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High reading participation using an interactive textbook for a first engineering thermodynamics course: A study at two universities

Prof. Matthew W Liberatore, Trine University

Matthew W. Liberatore is a Professor and Department Chair in the McKetta Department of Chemical and Bioprocess Engineering at Trine University in Angola, Indiana. He previously served on the faculty at the University of Toledo and at the Colorado School of Mines. Professor Liberatore earned his B.S. degree from the University of Illinois Chicago (UIC) and his M.S. and Ph.D. degrees from the University of Illinois Urbana-Champaign, all in chemical engineering. His expertise lies in the unique rheology measurements of complex fluids as well as engineering education research related to novel uses of technology and big data. He has authored several interactive textbooks with zyBooks and has published over 100 peer-reviewed articles. https://www.trine.edu/academics/colleges-schools/faculty/engineering/liberatore-matthew.aspx

Alexandra M Davidson, Trine University

Alexandra Davidson is a graduate student in the Master of Business Administration program at Trine University. She holds a bachelor's degree in chemical engineering from Trine and currently supports the university's Chemical Engineering Department as a teaching assistant, which led to her contributions for this paper. Her interests include engineering education, data management, and the intersection of engineering and business practices.

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Abstract

Interactive textbooks provide a new, student-centered paradigm based on many best practices from learning science, including active engagement, chunking, and visual learning. Thermodynamics, a foundational yet often conceptually challenging subject for mechanical and chemical engineers, presents a valuable opportunity to evaluate the effectiveness of interactive resources. Here, a learning analytics study is completed to quantify and interpret students' reading participation. The interactive textbook is titled Engineering and Chemical Thermodynamics zyBook published by Wiley. The book includes dozens of animations and questions sets – including true and false, multiple choice, and matching. Thus, students' engagement generates big data. Two research questions ground this work: 1. Do students complete reading participation by the due date? And 2. How does reading participation vary across two universities? Data from two undergraduate cohorts at different universities (n=57) demonstrated high reading participation rates, with the median exceeding 99% for both groups of students, far exceeding the reported average of 20 to 50% over the last few decades. Further, this effort-based measure of reading participation exhibited no significant variation by class size, university type, or location. Student performance on auto-graded challenge problems demonstrated more significant variation between the two cohorts, although the fraction correct remained consistently high (median ≥84%). Overall, students who achieved A course grades engaged more deeply and regularly with the interactive materials, completing nearly all assigned reading tasks and auto-graded problems. This contribution underscores the potential of interactive textbooks to enhance learning outcomes, particularly in challenging STEM courses.

Introduction

Textbooks have long served as foundational tools for student learning in higher education, offering structured content to guide knowledge acquisition. Traditional textbooks, however, have been criticized for their passive nature and static content, often resulting in low engagement and minimal interaction from students. Reading rates for conventional textbooks in higher education are typically reported to range between 20% and 50% [1-3]. To address these challenges, interactive textbooks have emerged as dynamic alternatives that integrate technology with active learning principles.

Interactive textbooks leverage features such as multi-step animations, embedded quizzes, and auto-graded problems to promote student engagement and enhance learning outcomes [4-6]. These features are rooted in cognitive load theory and the principles of deliberate practice, which emphasize chunking of information, repetition, immediate feedback, and scaffolding of content [7-10]. By transforming static text into interactive elements, these digital resources engage students in ways that traditional textbooks cannot. For example, animations enable visualization of complex phenomena, while interactive problem-solving exercises provide opportunities for immediate skill application and assessment [11, 12]. Especially in science and engineering, interactive textbooks can transform content delivery to skill development and thus serve as an effective learning tool instead of just a repository of information.

Recent studies have demonstrated the significant impact of interactive textbooks and other digital tools on student engagement and learning outcomes across a range of disciplines [3, 4, 13-15]. Research highlights that interactive textbooks, animations, simulations, quizzes, and other tools effectively enhance engagement by encouraging students to participate in the learning process rather than passively consuming content. While math and science educators have long studied the effectiveness of online homework, the combination of interactive textbooks with auto-graded problems remains an emerging area of research [16-18]. Looking only at the interactive content portion, studies across multiple engineering courses have shown that assigning course credit for completing interactive activities significantly boosts student participation, with engagement rates increasing by over 35% when tied to grades [6]. Research on chemical engineering interactive textbooks, specifically for Material and Energy Balances courses, has shown reading participation rates exceeding 90% across multiple cohorts, far surpassing traditional benchmarks [13, 15]. In addition, student surveys showed students liked many of the features of the interactive textbook [3]. Moreover, interactive textbooks allow for the collection of large-scale, real-time learning analytics, enabling educators to monitor student engagement, identify misconceptions, and tailor interventions accordingly [19, 20].

The field of thermodynamics education stands to benefit significantly from advancements and innovations in interactive textbooks and related technologies. Despite its position as a foundational subject in engineering curricula, thermodynamics is often perceived as conceptually difficult and abstract by many engineering disciplines including mechanical and chemical [21-24]. For example, one of this paper's authors has 23 textbooks with the word thermodynamics in the title in his office, which may indicate both the importance of the subject as well as the need for multiple perspectives to grasp the concepts. By integrating interactive technologies into thermodynamics instruction, these multi-modal tools then have the potential to make abstract concepts more tangible, improve student understanding, and enhance overall engagement. This study represents what is believed to be one of the first implementations of an interactive textbook for a thermodynamics course, which should add to the broad study of thermodynamics education cited earlier.

Thus, the use of learning analytics further amplifies the advantages of interactive textbooks. Data on click streams, animation views, and quiz performance enable instructors to monitor student progress and adapt teaching strategies in real time [25-27]. These capabilities not only support individualized learning but also promote engagement and allow learners to respond to feedback. This paper builds upon prior research on interactive textbooks by examining reading participation and engagement in a newly developed interactive textbook titled Engineering and Chemical Thermodynamics. By analyzing click-stream data and other interaction metrics, this study aims to evaluate how effectively this new tool supports students in mastering core thermodynamic principles. These new findings will inform the design of future instructional materials and contribute to the broader understanding of the role of technology in engineering education.

Materials and Methods

The Engineering and Chemical Thermodynamics zyBook (ECT) is a fully interactive textbook designed to support foundational thermodynamics courses in engineering curricula [28]. ECT is a re-formulation of the traditional textbook, Engineering and Chemical Thermodynamics, 2nd Edition, published by Wiley since 2003 [29]. ECT follows a standard sequence of topics, including properties of pure substances, the first and second laws of thermodynamics, and applications to power and refrigeration cycles. The zyBook incorporates dynamic features such as multi-step animations, interactive learning questions, and auto-graded problems. These elements aim to promote active learning and engage students in conceptual understanding and problem-solving. The cost of ECT was $64 per student for the Fall 2024 semester, which included both content and auto-graded problems.

The current study focuses on analyzing student interaction data from ECT, with the primary metrics of interest being reading participation and completion of auto-graded challenge activities. The features of ECT are tabulated below (Table 1). For instructors curious about the presentation of student data for use in their courses, zyBooks has an instructor help center, including [30]. The clicks metric encompasses multiple choice, matching, and true/false learning questions as well as each step to complete watching an animation. Most challenge activities were derived from the end-of-chapter questions of the previous editions with the addition of randomized, rolling numbers and some variations in content. Specifically, for the Thermodynamics I courses being examined here, Chapters 1 to 4 were covered along with the first 3 sections of Chapter 5. The subjects covered by these chapters are: Thermodynamic Properties; the First Law of Thermodynamics; Entropy and the Second Law of Thermodynamics; Equations of State and Intermolecular Interactions; and the Thermodynamic Web. Thus, students were assigned 752 reading clicks over the semester. The reading rate is the ratio of clicks completed by the due date compared to the total clicks assigned.

Table 1. Metrics for the interactive Engineering and Chemical Thermodynamics zyBook.

Metric	ECT zyBook
Chapters	9
Sections	76
Animations	153
Auto-graded problems	65
Reading clicks	1275

The study collected data from two cohorts of undergraduate engineering students enrolled in a first thermodynamics course. One cohort, in Fall 2023, was at a medium-sized public university, and a second cohort, during the Fall 2024 semester, was at a small, private, primarily undergraduate serving institution. One of the authors was the instructor of both cohorts. Each cohort participated in an in-person course supplemented by zyBook and other assignments. Student interaction data, including animation views, clicks per activity, and completion rates for challenge activities, was automatically logged by the zyBook platform. Unlike previous studies that examined engagement after assignment due dates, which related to cramming [13], this study reports interactions at assignment deadlines. Reading participation was incentivized with

5% of the final course grade, while challenge activities accounted for an additional 1-2%. Students' overall course performance, that is, final grades, was also examined to explore potential correlations between engagement metrics and academic outcomes.

The assignments for the course overall included reading participation, challenge activities, and traditional problems done by hand. Each assignment was assigned at least 1 week before the due date with about 10 reading, 5 challenge activity, and 7-9 static homework assignments over a 15- or 16-week semester. Static homework problems, referred to as zyExercises, are included at the end of each chapter with instructor control over releasing the embedded solutions. Students electronically scanned and submitted hand-written work for the static homework assignments.

Reading participation, an effort-based metric, was measured as the ratio of completed clicks to assigned clicks by the due date. Auto-graded challenge activities were analyzed based on the percentage of correct responses, also at the due date. The authors considered challenge activities to be formative assessments and so attempts are unlimited, although some content or numbers change after each incorrect attempt. Numeric tolerances allow for rounding differences and vary by question. About 1-2% of the total assigned challenge activities are forgiven in students' grades to reduce stress when a student is stuck on a problem without support (e.g., late at night) [31, 32]. The uncorrected fraction correct (%), that is the fraction correct without grade forgiveness, are presented here. In addition, animation view completion rates, re-watch frequencies, and view times as well as the number of attempts per question for challenge activities were measured, but these metrics are beyond the scope of this work. This limitation may also be considered an opportunity for future studies that would parallel work from the Material and Energy Balances zyBook [3, 12, 13, 15].

Statistical analyses, including t-tests, were conducted to compare interaction metrics across cohorts. Differences may be reported using Hedges' g for effect size and p-values to determine statistical significance. By presenting median and quartile data in box plots, a large fraction of each cohort can be presented without bias from outliers. In addition, triangles represent the mean in the box plots.

The study was approved by both universities' Institutional Review Boards (IRB). Participation in zyBook activities was integrated into the course requirements, and students were assured that individual performance data would remain anonymized during analysis.

Results and Discussion

The research questions explore both reading participation and auto-graded questions. Using multiple metrics generated by students using the interactive thermodynamics book, a quantitative study is presented here that correlates traditional metrics, such as exam scores and final grades, with students' interactions with ECT. By examining two cohorts at different universities, some transferrable or generalizable results may be found. Specifically, the following research questions will be addressed in this study:

1. How do reading participation and fraction correct on auto-graded problems vary with different cohorts?

2. Does reading participation and/or fraction correct on auto-graded problems correlate with final course grades?

Overall, 42,000 reading clicks and 2,000 auto-graded questions were analyzed to answer the research questions.

> Research Question 1: How do reading participation and fraction correct on auto-graded problems vary with different cohorts?

Reading participation was very high for both cohorts (Figure 1). The median reading rate was 99% or higher for both groups of students. Thus, at least half the class in both cohorts completed nearly all of the reading clicks before the deadlines, which were approximately weekly. Exploring further, the 1st quartile reading rates were 93 and 97%, respectively for the 2023 and 2024 cohorts. Box plots and quartiles were used to capture the reading habits of three-quarters of the students in each cohort. These reading rates over 90% far exceed any traditional textbook reading rates reported in higher education [1-3]. These reading rates are similar to reading rates for other engineering interactive textbooks [3, 13, 15].

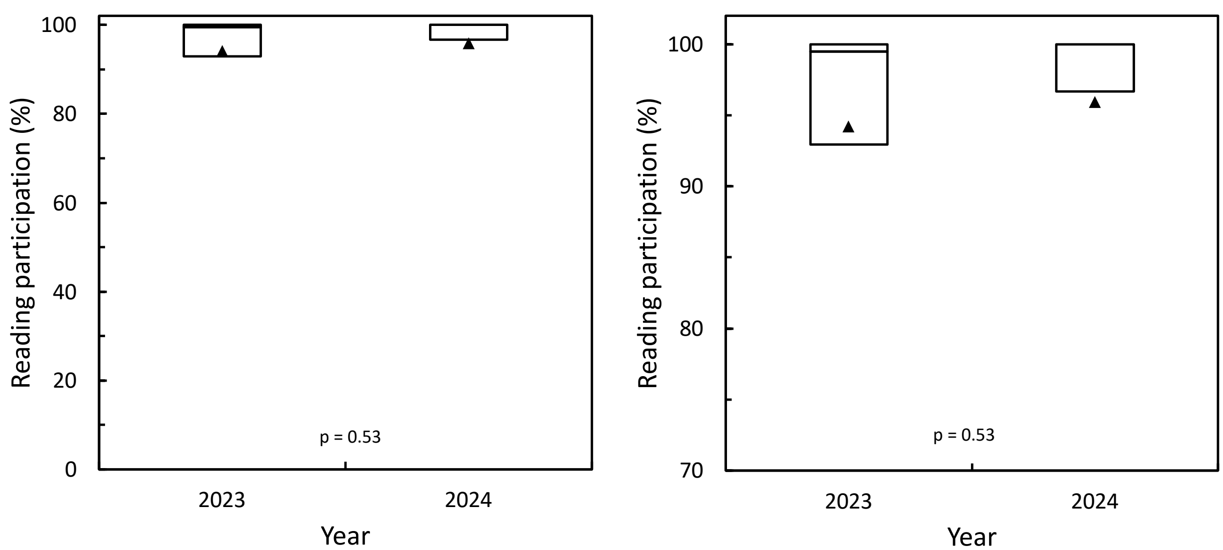

Figure 1. Reading participation as a function of cohort by year. Left. Y-axis scaled from 0 to 100%. Right. Y-axis zoomed into to 70 to 100%. n=39 and 18 for 2023 and 2024, respectively.

Comparing the reading rates of the two cohorts shows small differences. Performing a t-test on the two cohorts finds the groups' reading participation to be statistically similar ($p = 0.53$). Therefore, an effort-based metric, such as reading participation, was unaffected by class size, university type, or location. This finding implies transferability of using a small grade incentive to generate high reading participation in chemical engineering courses using interactive textbooks.

The metric of interest for auto-graded problems, called challenge activities in ECT, was the fraction of problems correct by the due date. Students have unlimited attempts with rolling numbers and some variations in content with each attempt. First, the median fraction correct was high for both cohorts at 84 and 96%, respectively for the 2023 and 2024 cohorts (Figure 2). The 1st quartile values show an even larger difference at 73 and 94%, respectively. Using a t-test to more broadly compare the cohorts' performance on auto-graded problems finds the groups statistically different ($p < 0.001$). This difference may be attributed to the smaller class size (18 versus 39) or stricter pre-requisite criteria for the 2024 cohort. The pre-requisite course for the 2024 cohort's Thermodynamics I course was a C or better grade in the Material and Energy Balances course, while the curriculum for the 2023 cohort does not have this grade-based restriction. Comparing to other studies of auto-graded problems in chemical engineering, the fraction correct for thermodynamics are similar to material and energy balances on two platforms [9, 15, 18, 33].

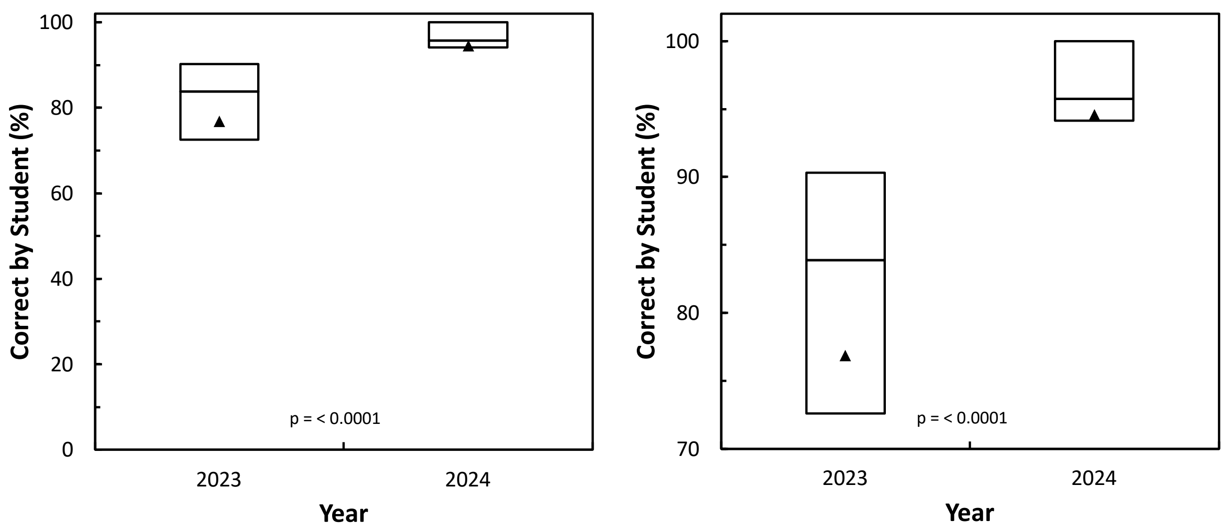

Figure 2. Auto-graded problems percent correct as a function of cohort by year. Left. Y-axis scaled from 0 to 100%. Right. Y-axis zoomed into to 70 to 100%. n=39 and 18 for 2023 and 2024, respectively.

Overall, answering the first research question found high reading participation and fraction correct on auto-graded problems for both cohorts. Both cohorts showed statistical similarity for effort-based reading while the smaller, 2024 cohort correctly answered a statistically significantly higher fraction of auto-graded problems.

> Research Question 2: Does reading participation and/or fraction correct on auto-graded problems correlate with final course grades?

With small- and medium-sized cohorts of 18 and 39 students, correlating interactive textbook metrics and grades were completed in aggregate. Additionally, the smaller number of D and F grades (4 in total) were not included in this analysis. Thus, effort-based reading and formative auto-graded problems are first correlated with binned letter grades for 53 students.

Reading participation decreased at each lower course grade (Figure 3). Thus, students earning A grades in the thermodynamics course completed more reading than students earning B grades, and students earning C grades on average and median read less than students earning Bs.

Quantitatively, almost all students earning A grades completed 100% of the reading tasks by the due date. Specifically, 11 of the 13 students earning A grades completed 99% of the reading clicks or more, which is not articulated in a box plot based on quartiles. This level of reading participation for students earning A grades in thermodynamics is consistent with students in material and energy balance courses [13, 15].

Next, the median reading participation for students earning B and C grades were 100 and 94%, respectively. The 1st quartile scores showed a larger difference with 97 and 86% for the B and C groups. While the reading participation did decrease with subsequent letter grades (more clearly observed for the zoomed in right panel of Figure 3), the differences were not statistically significant comparing the group earning one letter grade and the next lowest letter grades ($p > 0.05$). Overall, high reading participation was slightly lower with each subsequent letter grade earned in the course with individual, proctored exams and quizzes accounting for 80% of the total course grade.

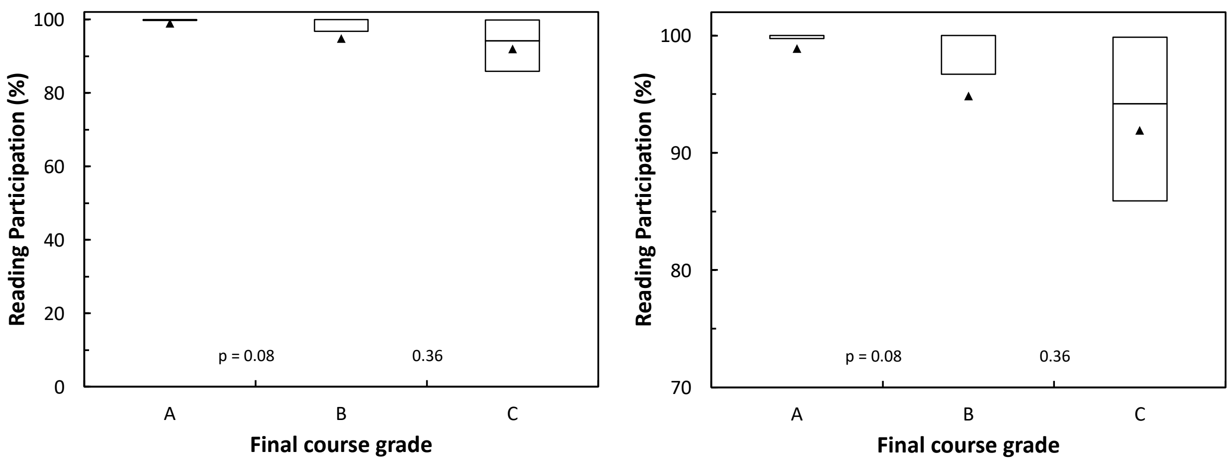

Figure 3. Reading participation as a function of final grades for 2 cohorts in aggregate. Left. Y-axis scaled from 0 to 100%. Right. Y-axis zoomed into to 70 to 100%. n=13, 25, and 15 for A, B, and C, respectively.

Fraction correct on auto-graded problems decreased more significantly with each lower letter grade than reading participation (Figure 4). Starting with the top quarter fraction correct, students in both A and B final grade groups completed 100% of the auto-graded problems before the deadlines. The students earning C grades in the 3rd quartile completed a more modest 87% of the problems correctly. Next, median fraction correct decreased also from 96, 87, and 84% for students earning A, B, and C grades, respectively. First quartile fraction correct showed similar decreases. While statistical significance was not found when comparing to the next lowest course grades, the general trend is that earning less than 90% fraction correct on formative challenge activities is a strong indicator that averaging A grades on quizzes and exams is unlikely.

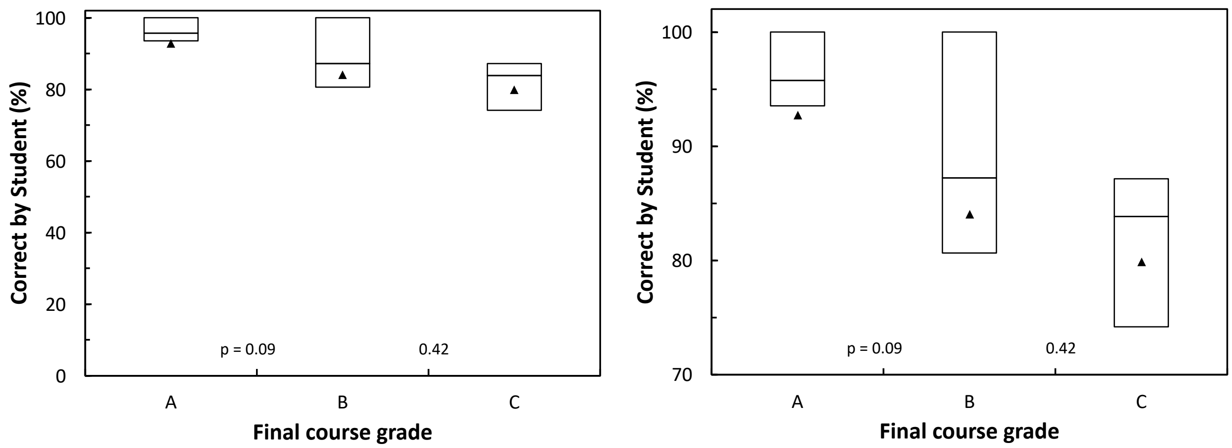

Figure 4. Auto-graded problems' fraction correct as a function of final grades for 2 cohorts in aggregate. Left. Y-axis scaled from 0 to 100%. Right. Y-axis zoomed into to 70 to 100%. n=13, 25, and 15 for A, B, and C, respectively.

A weak positive correlation was observed between reading participation and students' final course grades (Figure 5). Increases in final course grades tended to be associated with slight increases in reading participation, indicated by a trend line with a slope of 0.27. The majority of students who achieved high final grades (>85%) maintained nearly 100% reading participation, whereas students who achieved slightly lower final grades (<75%) experienced more widespread variation in reading participation.

A stronger positive correlation was observed between the fraction correct on auto-graded problems and students' final course grades (Figure 5). Students with higher final course grades tended to achieve a higher fraction correct on auto-graded problems, indicated by a trend line with a slope of 1.2. The majority of students earning final course grades >90% tended to achieve over 95% correctness on auto-graded problems, while students earning final grades <90% exhibited a much broader range of accuracy on auto-graded questions.

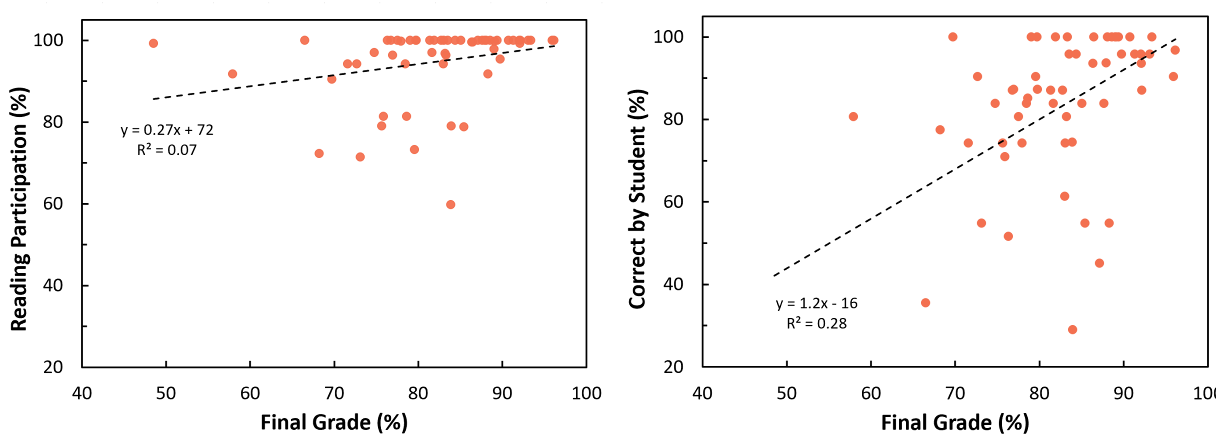

Figure 5. Reading participation (left) and fraction correct on auto-graded problems (right) as a function of final grades for 2 cohorts in aggregate. n=57 students.

Overall, the correlations between reading rates or fraction correct on auto-graded problems are qualitatively similar to those found for the Material and Energy Balances zyBook [13, 15, 18]. Quantitative comparisons may be possible as larger data sets for Thermodynamics become available.

Conclusion

This research helps demonstrate the potential of interactive textbooks to enhance student engagement and learning in challenging STEM courses, specifically thermodynamics. Reading participation was quantified by completing clicks while auto-graded problems were measured by the fraction answered correctly – both metrics were taken at the due date. High reading participation rates—exceeding 99% median across both cohorts—quantify the efficacy of assigning course credit (5% in this case) to incentivize regular engagement before class meetings. The effort-based nature of reading participation in thermodynamics was unaffected by class size, university type, or location. These findings suggest that this approach can be successfully implemented across diverse educational settings. In comparison, performance on auto-graded challenge activities varied more significantly between cohorts, potentially reflecting differences in class size. However, fraction correct without limiting attempts was still quite high with median correct of 84% or higher.

Interactive textbook metrics correlated with final course grades. Both higher reading participation, an effort-based metric, and fraction correct, a competency-based metric, were associated with better exam and quiz scores determining final grades. Using a linear regression, fraction correct on auto-graded exercises more strongly correlated with final grades than reading participation, slopes of 1.2 and 0.27, respectively. For one specific group, students achieving A course grades consistently engaged more deeply with the interactive textbook, completing nearly all reading tasks and auto-graded problems. While not statistically significant in all cases, these trends emphasize the importance of integrating interactive tools into course designs to foster active learning and incremental mastery of complex concepts.

These insights contribute to the growing body of research on the use of educational technology in engineering education. Overall, this study used only about half of the content in the Engineering and Chemical Thermodynamics zyBook, which is configurable for a multi-course sequence and potential future research. Future work may explore additional engagement metrics, such as animation views and number of attempts before correct, to provide a more comprehensive understanding of how interactive textbooks impact learning. Problem difficulty was examined using a metric called the deliberate practice (DP) score, which was detailed in a previous publication [9]. By leveraging real-time learning analytics, educators can further refine instructional strategies and support student success in challenging STEM courses including thermodynamics.

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Disclaimer

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

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