INTERACTIVE READING AND AUTO-GRADED HOMEWORK ANALYTICS AND CORRELATIONS FOR MULTIPLE COHORTS WHEN USING AN INTERACTIVE TEXTBOOK FOR MATERIAL AND ENERGY BALANCES

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INTRODUCTION

Digital devices generate big data, such as sensing your steps, providing driving directions, or messaging for one-on-one text/video communication or public consumption. Engineering education, especially in higher education, creates similar large data sets for both faculty and students that can help measure learning experiences. From clicks to view times, points can be awarded for engagement or left as an opportunity for student self-evaluation, i.e., metacognition. The digital platform of interest here is an interactive textbook with integrated online homework. While these tools are more common in math and introductory science courses, interactive textbooks for engineering courses are becoming more widely available.[1-5]

Historically, engineering textbooks have been the antithesis of active learning with static text that is updated about once per decade. However, interactive textbooks put the onus on students to complete participation clicks, view animations one step at a time, match terms with examples, etc.[6] Since the learner's participation with the interactive textbook is recorded, incentives for reading can be given. These small incentives (2-10% of total course grade) have led to high student engagement.[1,3,4,7-9] For example, traditional textbooks in higher education generally garner reading rates between 20 and 50% [10-13] compared to median reading rates as high as 99% for interactive textbooks.[4,14,15] This level of engagement will be examined further for numerous cohorts in this contribution.

Beyond reading, auto-graded problems, generally called online homework, have become a common tool in science and engineering courses.[16-22] Auto-grading provides immediate feedback to students in most cases and can also minimize the time faculty and teaching assistants spend on grading. On one hand, online homework applies some of learning's best practices, such as scaffolding, multiple attempts, immediate feedback, randomized numbers, and rolling content.[23-25] These features align well with the tenets of deliberate practice and growth mindset.[26-28] On the other hand, online homework focuses primarily on algorithmic,

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computational problems and getting the correct numeric answer. Limited availability for conceptual, drawing, and graphical problems does not address the breadth of engineering topics and practice in many cases.

While most of this contribution could be general for engineering textbooks and online homework, some subject matter details are also relevant. The interactive textbook and online homework are for a course nominally titled Mass and Energy Balances (MEB). This course is generally the first core chemical engineering course taken near the end of the first year or beginning of the second year.[29] Course content includes developing engineering problem solving skills as well as multi-unit and multi-phase processes and reacting systems. Many publications in the literature related to this course are available and cover topics from course structure to novel teaching interventions.[3,29-32] Additional course-level findings will be included in the discussion as appropriate.

Overall, few instances of the engineering education literature provide quantitative studies that correlate the use of specific educational resources, such as textbooks, with student performance in the course. Thus, this multiple cohort study leverages an interactive textbook that applies established learning theories, including scaffolding and deliberate practice. Comparing students' course performance — as determined by traditional hand-written quizzes and exams — with execution of formative textbook reading and auto-graded homework fills a gap for justification of interactive learning tools for chemical engineering courses.

Research Questions

This manuscript expands upon our recent investigation across multiple cohorts using an interactive textbook for an MEB course.[33] The following research questions provide new perspectives on multiple cohort data sets. While the topic of reproducibility is one of the hallmarks of scientific research, the term is rarely found in the engineering education literature and usually only in the context of data produced by equipment in laboratory courses or exercises. Thus, the aggregation of multiple, statistically similar cohorts provides a unique opportunity to identify robust correlations between student activity and success in a course. Moving beyond reproducibility, the research questions address interactive textbook responses and grades as well as variations across course content. Specifically, the research questions are:

1. How does reading participation — an effort-based metric — correlate with final course grades?
2. How does fraction correct on auto-graded problems — a formative assessment — correlate with final course grades?
3. Does fraction correct on auto-graded problems vary with course content?

MATERIALS AND METHODS

A fully interactive textbook titled *Material and Energy Balances zyBook* follows the concepts normally covered in a first course in chemical engineering.[34] Since the interactive features and online homework have been detailed in other contributions in recent years, a brief summary is included here. Example screenshots have been provided in previous publications.[3, 14, 35] The February 2023 version included 150+ animations, 1400+ clicks to complete reading participation, and 730+ online homework problems. Each online homework problem has unlimited attempts and tens to millions of versions per problem, which was detailed previously.[3,36] The first eight chapters covering material and energy balances will be emphasized here; the ninth chapter covers spreadsheet skills that have been discussed in other papers.[5,37-39] All data are presented at the due date, while some previous work examined differences between the due date and end of semester.[40]

Reading participation was nominally worth 5% of the total course grade. The online homework, which are called challenge activities in the zyBook, accounted for an additional 5% of the final course grade. Finally, individual performance on the quizzes and exams represented 80% of the final course grade. Handwritten homework graded by teaching assistants as formative exercises accounts for the final 10% of the grade. Conflating of reading with final grades is small and was discussed previously.[4]

Reading participation encompasses click analytics to view all steps within animations, selecting correct answers on true/false or multiple-choice learning questions, and correctly completing matching exercises; the fraction of reading participation includes the clicks completed by the due date to the total assigned clicks. On one hand, reading participation is an effort-based grade with points being awarded for reading done before the due date; reading effort after the due date and its implications related to cramming were discussed in a previous publication.[4] On the other hand, challenge activities are scored as correct or incorrect with no limit on attempts. While all reading participation is accounted for in the final course grade, a forgiveness factor of 15 problems (2-3% of the total assigned problems) is used to minimize stress when students get stuck on auto-graded problems. This grade correction is not represented in the (raw) fraction correct presented here.

All seven cohorts discussed were taught at a public university by one of the authors; all students completing the course are included in the analysis. Five cohorts were taught in an in-person modality (2016-2019, 2022). The 2020 cohort received about half of a semester in person and half as a synchronous online course. The 2021 cohort was taught online synchronously. The enrollments include only those students completing the course, i.e., not withdrawing during the semester (Table 1). The fraction of female and male students was provided previously.[33] The higher usage and performance of female students, a group generally underrepresented in engineering, were discussed at length in the previous paper[33] and is outside the scope of this contribution.

The learning analytics described in the results leverage several data types related to the interactive textbook. First, reading participation quantifies the clicks when reading a section, which includes advancing through steps of animations, multiple choice questions, and matching exercises. For the nine chapters, over 1,400 clicks per student were assigned for the five most recent cohorts, and in total, over 600,000 reading interactions were completed. The number of auto-graded problems varied by cohort (Table 1). The 2020 to 2022 cohorts also included end-of-chapter problems, which were discussed elsewhere.[35,41] In total, over 150,000 problems are included in the analysis here.

Since individual outliers can skew mean values, box plots provide a more complete view of a data set by presenting the middle 50% (1st quartile, median, and 3rd quartile). This wider lens is especially valuable when studying unique human subjects. Mean values may also be plotted to identify skewness. Pairs of data sets were compared using hypothesis tests. These t-tests output p values and statistical significance is defined to occur when $p < 0.05$. Data generated by groups of students do not follow a normal distribution in many cases. However, t-tests are justifiable for larger data sets ($n > 20$) with non-normal distributions.[42]

RESULTS AND DISCUSSION

Studying multiple cohorts, especially when the groups are statistically similar,[33] allows for general trends and correlations to be captured, which is done here using student generated data from an interactive textbook for an MEB course. The first two research questions examine how reading participation and fraction correct on auto-graded problems correlate with final course grades. The third question focuses on variations in the fraction correct on auto-graded questions with respect to the specific course content, which is most relevant for instructors of the MEB course.

The primary metrics of reading participation and fraction correct help document cohort-to-cohort variation and the level of engagement and success within a cohort. Building upon previous work,[33] first quartile values represent the metric for at least 75% of the students within a cohort. Using quartiles avoids biases in averaging, especially when outliers occur. In Table 2, the first quartile reading participation was at least 80% for all cohorts, and six of the seven cohorts showed first quartile reading participation of 88% or higher. These values for interactive textbooks are much higher than reported across higher education for course or textbook readings, which normally ranges from 20 to 50%.[10-13]

TABLE 1
Cohort Information Including Number of Students and Number of Auto-graded Problems

Cohort	Students (#)	Auto-graded Problems	
		Required In-section Chapters 1-8 (#)	Total Available Chapters 1-9 (#)
2016	100	0	0
2017	88	173	173
2018	98	300	300
2019	98	408	408
2020	94	400	524
2021	66	378	712
2022	57	378	712

TABLE 2
Reading Participation and Percent Correct on Challenge Activities (CA) for the First Quartile

Cohort	Reading (%)	CA Correct (%)
2016	82	—
2017	88	81
2018	91	84
2019	93	81
2020	88	83
2021	89	84
2022	97	74

Additionally, as shown in Table 2, fraction correct on the auto-graded challenge activities ranged from 74 to 84% for the first quartile across six cohorts. With five of the six cohorts having a first quartile fraction correct of 81% or higher, some may question the difficulty of the problems. The high fraction correct is appropriate for formative exercises. In addition, an unlimited number of attempts is offered before the due date to earn points toward a student's grade. Therefore, students can make mistakes, check the solution, and correctly solve the next, randomized problem. Thus, these challenge activities align with many of the tenets of deliberate practice.[28,43,44] Beyond fraction correct, attempts before correct have been discussed in previous work and are beyond the scope here.[3,5,36] With the base case for reading participation and fraction correct now established, the research questions are addressed next.

Reading Participation and Grades

Two representations capture the correlation between effort-based reading participation and final course grades (Figure 1). Reading participation correlated with final course grades from both perspectives, i.e., when binned by letter grade or scattered by final grade (%). When grouping by final letter grade, boxes for A and B grades are visually smaller than C, D, and F grades. For A and B final grades, the median and third quartile reading participation were 100%. Thus, at least 50% of A and B students do not miss a single click of reading participation before the due date over the entire semester. Statistical comparison with the next lowest letter grade are captured by p values reported on the box plot.

Hypothesis tests comparing a letter grade with the next lowest letter grade were complete from A to B through D to F. The largest statistically significant change in reading participation comes between B and C students (Figure 1). Since reading is an effort-based grade, a hypothesis could be that all students read the same amount. However, this hypothesis is disproved for all cohorts. The significant decrease of reading, and thus effort, is clearly found between B and C students. Performing interviews with students in these categories could be a fruitful new direction for future inquiry, as no explanation is obvious from the reading data alone.

Further examining the box plot for reading (Figure 1), the median reading participation decreases from 96% for C students to 83% for F students. For all letter grades, the mean reading participation is lower than the median reading participation, which is due to small numbers of students doing measurably lower reading participation. These low reading students are captured in the scatter chart and discussed next.

The scatter chart displays all 601 students' reading participation as a function of their final grade (Figure 1). Fifty percent of students completed > 99% of the reading participation by the due date. The > 99% readers spanned final grades from 37% to 99%. More specifically, over 97% of the > 99% readers earned over 60% final grade (or passing the course with a D or higher); 92% of the > 99% readers earned over 70% final grade (many programs require a C or better for the MEB course). Reading participation alone should not be taken as a sole indicator or predictor of performance on the quizzes and exams that represent 80% of the final course grade. Fitting a line to correlate reading participation and final grade percentages finds a slope of 0.49. Therefore, reading participation is modestly predictive of final course grades, which will be further examined next when discussing auto-graded problems.

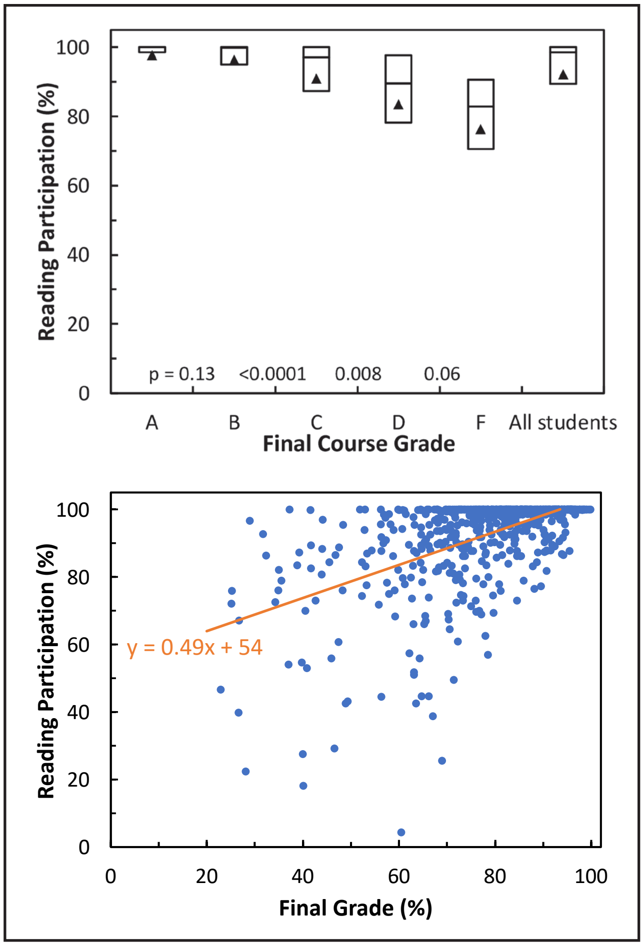

Figure 1. *(Top) Reading participation at the due date as a function of final course grades aggregated over seven cohorts (601 students). A, B, C, D and F grades represent 170, 160, 152, 60, and 59 students, respectively. Triangles represent the mean. Hypothesis tests between two letter grades are summarized with p values. (Bottom) Reading participation as a function of final course percentage with linear regression for 601 students.*

Auto-Graded Problems and Grades

The fraction of auto-graded problems answered correctly is correlated with final grades using both a binned box plot and a scatter plot (Figure 2). Thus, correlations for effort-based reading participation can be compared with competency-based auto-graded problems for the same cohorts of students. First, statistically significant differences are observed between all subsequent letter grades (as noted by the p values on the box plot). Since the first quartile captures at least 75% of students earning the final letter grade, additional discussion is pertinent. The first quartile correct was found to be 99% and 91% for A and B students, respectively. Since both A and B students successfully completed enough auto-graded problems to be considered an A student, this metric alone cannot explain differences between these two groups of students. Moving to C, D, and F students, the first quartile fraction correct decreases from 81% to 41%, and the interquartile range increased from 15% to 41%. Of note, for B, C, D, and F grades, the first quartile of the higher grade is equal to or larger than the median of the next lowest grade. While most (75% or more) of the

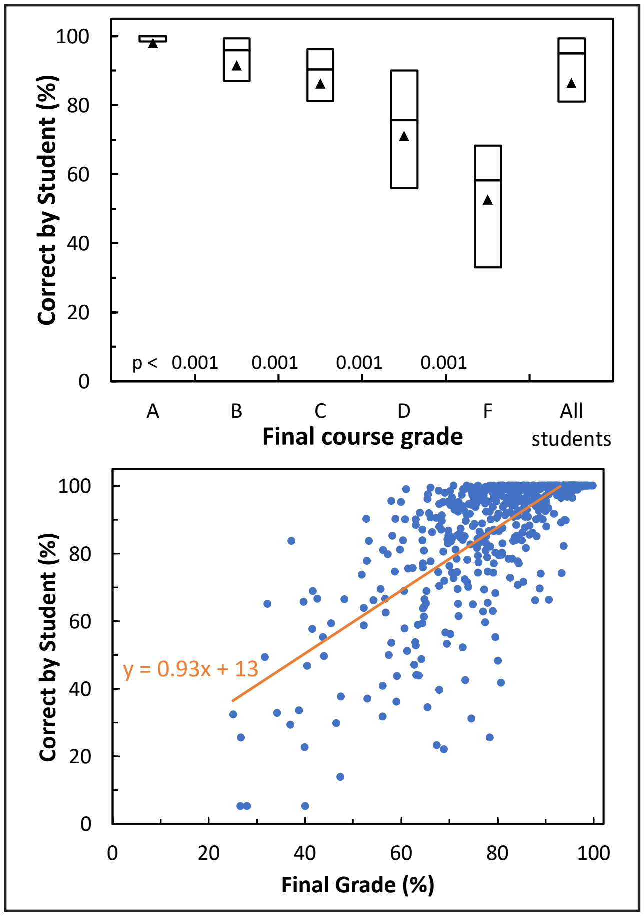

Figure 2. *(Top) Percent of auto-graded problems answered correctly on challenge activities over the entire book as a function of final course grades aggregated over seven cohorts (501 students). A, B, C, D and F grades represent 134, 146, 122, 56 and 43 students, respectively. Triangles represent the mean. Hypothesis tests are summarized with p values. (Bottom) Percent correct as a function of final course percentage with linear regression for 501 students.*

higher final grade students correctly complete this fraction of auto-graded problems, less than half of the students in the subsequent final grade group complete this fraction of auto-graded problems correctly.

A scatter chart for auto-graded problems (Figure 2) captures all 501 students as a function of the final grade (%). While unlimited attempts led to high fraction correct, the correlation between correct on auto-graded problems and final grades is much stronger than reading participation. For comparison, students completing > 99% of the auto-graded problems correctly represented 30% of students across the seven cohorts, which contrasts with 69% completing > 99% of the effort-base reading participation. Almost all of the students completing > 99% of the auto-graded problems by the due date earned a 70% or higher for the course (149 of 151 students or 99%), which translates to A, B, or C final course grades. In contrast, 92% of students completing > 99% of the reading interactions earned a C or higher for the course.

A linear correlation between fraction correct and final grade percentage found a slope of 0.93. Thus, the formative, auto-graded problems correlate strongly with final course grades. The slope is almost twice as large for auto-graded problems (formative assessment) than reading participation (effort-based metric). While auto-graded problems (5% of final grade) are conflated with the final grades, the influence is small. For example, first quartile for all students on auto-graded problems is 84%, which means that most students had 98-99% of their grade available after accounting for auto-graded problems (even before the forgiveness factor discussed in the methods section earlier).

Overall, fraction correct on auto-graded problems is predictive of final course grades and correlates more strongly than effort-based reading participation. Some strengths and limitations merit further discussion of these correlations. First, the large data sets created by six or seven statistically-similar cohorts make the work unique and robust. Linear correlations for both reading and auto-graded problems are included in the Appendix and demonstrate the similarities and ranges of slopes with cohort. This type of multi-year and cohort analysis overcomes a common criticism of engineering education research as not transferable or reproducible. Additionally, using box plots and quartiles in analysis captures the behaviors of large fractions (75% or more) of the cohorts. This type of statistical representation more directly captures the engagement and fluency across a diverse set of students. One limitation and opportunity for future work would be to investigate, e.g., interview, students falling measurably below the correlations for reading participation and fraction correct. For example, students earning B or C final grades in the course (70 to 89%) who completed less than 60% of the auto-graded problems likely have different study habits and behaviors for preparing for quizzes and exams. Researchers may be able to characterize these additional learning habits to help a larger fraction of students learn engineering concepts in the future.

Variations Across Course Content

An MEB course broadly covers the chemical engineering curriculum at an introductory level. Providing an initial exposure to concepts and equipment, including reactors and separators, establishing strong fundamental problem-solving skills, and writing/deriving material and energy balances should set students up to be successful in subsequent classes.[35,45] While these publications offer some anecdotal evidence on the course topics that students struggle with, more quantitative chapter, section, and question level analysis can be performed using the challenge activities in the MEB zyBook.

Thus, examining the fraction correct on auto-graded problems across chapters, and their related concepts, provided quantitative data to compare with an instructor's intuition and experience with concepts/chapters that students find difficult (Figure 3). Here, the analysis included both scaffolded, in-section problems, and comprehensive end-of-chapter problems. End-of-chapter problems were discussed previously.[35,41] Thus, fraction correct on challenge activities provide instructors real-time data to adapt to the needs of their students during the current semester, which have varied widely given the campus closures and subsequent remote instruction in 2020 and 2021.

The first chapter reviews quantities and units, including pressure, temperature, and concentrations. In many cases, these sections review content from high school and first-year college chemistry and physics. Thus, a first quartile score of 100% is not surprising. In addition, students have a lot of energy related to a new semester. Some concepts that are more difficult for students in this chapter include converting between volume, mass, and mole fractions as well as gauge pressure. Next, material balances for non-reacting systems are the topic of the second chapter. This chapter focuses on a 12-step problem-solving method, i.e., procedural knowledge.[31] The auto-graded problems for individual problem-solving steps lead to first quartile scores above 90%. However, the first problem asking the students to use the 12-step method with limited scaffolding, which is titled Distillation Columns with B, T, and X, leads to less completion of all question levels.

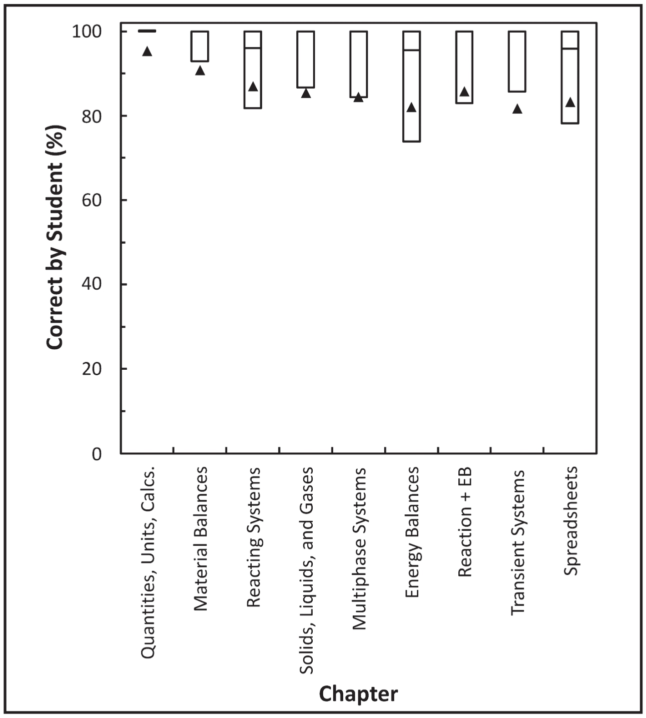

Figure 3. *Percent correct on challenge activities as a function of chapter aggregated over seven cohorts (501 students). Triangles represent the mean.*

In the next chapter Reacting Systems are introduced, with many new concepts or applying concepts from general chemistry courses in unfamiliar ways, such as steady-state flowing systems. This chapter is one of two chapters where the median fraction correct is less than 100% (96%). The interquartile range of 18% also shows some struggle across multiple concepts and activities. Yield and selectivity, reaction equilibrium, and reacting systems with recycle are more challenging topics that lead to a lower fraction correct. The next chapter covers treatment of different physical phases. The median fraction correct returns to 100%, while the third quartile correct remains below 90%. While directly reading the steam tables has a high fraction correct, applying calculations, including quality and interpolation, lead to lower fractions of correct responses. Standard temperature pressure (STP) and vapor pressure are the more challenging concepts in this chapter.

Multiphase systems, primarily vapor-liquid systems, are presented in the next chapter. Here, single calculation problems with Raoult's law and reading Pxy and Txy diagrams led to higher fraction correct, while material balance problems with Henry's law and flash analysis, even with some scaffolding, resulted in lower fraction correct.

Energy balance problems are divided between a chapter for non-reacting systems and one for reacting systems. Challenging topics for non-reacting energy balances include multi-step enthalpy paths and applying humidity definitions in a multiphase material balance problem. Similar trends are observed for reacting system energy balances, i.e., the fraction correct is higher for single calculations and lower for scaffolded problems integrating those single calculations into a full-scale material and energy balances. For example, the median correct for heat of formation calculations was 81%, while applying those heat of formation calculations on a problem titled Acetic Acid Series Reactions Energy Balance led to a median correct of 75%. The acetic acid problem includes seven scaffolded levels, which is very different than a traditional end-of-chapter textbook scenario with a paragraph of text and little to no guidance.

Finally, transient systems complete the material and energy balance chapters. Since the cohorts are primarily in their second semester of their first year of college, i.e., freshman, many are taking their first or second semester of calculus co-currently with MEB. Thus, the interquartile range of fraction correct for this chapter was 86 to 100%, which likely captures this more limited math preparation than courses held in the second year – the most common timing of MEB according to one recent study.[29] Challenge activities related to the ninth chapter covering spreadsheets are included in Figure 3 for comparison, but detailed analysis was previously published.[5,39]

CONCLUDING REMARKS

Interactive textbooks create new types of learning analytics that allow instructors to monitor their students in real time as well as after a course is complete. Here, seven cohorts encompassing 601 students were aggregated to investigate how students engaged with reading participation as well as correct completed auto-graded problems. These large data sets included over 700,000 reading interactions and 150,000 auto-graded problems. Specifically, the first two research questions focused on correlations between textbook analytics and final course grades. We believe that these correlations may be generalizable to other interactive textbooks and courses using effort-based assignments and formative assessments. Also, auto-graded problem data as a function of the course material was analyzed. This content-level data and discussion should assist MEB instructors related to topics that students struggle with. Thus, MEB instructors could adapt their individual class schedule to clarify these difficult concepts using the real-time data in the MEB zyBook. This technique is generally called just-in-time teaching.[31,46,47]

With median reading participation of 99% across the seven cohorts, engagement was high for all students and highest for students earning A and B final grades in the course. Reading participation correlated with final course grades when either binned by final course letter grade or scattered by final grade percentage. The most statistically significant change in reading participation came between students earning B and C final grades. Thus, the change in effort – since reading participation is solely based on effort – between B and C students may signal an opportunity to intervene with C students to improve their study habits and earn higher grades.

Fraction correct on auto-graded problems correlated more strongly with final course grades than reading participation. First, median correct of 91% or higher was found across six cohorts. Thus, allowing unlimited attempts on these formative problems allows students to persist in answering the randomized questions correctly. Here, students in each subsequently lower letter grade completed significantly fewer auto-graded problems correctly ($p < 0.05$). Finally, linear correlations between fraction correct on auto-graded problems found a slope of 0.93. Thus, final course grades, which are determined primarily by quiz and exam performance, correlates with performance on the auto-graded problems, that is a formative assessment with unlimited attempts. The slope of the linear correlation for fraction correct on auto-graded problems is larger than the effort-based reading participation (0.93 vs 0.49) when comparing an interactive textbook metric with final course grades.

By applying some of learning's best practices — including visuals and chunking in animations, immediate feedback in learning questions, and varying the interactive reading activities — the interactive textbook quantitatively engaged all learners. The auto-grading allowed for individual or class-level interventions to occur in real time and not after the next quiz or exam. We hope this type of learning analytics study becomes more common across chemical engineering education as data-generating digital tools are become prevalent across chemical engineering courses.

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APPENDIX

TABLE S1

Linear Correlations for Reading Participation and Percent Correct on Challenge Activities (CA) for Each Cohort and all Cohorts Combined

Year	Reading vs Final Grades	R^2	%correct vs Final Grades	R^2
2016	%RP = 0.45×FG + 55	0.22	—	—
2017	%RP = 0.54×FG + 51	0.29	%corr = 0.91×FG + 17	0.45
2018	%RP = 0.44×FG + 60	0.32	%corr = 0.77×FG + 28	0.38
2019	%RP = 0.42×FG + 60	0.19	%corr = 0.91×FG + 13	0.49
2020	%RP = 0.68×FG + 38	0.48	%corr = 1.12×FG + -3	0.62
2021	%RP = 0.40×FG + 60	0.20	%corr = 0.79×FG + 26	0.57
2022	%RP = 0.33×FG + 70	0.22	%corr = 0.98×FG + 5	0.51
ALL	%RP = 0.49×FG + 54	0.29	%corr = 0.93×FG + 13	0.50