STUDENT SUCCESS AND ATTEMPTS ON AUTO-GRADED HOMEWORK ACROSS MULTIPLE COHORTS IN MATERIAL AND ENERGY BALANCES

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INTRODUCTION

Big data is encompassed by volume, velocity, and variety.[1] The rapid expansion of the Internet has led to big data in many ways. For example, the location, look, and size of buttons or ads on a screen have been thoroughly studied and optimized – in many cases to increase revenues.[2] In general, big data comes from interactivity, i.e. a person clicking or scrolling on a webpage or sensors in either a home or chemical plant. In the same vein, combining interactivity with textbooks has begun to create big data in the engineering classroom.

Student-centered teaching techniques are commonly called active learning.[3-8] This type of pedagogy focuses on students "learning by doing" in many cases. Despite the large body of evidence supporting these best practices of teaching, adoption is not the norm. While not adopting the new standard techniques in laboratory research may leave faculty behind, the same expectation does not hold for many faculty with regard to their teaching. Changes in teaching techniques may be considered a social change, which generally changes more slowly than technology.[9, 10] Other authors have extensively documented the rationale for the limited adoption of active learning in engineering faculty, including a persistent lack of professional development programs.[8, 11, 12]

One recently investigated topic at the cross section of big data and active learning is interactive textbooks. Using clicks to quantify a student's progress through animations and questions embedded within an interactive textbook, median reading rates significantly above 94% have been recorded.[13-17] Additionally, students earning A and B grades in a course demonstrated statistically significantly higher reading rates than C, D, and F students; female students read statistically more than male students. Overall, reading participation within an interactive textbook quantifies effort of students, while auto-graded questions provide more information related to each student's mastery of course material. Here, the cross section of big data and active learning are studied in the context of online homework.

Many chemical engineering students experience different online homework platforms in math, chemistry, and physics courses. Online homework questions can be directly connected to a textbook, provide additional features, or operate independently from course readings. Some formats limit attempts on each question, and others may deduct points with each incorrect response. Multiple attempts are generally observed as a productive learning strategy.[18] Feedback for

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incorrect responses may include full solutions, hints, or only the expected answer – answers could be numerical, drawn chemical structures, or text, such as names of chemical components.[5, 19] Some questions generate new numbers for each attempt, so students must rework the question before making another attempt. For example, a system called ALEKs® requires multiple correct responses in a row for questions about one topic before the next topic is presented.[20] While each online homework system has pros and cons, providing immediate feedback to students is one significant advantage.

For more than a decade, significant findings related to online homework have been presented for engineering and technical courses.[21, 22] For example, significant learning gains were observed in a statics course.[23] Also, a smaller percentage of a class earned failing grades when adopting online homework in the Material and Energy Balances course of interest.[24] In general, the availability of multiple versions and attempts per question may help students feel more in control of their learning, which can be beneficial.[25]

Material and Energy Balances (MEB) is nominally the first chemical engineering course that introduces engineering problem solving and foundational topics, such as conservation of mass and energy. Many significant contributions, e.g.[26, 27], can be found in the literature on best practices for teaching this course. Here, new types of data and comparisons related to student success and attempts on online homework within an interactive textbook will be explored.

MATERIALS AND METHODS: ONLINE HOMEWORK WITHIN AN INTERACTIVE TEXTBOOK

The Material and Energy Balances zyBook® is interactive content for use within any HTML5 compliant web browser without additional plug-ins.[28] The zyBook's content follows other textbooks for the course and includes over 80 sections, 140 animations, and 1300 clicks to read the whole book. Previous journal publications have detailed the interactive reading and format.[13, 17] More specifically in this paper, online homework questions, which are called "challenge activities," will be examined. Hundreds of challenge activities are available (Table 1) and more question levels were added annually, which are detailed in the Appendix. The percent of questions answered correctly, attempts before correct, and total attempts are three key metrics generated from using the interactive textbook; reading participation is an independent metric discussed in previous publications.[13, 17] Surveys on the students' attitudes related to the interactive textbook were discussed previously[13, 17] and will not be expanded upon here.

The course consisted primarily of freshman students with enrollment between 88 and 105 students across three years, approximately 63-66% male and 34-37% female at a public, research university (details are tabulated in the Appendix). A single section of the course was taught by the same instructor – one of the co-authors – for all three cohorts. Students' final course grades were dependent on both reading participation (5%) and correctly completing/answering challenge activity questions (5%). All of the reading participation clicks were required to earn the full grade; however, challenge activities were given a 15-question forgiveness factor (3-5% of questions). For example, a student correctly answering 350 out of 400 questions earns a grade of 91% (350/385). However, the success – as correct by percent – presented here encompasses all attempts without accounting for the forgiveness factor. Correct percentages from students completing the course, i.e. not withdrawing, are included.

TABLE 1
Online homework questions in 2019 MEB zyBook.

Chapter	Questions
1. Quantities, units, and calculations	58
2. Materials balances and problem solving	35
3. Reacting systems	44
4. Solids, liquids, and gases	30
5. Multiphase systems	33
6. Energy balances	44
7. Energy balances with reactions	32
8. Transient systems	7
9. Spreadsheets	125
Total	408

Challenge activities are available in most sections and usually consist of three to six question levels. These question levels are scaffolded, so easier questions precede more challenging ones.[18, 29, 30] Therefore, a student must answer an earlier question level before proceeding to the next question level. The success of the scaffolding was recently quantified.[31] Challenge activities are primary distributed in each section with some longer questions at the end of each chapter. By integrating challenge activities into a section, new content is chunked, which is consistent with cognitive load theory.[5, 32]

The features of one question level are summarized here to distinguish challenge activities from other online homework platforms. Rolling numbers in multiple locations as well as changing content are common; therefore, each question level contains tens to thousands of variations. For example, a chemical reaction may change between questions in a single question level (Figure 1). In addition to being integrated into sections and having multiple levels, question levels do not limit the number of attempts before a student answers correctly. Students are allowed and encouraged to seek assistance from the faculty, teaching assistants, or classmates before/after class or during office hours when solving challenge activities.

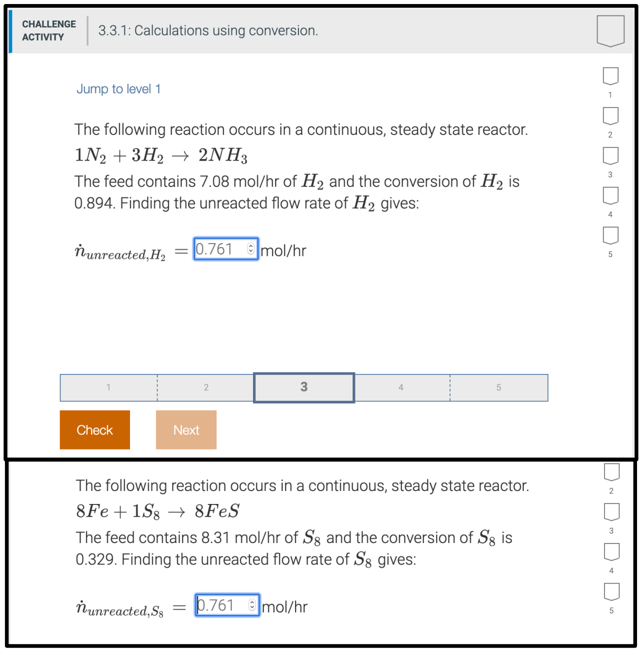

Figure 1. *(Top) The third question level from a challenge activity related to fractional conversion. Check and Next buttons are used to interact with challenge activities. (Bottom) Another question iteration of the same question level. The chemical reaction, feed rate, and conversion are randomly generated with each attempt.*

Most success and attempts data will be presented using box plots. Each box represents the middle 50% of data, including 1st quartile, median, and 3rd quartile. Using box plots removes the effects of individual outliers that can skew average value — for example, one student making 100+ attempts on a single question level. Generally, average or mean values may also be included for added clarity of skewness. In order to correlate different data sets, hypothesis testing was conducted. Performing t-tests generated p values with statistically significance being considered when $p < 0.05$. When $n > 20$, using t-tests is justifiable even with nonnormal distributions.[33, 34] Different types of non-normal distributions showed coverage probabilities of 91% or higher.[33, 34]

RESULTS AND DISCUSSION

Quantifying students' success and attempts on challenge activities will be investigated as a function of course grades, content, and other pertinent variables. Additionally, the number of attempts before correct and total attempts provide new information about students' effort. Unless noted, data are presented as an aggregate of three cohorts. Differences between cohorts will not be explored in detail as findings are similar; however, data from each cohort were available to the reviewers and are available from Professor Liberatore at matthew.liberatore@utoledo.edu.

Success on Challenge Activities and the Course Overall

A correlation between success on challenge activities and overall course grade is observed (Figure 2). Since challenge activity success is part of the final course grade, the degree of conflation is quantified to better frame further discussion. Challenge activities make up 5% of the overall course grade. The median A-student earned 100% on challenge activities compared to 93% for the median C-student. Thus, the difference in overall contribution to the final grade varied less than 0.5% when at least an 11% difference in overall grade would be required to change an A (90%) to a C (79%). Therefore, conflation of grades play a very minor role in the correlations discussed here.

First, a linear regression between challenge activity correct and final course score was completed for all of the students (Figure 2 top). A strong correlation resulted based on the Pearson coefficient ($r = 0.66$).[35] The slope of the linear correlation is 0.86, which shows that successfully completing challenge activities does directly correlate with higher grades. Overall, the median success on challenge activities was 94% (Figure 2), and the average success was 88±16%, which shows the effects of a few low scoring students. At least 75% of all students earned above 80% correct on challenge activities (1st quartile). While the 1st quartile value may seem high, the lower success of D and F students represent only 18% of all students. Each of the three cohorts shows a similar correlation between grades and overall success. For example, performing t-tests between each pair of cohorts finds significant statistical similarity ($p = 0.91$ to 0.98).

Alternative to linear regression, course grades generally capture final course scores in 10% windows. Median challenge activity correctness decreased at a much smaller rate than final course grade. For higher performing students, median performance decreased 4% and 3% for A to B and B to C students, respectively. Much more significant decreases of 17 and 10% were measured from C to D and D to F students, respectively. More broadly, A students' median challenge activity success is greater than F students by 34% (100 vs. 66%).

Performing hypothesis tests comparing challenge activity success between sequential final grade pairs find two statistically significant differences. For A versus B as well as C versus D students, $p < 0.0001$ were found, signifying an extremely statistically significant difference. These statistically significant differences vary from a correlation between reading effort using the same interactive textbook.[17] The only significant drop in reading effort occurred between B and C students. Here, challenge activity scores distinguish nearly perfect scores for A students (98% 1st quartile score) to a broader distribution of success for B students (85% 1st quartile score). One possible explanation for this difference is the forgiveness factor for challenge activities. Since 3-5% of the challenge activities were not counted toward the final

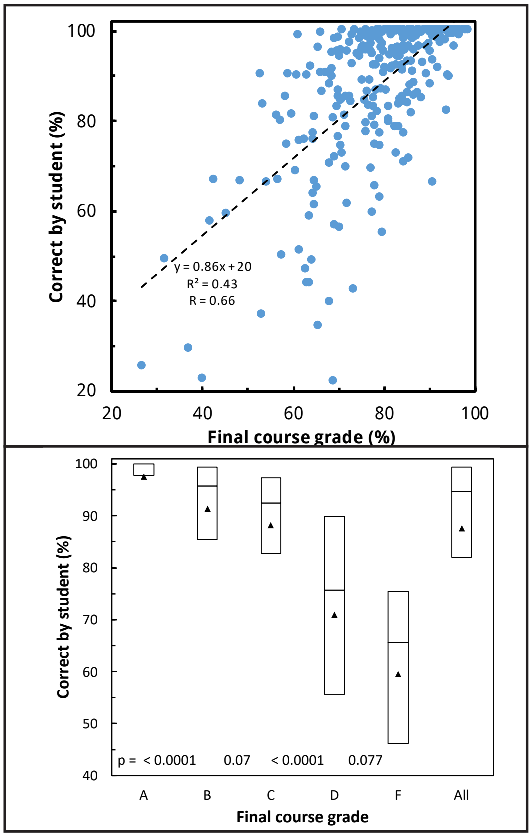

Figure 2. *(Top) Percent correct as a function of final course percentage with linear regression for 284 students. (Bottom) Percent correct on challenge activities over the entire book as a function of final grades and all students aggregated. A, B, C, D, F represents 67, 97, 68, 36, and 16 students, respectively. All represents 284 students. Triangles represent the mean. Hypothesis tests are summarized with p values as described in the text.*

grade, more B students may be content with a high grade while most A students persisted until all of the challenge activities were completed correctly. The other statistically significant decrease in challenge activity success was between C and D students, which showed median success decreasing from 92% to 76%. One possible explanation is that D students complete the easier question levels and not the more difficult levels. Alternatively, C students may benefit from collaborating with classmates, using office hours for questions and assistance, or putting in more effort, which was previously discussed related to reading participation and the same interactive textbook.[17] This hypothesis may be explored in the future with larger data sets, and problem difficulty will be further explored for a future publication.

Female students complete a higher percentage of the challenge activities than male students (Figure 3), and this difference is statistically significant ($p = 0.021$). More specifically, median success on challenge activities was 4% higher for female students compared to male students (96 vs. 92%). The interquartile spacing for females was 13%, which is 7% smaller than the spacing for male students (20%). This finding for the challenge activities mirrors the gender differences observed with reading effort in the same interactive textbook.[13, 17] Additional surveys or interviews are outside the scope of this work, but understanding both engagement and persistence from a diverse group of students provides one avenue for future research.

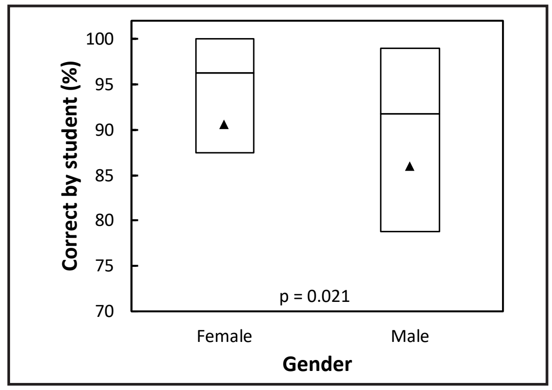

Figure 3. *Percent correct on challenge activities over the entire book as a function of gender for 284 students. Female and Male represent 101 and 183 students, respectively. Triangles represent the mean.*

Challenge Activity Success and Course Content

Eight chapters of content related to the Material and Energy Balances course contain numerous auto-graded problems, and instructors know the difficulty of the content varies. Here, both success and attempts before correct give two perspectives on students' learning as a function of the course material. The number of question levels varied by chapter, averaging 35 question levels per chapter in 2019 (Table 1). Correctness was recorded at the due date and was independent of the number of attempts taken before the correct answer was submitted (Figure 4).

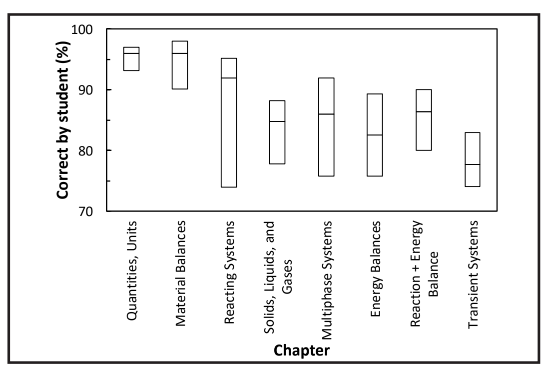

Figure 4. *Percent correct on challenge activities over the entire book as a function of chapter for 284 students.*

The difficulty of the content across the chapters warrants additional discussion. Chapters covering Quantities, Units and Material Balances showed the highest median percent correct at 96% and shows statistically significantly higher scores than all of the other chapters. Several factors likely explain these high success rates, such as high engagement during the first couple of weeks of the course, the inclusion of content covered in previous math and science courses, and the ability to use multiple attempts without penalty. Next, the chapter on Reacting Systems captures one of the significant changes and challenges of this course. Transitioning from easier concepts (balance a chemical reaction) to more difficult, interconnected problems (e.g. reacting systems with recycle and purge) has been noted as concepts that can result in low exam scores.[27] Quantitatively, the easiest 25% of questions in Reacting Systems (95% 3rd quartile) are on par with earlier chapters, while the most difficult 25% of questions shows the lowest 1st quartile success (74%).

The next four chapters (Solids, Liquids, and Gases through Reaction + Energy Balances) are covered sequentially and show relatively similar median success between 83 and 86%. In addition, p values comparing each pair of chapters show some to significant statistical similarity between these four chapters. These chapters emphasize new concepts and problem solving strategies that students may not have seen previously and in some ways define chemical engineering thinking. Additionally, this median success may be reflective of the fraction of students who earned D and F grades (18%) across the three cohorts. Finally, Transient Systems has the lowest median challenge activity success. Explanations may include the small number of questions (7), not including this content on the final exam, and multiple questions involving integration. Integration is challenging for students taking their first calculus class co-currently with Material and Energy Balances during the second semester of the freshman year.

Successfully completing challenge activities provides only a partial view of students' behavior. First, the number of attempts is unlimited to create a low-risk assessment, and students can view the solution to the previous iteration before attempting again with new numbers/content, which was discussed earlier. Therefore, attempts before correct may indicate problem difficulty, poorly written questions, or tolerances that are too small. The distribution of attempts before correct across chapters (Figure 5) follows similar trends to the fraction of questions correctly completed by the due date (Figure 4). The median attempts before correct varied from 1.25 and 1.33 for Quantities, Units as well as Material Balances chapters on the low end to a maximum of 3.4 attempts for Transient Systems. Median attempts ranged from 1.7 to 2.9 for the remaining chapters. The interquartile range was largest for the two Energy Balances chapters and Transient Systems. Since these three chapters come near the end of the course, the questions can include and build upon concepts covered earlier in the course. Overall, a finding of 3 or less attempts before correct for the vast majority of questions shows that the challenge activities are achievable without onerous effort.

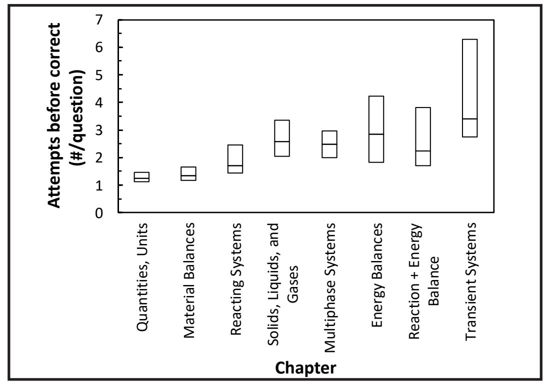

Figure 5. *Attempts before correct on challenge activities over the entire book as a function of chapter for all 284 students.*

Since challenge activities regenerate randomly, students can use the problems for practice in any chapter (Figure 6). The median attempts after correct on any single question varies from 11 to 23 across the eight chapters. The middle 50% of attempts after correct varies some with chapter; however, the ranges do not follow the trends observed for success or attempts before correct. Quantities, Units is a chapter with concepts that do not need additional practice, and Solids, Liquids, and Gases includes most students' first introduction to steam tables. Practicing steam table problems, which are not algorithmic, is another advantage of these types of online homework problems. Therefore, evaluating attempts after correct by student and not chapter is presented next to expand upon this extra effort put forth by students.

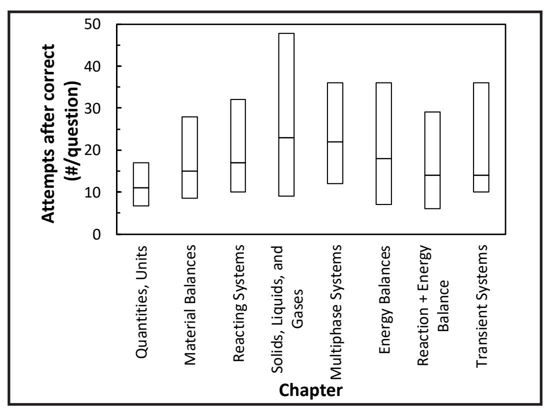

Figure 6. *Attempts after correct as a function of chapter for 284 students*

Challenge Activity for Extra Practice

After removing the stresses of due dates and earning a grade, students continue to use the challenge activities after solving a question level correctly. More than 17,000 attempts after correct were recorded, and annual details are tabulated in the Appendix. Since the number of questions increased annually, the number of attempts before and after correct increased also. Analyzing attempts after correct from different perspectives provides new insights on students use of these online homework questions.

Aggregating across chapters condenses data from Figure 6 to provide a quantification of the number of practice attempts on the middle 50% of questions across the cohorts (Figure 7). Between 4 and 29 attempts after correct are observed for the middle 50% of questions in any given year, which shows that some questions with high success and low numbers of attempts before correct are still re-used by students. Thus, many questions are being used for practice, likely before the weekly quizzes or exams (14 total assessments over the semester). Next, we address how many different students are making practice attempts.

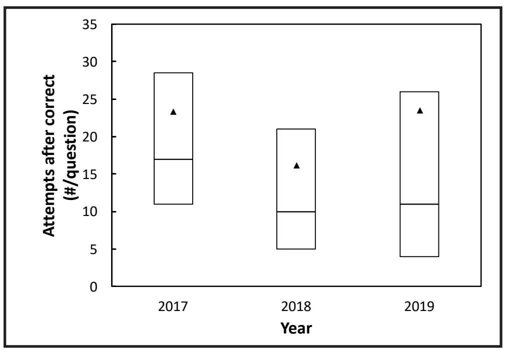

Figure 7. *Attempts after correct normalized by question across three cohorts.*

Almost every student across the three cohorts made at least one practice attempt during the course (282 out of 284 = 99%). Both the fraction of a cohort making attempts after correct and the number of attempts after correct summed over the course vary across cohorts (Figure 8). Across all of the question levels, between 4 and 15% will make an extra attempt (Figure 8, top). This finding could be inferred that only the A students are doing practice attempts; this hypothesis could not be explored due to the anonymity of the attempts data. However, the largest fraction of students making an attempt after correct on a single question varied between 62 and 67% across the cohorts.

With additional questions available each year, attempts after correct per student also increase (Figure 8, bottom). The median attempts after correct increase from 27 to 34 to 75 attempts as question count increased from 175 to 300 to 408. Students may be practicing more due to the instructor's prompting during class or other factors. In general, thousands of attempts after correct imply that auto-graded questions can serve as an interactive study tool before a quiz or exam. Thus, having access to questions that generate new numbers/context with each attempt seems to address the common request for more practice questions before a quiz or exam.

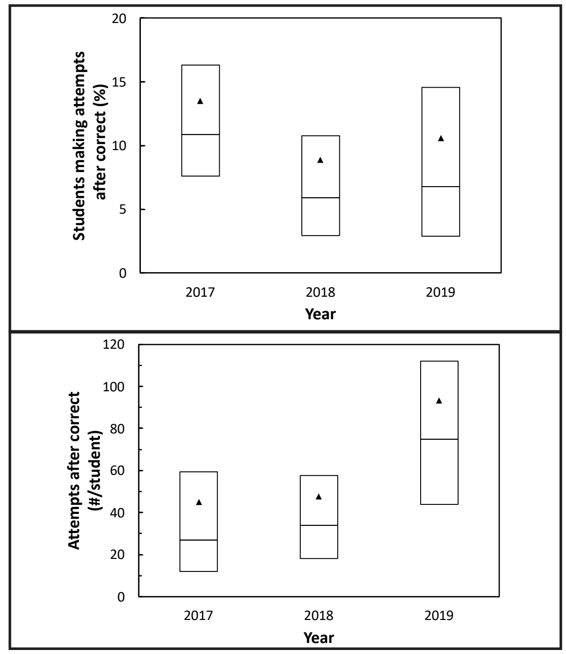

Figure 8. *(Top) Percent of the class with attempts after correct on challenge activities over the entire book as a function of year. (Bottom) Attempts after correct per student on challenge activities. 2017, 2018, 2019 represents 92, 102, and 103 students, respectively.*

CONCLUSIONS

Big data in terms of success and attempts on online homework questions were explored. Allowing students multiple attempts for solving each question led to median success of 94% over three cohorts and hundreds of questions. Success correlated strongly with final course grade. Specifically, for A versus B and C versus D students, statistically significant differences were measured. Furthermore, female students showed greater success than male students. Chapters introducing new concepts led to lower success than chapters whose content is previously covered, e.g. introductory chemistry. Even without the incentive to improve grades, students completed thousands of attempts after correct, ~19 attempts per question. This observation verifies that students use these online homework questions containing rolling numbers/content for additional practice – a widely accepted learning best practice. Future work will attempt to correlate success and attempts to identify difficult questions and improve student success using the interactive textbook, which hopefully will also translate to improved outcomes in the course.

DISCLAIMER

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

ACKNOWLEDGMENTS

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REFERENCES

1. Poulson B. Big Data in Data Science Foundations: Fundamentals. https://www.lynda.com/IT-tutorials/Big-data/2805908/2232722-4.html accessed January 11, 2020.
2. Stephens-Davidowitz S and Pinker S (2017) *Everybody Lies: Big Data, New Data, and What the Internet Can Tell Us About Who We Really Are*. HarperCollins New York:
3. Edgcomb A and Vahid F (2014) Effectiveness of online textbooks vs. interactive web-native content, *Proceedings ASEE Annual Conference*. DOI: https://peer.asee.org/20351.
4. Edgcomb A, Vahid F, Lysecky R, Knoesen A, Amirtharajah R, and Dorf ML (2015) Student performance improvement using interactive textbooks: A three-university cross-semester analysis, *Proceedings ASEE Annual Meeting*. DOI: https://doi.org/10.18260/p.24760.
5. Chi MT (2009) Active-constructive-interactive: a conceptual framework for differentiating learning activities. *Topics in Cognitive Science*. 1(1):73-105. DOI: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1756-8765.2008.01005.x.
6. Chickering AW and Gamson ZF (1987) Seven principles for good practice in undergraduate education. *AAHE bulletin*. 3:7.
7. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, and Wenderoth MP (2014) Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*. 111(23):8410-8415. DOI: https://10.1073/pnas.1319030111.
8. Felder RM and Brent R (2016) *Teaching and Learning STEM: A Practical Guide*. Jossey-Bass: San Francisco, CA.
9. National Academy of Engineering (2005) *Educating the engineer of 2020: Adapting engineering education in the new century*. National Academies Press:
10. Martin CC, Newstetter WC, and Le Doux JM (2019) Inclusion requires a comprehensive understanding of justice. *Journal of Engineering Education*. 108(4):453-458. DOI: https://10.1002/jee.20296.
11. Ross L, Mayled LH, Krause SJ, Judson E, Hjelmstad KD, Middleton JA, Culbertson RJ, Ankeny CJ, Chen Y, Hjelmstad KL, Glassmeyer K, and Hoyt S (2019) Scaling and assessment of an evidence-based faculty development program for promoting active learning pedagogical strategies, *Proceedings ASEE Annual Conference & Exposition*. DOI: https://peer.asee.org/32240.
12. Borrego M, Froyd JE, and Hall TS (2010) Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments. *Journal of Engineering Education*. 99(3):185-207. DOI: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.2010.tb01056.x.
13. Liberatore MW (2017) High textbook reading rates when using an interactive textbook for a Material and Energy Balances course. *Chemical Engineering Education*. 51(3):109-118. DOI: https://journals.flvc.org/cee/article/view/104416.
14. Liberatore MW (2017) Reading analytics and student performance when using an interactive textbook for a material and energy balances course, *Proceedings ASEE Annual Conference & Exposition*. DOI: https://peer.asee.org/28780.
15. Liberatore MW and Roach K (2018) Quantifying self-guided repetition within an interactive textbook for a material and energy balances course, *Proceedings ASEE Annual Meeting*. DOI: https://peer.asee.org/30912.
16. Liberatore MW and Chapman K (2019) Reading anytime: Do students complete missed readings after the due date when using an interactive textbook for material and energy balances?, *Proceedings ASEE Annual Conference*. DOI: https://peer.asee.org/33224.
17. Liberatore MW, Chapman KE, and Roach KM (2020) Significant reading participation across multiple cohorts before and after the due date when using an interactive textbook. *Computer Applications in Engineering Education*. 28(2):444-453. DOI: https://doi.org/10.1002/cae.22210.
18. Lang JM (2016) *Small Teaching: Everyday Lessons from the Science of Learning*. John Wiley & Sons:
19. Atkinson RK, Renkl A, and Merrill MM (2003) Transitioning from studying examples to solving problems: Effects of self-explanation prompts and fading worked-out steps. *Journal of Educational Psychology*. 95(4):774-783. DOI: https://doi.org/10.1037/0022-0663.95.4.774.
20. McGraw-Hill. Aleks: Assessment and learning in knowledge spaces https://www.aleks.com/ accessed January 11, 2020.
21. Kortemeyer G, Kashy E, Benenson W, and Bauer W (2008) Experiences using the open-source learning content management and assessment system LON-CAPA in introductory physics courses. *American Journal of Physics*. 76(4):438. DOI: https://doi.org/10.1119/1.2835046.
22. McGroarty E, Parker J, Heidemann M, Lim H, Olson M, Long T, Merrill J, Riffell S, Smith J, Batzli J, and Kirschtel D (2004) Supplementing introductory biology with on-line curriculum*. *Biochemistry and Molecular Biology Education*. 32(1):20-6. DOI: https://doi.org/10.1002/bmb.2004.494032010312.
23. Steif PS and Dollar A (2009) Study of usage patterns and learning gains in a web-based interactive static course. *Journal of Engineering Education*. 98(4):321-333. DOI: https://doi.org/10.1002/j.2168-9830.2009.tb01030.x.
24. Liberatore MW (2011) Improved student achievement using personalized online homework for a course in material and energy balances. *Chemical Engineering Education*. 45(3):184-190. DOI: https://journals.flvc.org/cee/article/view/122149.
25. Medina J (2008) *Brain Rules 12 Principles for Surviving and Thriving at Work, Home, and School*. Pear Press:
26. Silverstein DL, Bullard LG, and Vigeant MA (2012) How we teach: Material and energy balances, *Proceedings ASEE Annual Meeting*. DOI: https://peer.asee.org/21460.
27. Liberatore MW (2013) Active learning and just-in-time teaching in a material and energy balances course. *Chemical Engineering Education*. 47(3):154–160. DOI: https://journals.flvc.org/cee/article/view/114520.
28. Liberatore MW (2020) Material and Energy Balances zyBook. Zybooks - a Wiley brand: 2020. https://www.zybooks.com/catalog/material-and-energy-balances/.
29. Barron BJS, Schwartz DL, Vye NJ, Moore A, Petrosino A, Zech L, Bransford JD, and Vanderbilt CTG (1998) Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences*. 7(3-4):271-311. DOI: https://doi.org/10.1080/10508406.1998.9672056.
30. Lape NK (2011) Tiered scaffolding of problem-based learning techniques in a thermodynamics course, *Proceedings ASEE Annual Conference*. DOI: https://peer.asee.org/18365.
31. Liberatore MW, Chapman K, and Davidson M (2020) Quantifying success and attempts on auto-graded homework when using an interactive textbook, *Proceedings ASEE Annual Conference*. DOI: https://peer.asee.org/35116.
32. Sloan ED and Norrgran C (2016) A neuroscience perspective on learning. *Chemical Engineering Education*. 50(1):29-37. DOI: https://journals.flvc.org/cee/article/view/87714.
33. Bonett DG (2006) Approximate confidence interval for standard deviation of nonnormal distributions. *Computational Statistics & Data Analysis*. 50(3):775-782. DOI: https://doi.org/10.1016/j.csda.2004.10.003.
34. Bonett DG (2006) Confidence interval for a coefficient of quartile variation. *Computational Statistics & Data Analysis*. 50(11):2953-2957. DOI: https://doi.org/10.1016/j.csda.2005.05.007.
35. Evans JD (1996) *Straightforward Statistics for the Behavioral Sciences*. Thomson Brooks/Cole Publishing Co: Belmont, CA. ❒

APPENDIX

Supporting Information

Many figures in the main paper aggregated 3 cohorts of data; the reviewers were also provided with many figures for each annual cohort. Additionally, p values for all pairwise t-testing were also included for review. At time of publication, these figures are archived on Professor Liberatore's website, https://www.utoledo.edu/engineering/chemical-engineering/liberatore/.

Table S1
Total number of students and percentage of female per cohort

Cohort	2017	2018	2019
Total Students	88	98	98
Female (%)	36	37	34

Table S2
Questions per chapter summary by cohort and in total.

	Number of Questions		
Chapter	**2017 (88 students)**	**2018 (98 students)**	**2019 (98 students)**
1	52	53	58
2	14	14	35
3	23	25	44
4	30	30	30
5	18	18	33
6	17	34	44
7	14	18	32
8	7	7	7
9	0	101	125
Total	175	300	408

Table S3
Questions and attempts summary by cohort and in total.
Attempts rounded to nearest 100

	2017	2018	2019	Total
Students	88	98	98	284
Questions	173	300	408	881
Attempts before correct	36,500	66,000	76,700	179,100
Total attempts	39,800	70,100	87,100	197,000
Attempts after correct	**3,300**	**4,100**	**10,400**	**17,900**