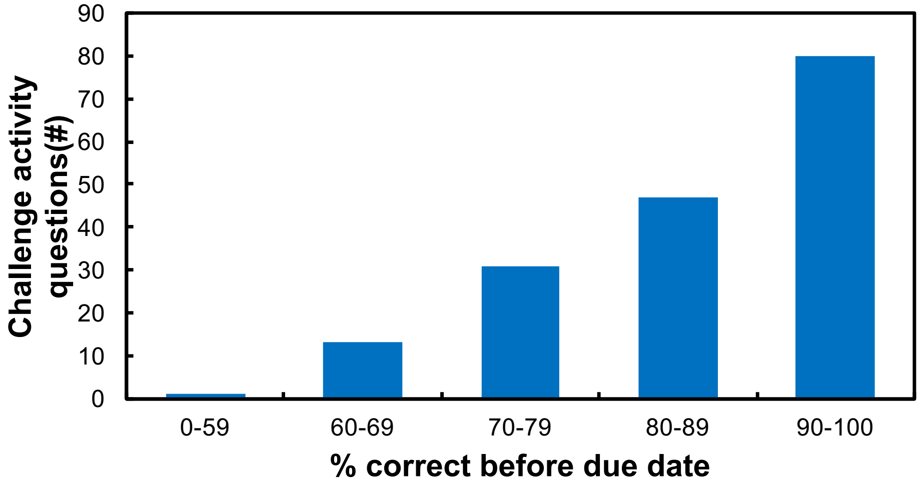


Figure 4. Number of challenge activity questions (172 total) as a function of the % correct before the due date.

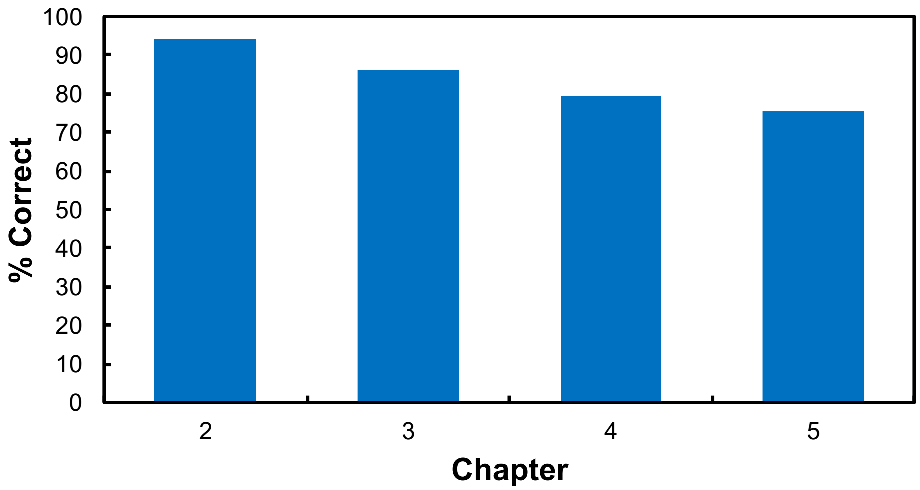


Figure 5. Percent correct for all challenge activity questions (14 to 30) for the 4 chapters covering material balances.

<u>Challenge activity attempts</u>
Beyond getting the correct answer and earning homework points, the number of attempts before correct and total number of attempts were provided to the author by zyBooks. Total number of attempts encompasses attempts before correct and any attempts completed after correct. Attempts after completing a problem correctly is voluntary, extra practice and does not change any earned grade. Analysis is underway and will be more thoroughly presented in the revised paper and talk.

First, over 40,000 attempts across 173 questions were recorded, and over 3,500 extra attempts were completed. Thus, providing an opportunity for extra practice is sufficient for students to use these interactive, auto-graded problems. Second, 50 to 88% of the class attempted at least one question after answering correctly in the final 5 chapters, so practice is not isolated to the "A" students. Third, an average of 20 attempts per question after correct is not evenly distributed, so some students are completing multiple practice attempts while others are not returning to the challenge activities after answering correctly. Finally, the mean, median, and 3rd quartile of attempts before correct all increase as the percent correct decreasing; harder problems take more effort, which is not surprising but difficult to quantify without detailed analytics available with the web book being discussed here.

Conclusion

An interactive textbook replacement from zyBooks for a material and energy balances course generates large data sets quantifying student interactions from reading to solving problems. Features making this textbook included animations, question sets, and a form of online homework called challenge activities. Reading analytics were presented previously and expanded upon here; average reading rates were 87 and 93% for 2016 and 2017, respectively (n = 100 in 2016 and 88 in 2017), and median reading rates were even higher than the averages. While these reading rates dramatically exceed rates of less than 30% reported for traditional textbooks, new research questions focused on using web analytics to quantify repetition. For the 2017 cohort, over 7,900 animation views were completed, i.e., all steps were clicked and watched, that corresponds to 114% of the class completing views of animations on average. Thus, animations are one form of repetition when using the interactive web book. Finally, students' attempts and success when completing auto-graded homework problems were analyzed for the 2017 cohort who completed over 170 auto-graded questions. Over 40,000 attempts were recorded across 88 students with 3,500 attempts being completed after a student answered the question correctly. Overall, an interactive web book allows students opportunities for self-guided repetition through animations and challenge activities, and initial analysis shows a large fraction of students take advantage of interactive features beyond the first attempt required to earn a grade.

Acknowledgments

The author thanks recent contributions from David C. Smith, Ian Mashburn, Logan Sherman, zyBooks, and countless teaching assistants.

Disclaimer

One of the authors may receive royalties from sales of the zyBook detailed in this paper.

Bibliography

1. Liberatore, M.W., *High textbook reading rates when using an interactive textbook for a Material and Energy Balances course.* Chemical Engineering Education, 2017. **51**(3): p. 109-118.
2. Liberatore, M.W. *Reading analytics and student performance when using an interactive textbook for a material and energy balances course*. in the Proceedings of the ASEE Annual Conference & Exposition. 2017. Columbus, OH.

3. Liberatore, M.W., *Quantifying reading and online homework completion using an interactive material and energy balances textbook*, in *AIChE Annual Meeting* 2017: Minneapolis, MN.
4. Edgcomb, A. and F. Vahid. *Effectiveness of Online Textbooks vs. Interactive Web-Native Content*. in the Proceedings of the ASEE Annual Conference. 2014. Indianapolis, IN.
5. Edgcomb, A., F. Vahid, R. Lysecky, A. Knoesen, R. Amirtharajah, and M.L. Dorf. *Student Performance Improvement using Interactive Textbooks: A Three- University Cross-Semester Analysis*. in the Proceedings of the ASEE Annual Meeting. 2015. Seattle, WA.
6. Chi, M.T., *Active-constructive-interactive: a conceptual framework for differentiating learning activities.* Topics in Cognitive Science, 2009. **1**(1): p. 73-105. http://dx.doi.org/10.1111/j.1756-8765.2008.01005.x.
7. Chickering, A.W. and Z.F. Gamson, *Seven Principles for Good Practice in Undergraduate Education.* AAHE Bulletin, 1987: p. 1-7.
8. Freeman, S., S.L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, and M.P. Wenderoth, *Active learning increases student performance in science, engineering, and mathematics.* Proceedings of the National Academy of Sciences, 2014. **111**(23): p. 8410-8415. http://dx.doi.org/10.1073/pnas.1319030111.
9. Felder, R.M. and R. Brent, *Teaching and Learning STEM: A Practical Guide*. 2016, San Francisco, CA: Jossey-Bass.
10. Silverstein, D.L., L.G. Bullard, and M.A. Vigeant. *How we teach: Material and Energy Balances*. in the Proceedings of the ASEE Annual Meeting. 2012. San Antonio, TX.
11. Liberatore, M.W., *Active Learning and Just-in-time Teaching In a Material and Energy Balances Course.* Chemical Engineering Education, 2013. **47**(3): p. 154–160.
12. Bowen, A.S., D.R. Reid, and M.D. Koretsky, *Development of interactive virtual laboratories to help students learn difficult concepts in thermodynamics.* Chemical Engineering Education, 2015. **49**(4): p. 229-238.
13. Sloan, E.D. and C. Norrgran, *A neuroscience perspective on learning.* Chemical Engineering Education, 2016. **50**(1): p. 29-37.
14. Paas, F., A. Renkl, and J. Sweller, *Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture.* Instructional science, 2004. **32**(1): p. 1-8.
15. zyBooks. *Material and Energy Balances from zyBooks*. 2017 [cited 2018 February]; Available from: https://vimeo.com/224528049.
16. Wistia. *How long should a video be?* 2016 [cited 2018 January]; Available from: https://wistia.com/blog/optimal-video-length.
17. Edgcomb, A. and F. Vahid. *How Many Points Should Be Awarded for Interactive Textbook Reading Assignments?* in the Proceedings of the 45th Annual Frontiers in Education Conference (FIE). 2015. El Paso, TX.
18. Yuen, J.S., A. Edgcomb, and F. Vahid. *Will Students Earnestly Attempt Learning Questions if Answers are Viewable?* in the Proceedings of the ASEE Annual Meeting. 2016. New Orleans, LA.
19. Hobson, E.H. *Getting Students to Read: Fourteen Tips*. IDEA Paper #40 from ideaedu.org. 2004 [cited 2016 December]; Available from: http://www.ideaedu.org/Portals/0/Uploads/Documents/IDEA Papers/IDEA Papers/Idea_Paper_40.pdf.

20. *National Survey of Student Engagement - Question 1c. During the current school year, about how often have you done the following? Come to class without completing readings or assignments*. [cited 2016 August]; Available from: http://nsse.indiana.edu/html/summary_tables.cfm.
21. Brost, B.D. and K.A. Bradley, *Student Compliance with Assigned Reading: A Case Study.* Journal of Scholarship of Teaching and Learning, 2006. **6**(2): p. 101-111.
22. Marshall, P., *How much, how often?* College and Research Libraries, 1974. **35**(6): p. 453-456.
23. Burchfield, C.M. and T. Sappington, *Compliance with required reading assignments.* Teaching of Psychology, 2000. **27**(1): p. 58-60.
24. Bullard, L.G. and R.M. Felder, *A Student-Centered Approach To Teaching A Student-Centered Material and Energy Balances. 2. Course delivery and assessment.* Chemical Engineering Education, 2007. **41**(3): p. 168-176.
25. Landrum, R.E., R.A.R. Gurung, and N. Spann, *Assessments of Textbook Usage and the Relationship to Student Course Performance.* College Teaching, 2012. **60**(1): p. 17-24. http://dx.doi.org/10.1080/87567555.2011.609573.
26. Self, J., *Reserve readings and student grades: Analysis of a case study.* Library & Information Science Research, 1987. **9**: p. 29-40.
27. Duckworth, A., *Grit: The power of passion and perseverance*. 2016: Simon and Schuster.
28. Dweck, C.S., *Mindset: The new psychology of success*. 2006: Random House Incorporated.
29. McGuire, S.Y., *Teach students how to learn: strategies you can incorporate into any course to improve student metacognition, study skills, and motivation*. 2015: Stylus Publishing, LLC.
30. Simkins, S. and M. Maier, *Just-in-time teaching: Across the disciplines, across the academy*. 2010: Stylus Publishing, LLC.