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Reproducible High Reading Participation and Auto-Graded Homework Completion across Multiple Cohorts When Using an Interactive Textbook for Material and Energy Balances

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Abstract

Interactive textbooks paired with online homework generate big data that can help answer questions about student engagement and learning. Here, a fully interactive textbook for a material and energy balances course measured over 1,300 reading interactions per student per cohort. In addition, several hundred auto-graded homework questions were assigned to students each semester. The auto-grading allowed for individual or class-level interventions to occur in real time and not after the next quiz or exam. In total, seven cohorts representing over 600 students and over 700,000 reading interactions are aggregated, which expands upon previous publications. For example, median reading participation was over 93% for all seven cohorts. In aggregate, female students completed reading participation at a higher rate than male students with statistical significance. Thus, applying some learning best practices including visuals and chunking in animations, immediate feedback in learning questions, and varying the interactive reading activities quantitatively engaged all learners, but showed even higher engagement with female students – an underrepresented group in engineering. Next, analytics from over 130,000 auto-graded problems are examined. 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. As with reading participation, female students completed a greater percentage of auto-graded problems than male students, however, statistical significance was not found for auto-graded problems. Overall, few articles in engineering education present data where an underrepresented group, female students in this case, outperform the majority group. While reasons for the differences are speculative at this point, we hope this contribution stimulates other qualitative and quantitative research on gender differences and educational technology.

Introduction

Digital devices generate big data including sensing movement, providing driving directions, or text/video messaging for one-on-one communication or public consumption. Engineering education, especially in higher education, creates similar big data for both faculty and students related to learning experiences. From clicks to page and video view times, points can be awarded for engagement or left as an opportunity for student self-evaluation. The digital platform of interest here is the 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 onus on students to complete participation clicks, view animations one step at a time, match terms with examples, etc. [6]. With learner participation in interactive textbooks 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, 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, has become a common tool in science and engineering courses [16-22]. Auto-grading provides immediate feedback to students in most cases and can minimize time grading for faculty and teaching assistants. On one hand, online homework applies some of learning's best practices, such as immediate feedback, scaffolding, multiple attempts, 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, computational problems and getting the correct numeric answer. Limited availability for conceptual, drawing, and graphical problems does not address the breadth of engineering topics in most cases.

While most of this contribution could be general for engineering textbooks and online homework, some subject matter details may also be relevant. The interactive textbook and online homework are for a course nominally titled Mass and Energy Balances. 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, e.g., [3, 29-32]. Additional course-level findings will be included in the discussion as appropriate.

Here, several research questions will be explored around the topic of reproducibility, which is term sparsely used when searching ASEE contributions. Specifically, two types of research questions are investigated:

1. As high reading participation and completion of auto-graded problems consistent across many cohorts?
2. Does reading participation or completion of auto-graded problems vary with gender?

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 [33]. Since the interactive features and online homework have been detailed in other contributions in recent years, a summary exclusive of example screenshots values brevity. The February 2023 version includes 150+ animations, 1400+ clicks to complete reading participation, and 730+ online homework problems. The 8 chapters covering material and energy balances will be examined here, while the 9th chapter covers spreadsheet skills that have been discussed in other papers [5, 34, 35] and another contribution at this conference [36].

Reading participation was nominally worth 5% of the total course grade, and the online homework, which are called challenge activities in the zyBook, accounted for an additional 5%

of the final course grade. 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 award for reading done before the due date; reading effort after the due date was 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 as a 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 is also provided. These data represent gender at birth. Applying a lens of other gender-related terms [37] is possible but is outside the scope of the current study and may be considered a limitation.

The learning analytics described in the results leverage several data types related to the interactive textbook (**Table 1**). 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 8 chapters of interest, over 1,100 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. The 2020 to 2022 cohorts also included end-of-chapter problems, which were discussed previously [38, 39]. In total, over 130,000 problems are included in the analysis here.

Table 1. Cohort information including number of students, fraction female and male, and number of auto-graded problems.

Cohort	Students (#)	Female (%)	Male (%)	Auto-graded problems	
				Required in-section Chapters 1-8 (#)	Total available Chapters 1-9 (#)
2016	100	40	60	0	0
2017	88	36	64	173	173
2018	98	36	64	300	300
2019	98	34	66	408	408
2020	94	39	61	400	524
2021	66	39	61	378	712
2022	57	46	54	378	712

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). 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 nonnormal distributions [40]. Also, Hedges g quantifies effect size with small being $g \leq 0.3$, medium $0.3 < g < 0.5$, and large $g \geq 0.5$.

Results and Discussion

Analyzing hundreds of thousands of interactions from reading and thousands of auto-graded homework problems will allow examining data from different perspectives and across cohorts. The results and discussion will address the following four research questions:

1. Is high reading participation reproduced over many cohorts?
2. Does reading participation vary with gender?
3. Is completion of auto-graded problems reproduced over many cohorts?
4. Does completion of auto-graded problems vary with gender?

Is high reading participation reproduced over many cohorts?

While class size varied from 57 to 100 students, high reading participation was observed for all seven cohorts (**Figure 1**). Median reading participation increased from 94% in 2016 to 99% in 2017 and was 100% in the subsequent five cohorts. The 1st quartile reading participation serves as another metric that captures reading for at least 75% of a cohort. The lowest 1st quartile reading participation was 82% in 2016, which was previously discussed as a change from reading assignments due every class session to once per week [4]. For the last five cohorts, the 1st quartile reading participation was lower for the 2020 and 2021 cohorts at 88 and 90%, respectively, compared to 95% and 99% of the 2019 and 2022 cohorts, respectively. The 2020 and 2021 cohorts were delivered in a different modality, i.e., partially or fully remote, than the other fully in-person cohorts. The combination of fully in-person instruction and smaller class size for the 2022 cohort may help explain the highest reading participation to date - a 1st quartile reading participation of 99%. As mentioned in the introduction, reading participation for an interactive textbooks is significantly higher than other reading reported for higher education, i.e., between 20 and 50% [10-13].

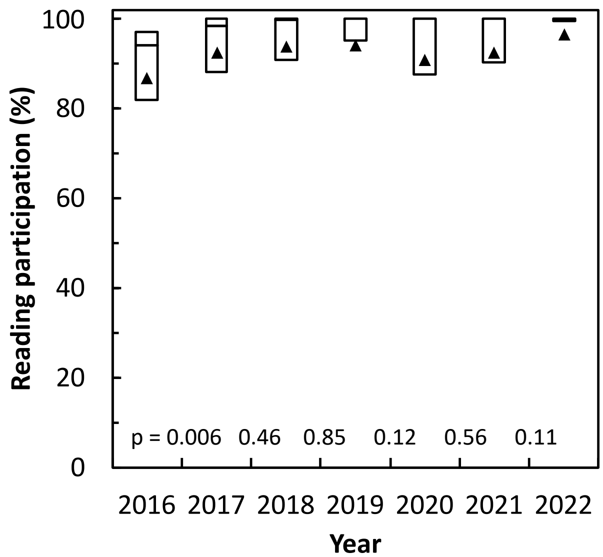

Figure 1. Reading participation for Chapters 1 through 8 in the Material and Energy Balances zyBook as a function of cohort. In aggregate, n = 601 students. p-values compare a cohort with the next subsequent cohort.

Cohort to cohort variations were quantified using t-tests and ANOVA analyses. First, one cohort was compared with the subsequent cohort. Cohort to cohort variations in reading participation were not statistically significant for the six cohorts between 2017 and 2022. The increase in reading rate between 2016 and 2017 was statistically significant ($p = 0.006$) and discussed previously [4]. Performing ANOVA test from 2016 to 2022 cohorts found a statistically significant difference ($p = 0.005$). However, performing ANOVA for the 2017 to 2022 cohorts finds these cohorts are statistically similar ($p = 0.21$), which verifies the t-tests on subsequent cohort pairs. Therefore, the last six cohorts show statistically reproducible high reading participation.

Overall, median reading participation above 95% was consistent over six recent cohorts and over 500 students. Providing an incentive of 5% of the final course grade correlates with high reading participation both within and across cohorts, which aligns with previous work [9].

Does reading participation vary with gender?

While high reading participation was observed for all students, reading participation based on gender showed some measurable differences (**Figure 2**). Female students are generally an underrepresented group in engineering, and in this case, the fraction of female students varied from 36 to 46% for the seven cohorts. Female students completed reading at a higher rate than male students with a measurable statistical significance ($p=0.01$). The y-axis in **Figure 2** is a much smaller range than **Figure 1** to focus on the differences between the two groups. When combining the seven cohorts, the median reading participation of female students was 2% higher than male students (99% vs 97%). The interquartile spacing for females was 7%, which is 5%

smaller than the spacing for male students (12%). A small effect size, quantified by Hedges g value of 0.20, was observed between female and male students.

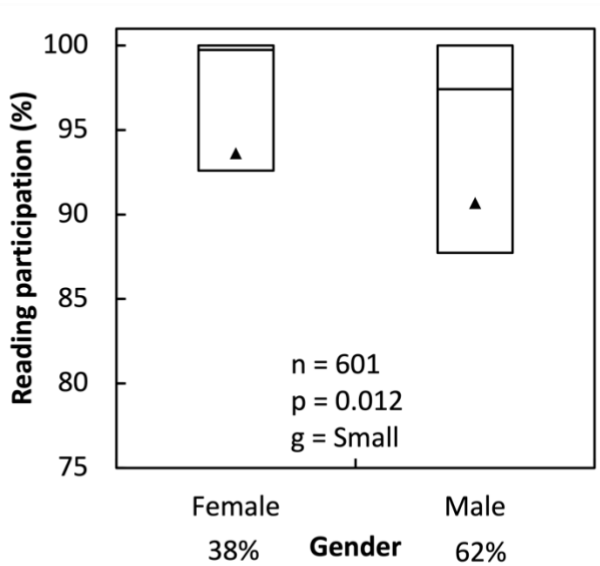

Figure 2. Reading participation (%) as a function of gender (female and male). Seven cohorts included 601 students (38% female/62% male). p-values compare female and male. A small effect size (g) is defined as a value less the 0.2.

Possible explanations for this difference in reading participation are speculative and require further research, especially when limiting to research related adult learners in higher education or engineering education. For example, imposter syndrome could play a role [41]. Female students rarely missed the effort-based reading assignments since they are trying to prove they belong despite being an underrepresented group. Another hypothesis is that could explain the difference in reading participation is that female students are following directions given by an authority figure, who traditionally was male. Authority has been studied related to other issues like classroom and laboratory work, but reading/following directions is not central to these studies [42]. A third possible explanation is that female students who self-select into engineering are better students on average than male students, which would involve a subset from other studies of first-year college students [43]. This third hypothesis could be examined using standardized test scores or high school grades or rank. Since most students in the MEB course are in their second semester of their engineering education, only one semester of grade data is available from their university transcripts.

When focusing on higher education, few examples of underrepresented groups outperforming the majority group were found. One reading study in psychology found women read more than men in some cases, however, women made up 60 to 90% of the participants across four studies [44]. In physical and life sciences courses, recent observations found women outperforming men but perceptions of being less able persist [45]. Small colleges with scholarship funds for underrepresented students in STEM were also able to show greater retention compared to control groups [46]. Our findings add to this area of ongoing research. While limiting comparisons to higher education studies may be considered a limitation of this study, the authors' feel that comparing reading or gender studies from K-12 with adult engineering students is too broad.

Analyzing the seven cohort individually finds some variations when comparing reading participation for female and male students (**Table 2**). The differences in reading between male and female students was statistically significant in aggregate (**Figure 2**), and four of the seven cohorts show statistically higher reading for female students. The measurably smaller class sizes in 2021 and 2022 (>30% decrease) may contribute to the statistical similarity of reading participation by gender for these cohorts. Since t-tests uses average and standard deviation to generate the p metric related to statistical significance, additional differences can be observed using other metrics. Median reading for female students was equal or greater than male students for all cohorts. The 1st quartile reading rate captured 3 to 11% higher reading participation for female students, but a lower reading participation at the 1st quartile is noted in 2021. The 2021 cohort is the only group that received fully remote instruction, which may contribute to this difference. Overall, we would be open to collaborate with or assist other researchers to initiate qualitative and mixed methods research to investigate reasons for the differences in reading rate by gender.

Table 2. Cohort variation of reading participation comparing female and male students. p and g values compare female and male of the same cohort.

Cohort	Female – Male Median (%)	Female – Male 1st quartile (%)	p	g	Effect size category
2016	+3.2	+11.3	0.008	0.55	large
2017	+3.0	+9.1	0.04	0.45	medium
2018	0	+4.0	0.09	0.30	medium
2019	+1.4	+6.3	0.8	-0.05	small
2020	+1.4	+10.5	0.02	0.30	medium
2021	+0.1	-4.0	0.6	-0.13	small
2022	0	+3.0	0.5	-0.21	medium
All	+2.3	+4.9	0.01	0.20	small

<u>Is completion of auto-graded problems reproduced over many cohorts?</u>

Auto-graded homework questions are both integrated into most sections and at the end of each chapter. End-of-chapter auto-graded problems were completed by the 2020, 2021, and 2022 cohorts only and discussed in previous publications [38, 39]. The in-section problems were called formative in previous work to emphasis the focus on a single concept. In addition, the in-section problems are scaffolded, so a set of 3 to 6 questions moves from easier to more difficult. Quantification of the author's intended scaffolding was discussed and supported in previous publications [5, 47].

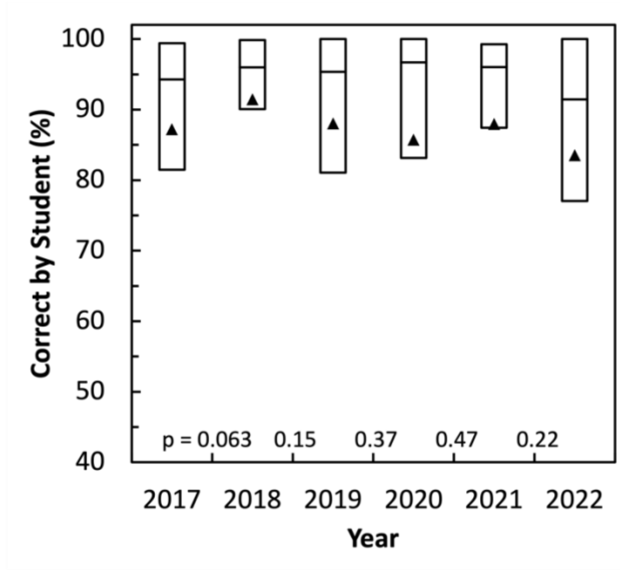

Figure 3. Percent correct at the due date (unlimited attempts) on auto-graded homework as a function of cohort. The six cohorts included 501 students. p-values compare a cohort with the next subsequent cohort.

Since auto-graded problems have unlimited attempts, many students persist until answering all of the problems correctly before the due date. Additional correct responses after the due date are outside of the scope of this contribution, but this topic has been discussed previously [3]. The fraction of correctly answered questions per student is quantified here (**Figure 3**). Median percent correct fluctuates over the six cohorts from 92% to 97%. First quartile correct ranged from 77 to 90%. The presence of these in-section auto-graded problems near the definitions and explanations related to the questions likely contributed to the high fraction correct. In addition, having unlimited attempts and the ability to ask questions of instructors, e.g., during office/student hours, may also contribute to the high fraction correct.

Returning to the theme of reproducibility, cohort to cohort variations were examined. Performing hypothesis tests comparing fraction correct between a cohort and the subsequent cohort found no statistical significance ($p > 0.05$) across all cohorts. In addition, ANOVA analysis confirmed the cohort-to-cohort comparisons ($F(5, 495) = 1.75$, $p = 0.12$). Thus, despite differences in class size, modality, and other differences in groups of students, the fraction correct on scaffolded, auto-graded problems for material and energy balances were reproducible for six cohorts.

<u>Does completion of auto-graded problems vary with gender?</u>

While effort-based reading participation showed differences between male and female students, auto-graded homework provides another metric related to the mastery of new concepts and calculations. Six cohorts from 2017 to 2022 were aggregated (**Figure 4**), which included end-of-chapter and in-section problems unlike **Figure 3**. No auto graded homework was available in 2016. Female students correctly completed auto graded homework at a higher rate than male students. The median percent correct of female students was 2% higher than male students (96%

vs 94%). The interquartile spacing for females was 15%, which is 5% smaller than the spacing for male students (20%). However, no measurable statistical significance (p = 0.137) was found, and the effect size was small (g = 0.14).

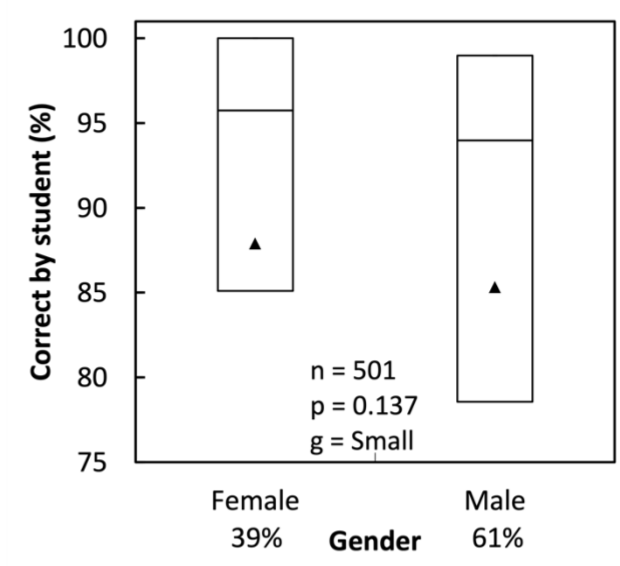

Figure 4. Percent correct on auto-graded homework as a function of gender (female and male). Six cohorts included 501 students (39% female/61% male).

Examining each cohort individually found similar results. Female students complete more auto-graded problems correctly for 6 of the 7 cohorts (**Table 3**). The overwhelming difference of the 2021 cohort merits additional commentary. The 2021 cohort was the only one of these six cohorts to be fully remote. The instructor, one of the co-authors, requested to teach the 2021 cohort both in-person and remote optional while abiding by all current campus health and safety rules (e.g., up to 80 students in a 1,000-seat auditorium). However, despite support from his chair and dean, the university-level administration did not allow the in-person option to be offered. This top-down decision likely contributed to the poor performance by female students on auto-graded problems. Greater numbers of students withdrew from the course during the remote period of 2020 and the fully remote course in 2021 than in any of the in-person cohorts. Another possible explanation for the differences for a fully remote course would be an analogy to gaming. In one previous study, females played a thermodynamics-related online game significantly less and advanced less often than males students [48].

Table 3. Cohort variation of fraction correct on auto-graded problems comparing female and male students. p and g values compare female and male of the same cohort.

Cohort	Female – Male Median (%)	Female – Male 1st quartile (%)	p	g	Effect size category
2017	+3.1	+9.7	0.26	0.25	small
2018	+1.6	+8.0	0.16	0.28	small
2019	+6.3	+8.0	0.14	0.31	medium
2020	+1.8	+16.7	0.04	0.31	medium
2021	-4.5	-24.8	0.03	-0.61	large
2022	+3.1	+12.4	0.51	0.21	small
All	+1.8	+6.5	0.14	0.14	small

The possible explanations for difference by gender presented with the reading participation outcomes may also apply in this case. Again, the underrepresented group outperformed the majority group in aggregate and for 5 of the 6 cohorts, which is uncommon in papers addressing these groups in engineering education. Thus, the opportunity for further quantitative and qualitative research can leverage these multi-cohort findings.

Conclusion

A learning analytics study quantified reading participation and auto-graded homework from a single interactive textbook for 7 cohorts involving over 600 students. For a material and energy balances course, a median reading participation over 93% was found that accounted for hundreds of thousands of unique clicks (reading interactions). Similarly, a median correct of at least 91% was presented for six cohorts using hundreds of auto-graded problems each year. These overall findings corroborate earlier studies for one to three cohorts, and thus, reproducible trends are observed. Providing a small grade incentive, 5% each for reading and homework in this case, correlates with high reading participation and auto-graded homework scores, which aligns with other work in the literature.

Female students, a group commonly underrepresented in engineering courses, were compared with their male classmates. In aggregate, female students earned higher median reading participation scores than male student and with statistical significance. Female students also correctly answered a larger fraction of auto-graded problems than male students in aggregate. Examining these trends for individual cohorts led to additional insights that were not always consistent with the findings aggregated across cohorts. Overall, a number of possible explanations, including imposter syndrome, were proposed for the higher engagement with female students, and additional research is encouraged in this area.

Further research into aggregated data sets to correlate with grades and the interactive textbook metrics should be considered. In addition, motivation for reading and question reuse is an open research area. Finally, the Material and Energy Balances zyBook is freely available to instructors and configurable to their course.

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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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