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# Student Performance Improvement in a Circuit Analysis Course when Interactive Web-Native Textbook Activities are Assigned for Points

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# Student Performance Improvement in an Introductory Circuit Analysis Course when Interactive Web-Native Textbook (zyBook) Activities are Assigned for Points


## Abstract

Paper-based homework with manual grading has significant benefits: it allows a grader to uncover student misconceptions and (potentially) give individualized feedback that can't be replicated by an autogradable system. And the student user experience is closer to that of a paper exam. This similarity of experience is important because student practice with the same test format has been demonstrated to result in higher exam scores. But there may be a significant time lag between when students work paper-based homework problems and when they receive feedback with manual grading. With autograded activities in an interactive web-native textbook (zyBook), students receive immediate feedback after submitting their answer, and can re-attempt the problem while they're still in the learning moment. We analyzed the difference between student performance in an introductory circuit analysis course when a zyBook was required but not assigned for points, and when the same zyBook was required, and activities were assigned and tracked for points toward student grades. Data was available for 345 students across seven semesters at a large public land-grant research university. Over five semesters, the zyBook textbook was required, and the activities were recommended but were not assigned for points, while paper-based homework was assigned for points. Over two semesters, total points for homework was not changed, but was split between paper-based homework and completion of activities in the zyBook. Paper-based homework assignments were modified to eliminate problems that were similar to the zyBook problems or repetitive of other paper-based ones, to achieve a total workload that was very similar to when points were awarded only for paper-based homework. Most other course features were the same across semesters, including the instructor and final exam; differences are noted. By dividing homework points between paper-based and auto-graded homework, students are incentivized to participate in both types of activities, and benefit from both. Final exam grades were analyzed across the seven semesters. When the zyBook trackable activities were assigned as part of the homework grade the percentage of students who received As, Bs, and Cs on the final exam increased from 45% to 57%, and the percentage of students who received Ds and Fs decreased from 55% to 43%, compared to when only paper-based work was assigned for the homework grade.


## Introduction

Introductory STEM (science, technology, engineering, and math) courses typically have high attrition rates. For STEM bachelor's degree students in the United States, 48% leave STEM before completing their degree. They either switch to another major, or exit college before earning a degree [1]. This is of significant concern, as demand for skilled professionals in STEM is high, and attrition reduces the number of graduates available to fill these roles. STEM fields are critical for innovation and economic growth, and a lack of STEM talent impacts a country's ability to compete globally [1][2][3][4]. Research has shown that (among other factors), students' belief in their own competence, how interesting or enjoyable they find tasks, and how much is required of students' time, effort, and emotional resources impacts student persistence in

STEM [5]. Consequently, instructional tools and resources that can be demonstrated to improve students' experience of these factors are of value in STEM education.

This study examines across seven semesters (Fall 2021 to Fall 2024) the impact of an interactive web-native textbook (zyBook) on student competence (as represented by average grade distributions in a consistent final exam) and student engagement (as represented by time spent), and compares results for semesters when activities in the zyBook were assigned for points vs. semesters when the activities were not assigned for points. Over five semesters, the zyBook was required, but was not assigned for points, while paper-based manually-graded homework was assigned for points. Over two semesters, total points for homework was not changed, but was split between paper-based homework and completion of activities in the zyBook. Paper-based homework assignments were modified to eliminate problems that were similar to the zyBook problems or repetitive of other paper-based homework problems, so the total workload was very similar to when points were awarded only for paper-based homework. Most other course features were the same across semesters, including the instructor and final exam; differences are noted. By dividing homework points between paper-based and auto-graded homework, students were incentivized to participate in both types of activities, and benefit from both. Final exam grades were analyzed across the seven semesters. When the zyBook was assigned as part of the homework grade, a higher percentage of students received As, Bs, and Cs (increased from 45% to 57%), and a lower percentage of students received Ds and Fs (decreased from 55% to 43%), compared to when only paper-based work was assigned for the homework grade.

Student survey data is available for five of the seven semesters to provide information about factors like student demographics (year in school and major) and student perceptions of effects and emotions experienced related to using the zyBook.

**Background and literature review**

Historically, engineering students have practiced applying knowledge and problem-solving through paper-based homework completed outside of class time and submitted for grading by an instructor or graduate student. Paper-based homework with manual grading has significant benefits. It allows a grader to uncover student misconceptions and (potentially) give individualized feedback that can't be replicated by an autogradable system. Completing homework on paper with a structured process allows students to demonstrate their problem-solving process, and can help them develop their critical thinking skills over time as they become more organized through practice and more easily identify errors [6]. And the student user experience is closer to that of a paper exam. Similarity of the user experience is important because student practice with the same test format has been demonstrated to result in higher exam scores [7]. But [8] found that paper-based, worked-out homework solutions do not tell the full story. Key information may be missing about the gap in a student's problem-solving skills, and consequently what feedback may rectify the gap. There may be a significant time lag between when students work on homework problems and when they receive feedback, and students may not see value in reviewing the returned work [9]. With autograded activities in a zyBook, students receive immediate feedback after submitting their answer, can re-attempt the problem while they're still in the learning moment, and may be more likely to persist until they solve the problem [10].

The pedagogical benefit of immediate feedback, and the potential resultant positive impact on student learning outcomes, combined with the reality that many institutions no longer have sufficient funding for graders has spurred a significant body of research over the last 10-15 years comparing student performance on assessments when student practice was in the form of computer-based questions vs. paper-based. Gifford [11] investigated whether grading homework is an effective use of instructor time and its impact on student learning outcomes. All students were assigned homework to be completed before class. In the control group, student completion of homework was never checked, while for two groups the student homework was checked for degree of completeness. All students also worked problems on boards during class, with immediate feedback from their instructor on their work. The typical class size in this study of 20 or less students made both tracking homework for completeness and practicing problems in class under instructor supervision possible. The results of the study suggest that grading homework for completeness may not significantly impact student performance, but providing detailed feedback is crucial for helping students understand their mistakes and improve their learning.

Bonham et al. [9] compared student performance using web-based homework vs. paper-based homework for college-level physics. They found that the difference in homework method has a limited effect on student performance, possibly due in part to student study practices reducing the differences between the methods. The same end-of-the-chapter type problems were used for both methods, with differences in completeness required and feedback. For paper-based homework, students were required to work out the solution and show their work. Students completing web-based homework only needed to submit the final numerical answer. Students with paper homework received more feedback, but after a time delay. Web students received immediate feedback on whether their answers were correct or not, and could revise their answer and resubmit. Paper students could check their answers with the back of the book and rework their solutions. The researchers found that the study practices of many students may reduce the apparent differences in the homework methods, as many web students printed out assignments, worked them out on paper, and then returned to the computer to submit them. The researchers also found that many of the students with paper homework did not spend a lot of time reviewing the returned homework, so did not get as much benefit as they might have.

Taraban et al. [12] found that online homework they developed for an introductory thermodynamics course was effective in providing timely feedback and improving students' mastery of course content. The study suggests that immediate feedback is a key factor in the effectiveness of online homework.

In an introductory engineering programming course [13], an instructor used an electronic system to give daily quizzes that combined autograded multiple choice questions and quickly gradable open-ended questions for which the instructor gave individualized feedback when appropriate. Exam scores and course evaluations were compared between two terms, one which did not have daily quizzes, and one that did have daily quizzes. Both exam scores and student evaluations indicated that the daily quizzes contributed to their overall learning.

In an introductory circuit analysis course [14] [10], researchers compared quiz results from alternating groups of students who did online homework sessions with immediate feedback and

ability to attempt a problem multiple times vs students who did the same homework on paper submissions, and so did not receive immediate feedback. Results were that online homework is at least comparable to paper homework for student learning. This paper also mentioned the value of online homework due to lack of funding for grader resources, and that they might not administer homework at all if they didn't have this resource. With online homework, they're able to assign homework for every class period.

Jones [15] found online homework in an engineering materials course to result in higher scores on exams, more consistent completion of the homework and a higher correlation between homework scores and exam scores, compared with a previous semester using traditional paper-based homework. The results were attributed to the immediate feedback in the online homework, and allowing multiple attempts to solve the problem. Student evaluations indicated that online homework was considered to be equivalent to or better than paper-based homework by most students.

For additional background, the research review in [16] examined many of the same papers mentioned earlier, as well as others, and assessed their quality. The majority of research has focused on online homework as an alternative to paper-based homework. A comparative study by [17] surveyed students about their experiences, satisfaction, and academic outcomes with online vs. traditional homework, and interviewed a smaller subset of students, parents, and educators. Findings suggest that students feel traditional homework is slightly more effective, but that the real impact on their academic outcomes may not differ significantly, and that a hybrid model integrating both traditional and online homework could provide the most comprehensive approach for students.

Research has also demonstrated that the level of student interaction with zyBook activities varies significantly based on whether the interaction is assigned for points toward the course grade [18].

This paper explores the differing level of student interaction when tracked and autograded activities are assigned for points, as well as the impact on final exam grade distributions, when assigned homework composition is changed to include autograded activities with immediate feedback in addition to paper-based homework. Student perceptions of the impact of the zyBook are also discussed.

**Methodology**

This study evaluates the impact of a zyBook on student learning and performance, engagement, and self-efficacy. The study involved computer and electrical engineering students enrolled in an introductory circuit analysis course across seven semesters at a large public land-grant research university, from Fall 2021 to Fall 2024. The class met MWF at 9:00 am for every semester in the study. Class periods consisted of traditional lectures with the instructor going over concepts and working problems by hand on a projector. All students received access to the zyBook as part of their required course materials through the university's inclusive access program.

Assessments included 16 homework assignments due 1 or 2 times per week, 3 mid-term exams, and a comprehensive final.

The semesters were divided into two groups of students based on the implementation of the zyBook as part of the homework in the semester. The two groups are as follows:

*Group 1 implementation:* zyBook was required as part of the course materials. Trackable activities within the zyBook were recommended but were not assigned for points. Paper-based manually graded homework was assigned, collected, and graded, accounting for 15% of the total course grade. The homework problems were traditional end-of-chapter circuit analysis textbook problems. There were no requirements or rubric provided to students for paper-based homework beyond submission of their own work and due date. Students were advised that collaboration with other students and answer checking are acceptable, but that each student must only submit his/her own work, and that to submit the work of others is an academic honesty violation.

The paper-based homework was graded and scored by graduate student graders based on correctness. Due to size of class, and resource and time constraints, there was not a high level of individualized feedback provided. Primary feedback was correctness, and partial credit was given. The solutions to the paper-based homework were not distributed to the students. After graded homework was returned to students with indications of correct/incorrect work, means for students to determine why paper-based work was graded as incorrect included: independent review, consultation with student peers, and consultation with a teaching assistant or their instructor. Students were not able to reattempt paper-based homework problems for points after receiving correctness feedback, which is akin to an exam experience. Additional information about Group 1 is included in Table 1.

**Table 1. Group 1 participants and zyBook characteristics.**

| **Group 1: zyBook not assigned for points** | | | | |
|---|---|---|---|---|
| **Semester** | **Number of students** | **Average total time spent in zyBook in minutes (min.)** | **Number of learning activities in zyBook** | **Number of traditional problem activities in zyBook** |
| Fall 2021 | 24 | 37 min. (37 min. for learning activities (animations and learning questions with feedback); 0 min. for traditional problem activities) Distribution (Distr.): 0 min. to 176 min. | 65 Animations 232 Question Sets (297 learning activities total) | 0 |
| Spring 2022 | 59 | 38 min. (38 min. for learning activities; 0 min. for traditional problem | 65 Animations 232 Question Sets (297 learning | 0 |

| | | | | |
|---|---|---|---|---|
| | | activities) Distr.: 2 min. to 177 min. | activities total) | |
| Fall 2022 | 53 | 59 min. (59 min. for learning activities; 0 min. for traditional problem activities) Distr.: 0 min. to 262 min. | 65 Animations<br>232 Question Sets (297 learning activities total) | 0 |
| Spring 2023 | 58 | 61 min. (45 min. for learning activities; 16 min. for traditional problem activities) Distr.: 0 min. to 557 min. | 66 Animations<br>237 Question Sets (303 learning activities total) | 58 |
| Fall 2024 | 49 | 83 min. (51 min. for learning activities; 32 min. for traditional problem activities)<br>Distr.: 0 min. to 737 min. | 69 Animations<br>242 Question Sets (311 learning activities total) | 99* |
| **Total** | 194 | | | |
| *The majority of additional activities compared to previous semester were for chapters not covered in this course, so did not have a significant impact on time spent. | | | | |

*Group 2 implementation:* zyBook was required as part of the course materials, and trackable activities within the zyBook were assigned for points as part of the homework grade. As with Group 1, homework accounted for 15% of the total course grade, but for Group 2, completion of assignments within the zyBook constituted half of this percentage. Manually graded paper-based homework constituted the other half of the homework percentage. The volume of paper-based homework was reduced to balance the workload with zyBook assignments, so that the total workload for students in Group 2 was the same as for Group 1[1]. Assigned homework for a particular date for Group 2 included activities in both the zyBook and as paper-based homework. For every paper-based homework, there was a corresponding homework assignment of activities in the zyBook from the same sections as the paper-based homework. The intent was for students to do the zyBook portion first and then attempt the paper-based homework, which was typically more difficult. Both homeworks would have the same due date. The activities tracked for points in the zyBook were:

[1] Fall 2024 was an exception in the volume of paper-based homework. The interactive web-native textbook was not assigned, but the volume of paper-based homework remained reduced. The volume of paper-based homework for Fall 2024 was consistent with the semesters in Group 2, rather than with the other semesters in Group 1. The percentage of the course grade allocated to homework remained unchanged at 15%.

*Animations:* Play completion of the animation steps was tracked. Points were awarded if all steps of an animation were played. No partial credit was given. Animation content included conceptual illustration explanations and applications in problem solving.

*Learning questions with feedback:* The platform tracked correct completion of multiple-choice, short answer, and matching questions. Question content focused on applying knowledge and problem solving skills from the textbook exposition. Correct/incorrect feedback was given, as well as answer-specific explanatory feedback for multiple choice questions, and explanatory feedback for short answer questions. Students could reattempt the question until they got it correct. If a student was not able to figure out the correct answer on their own, the correct answer could be accessed with explanation, so that the student could always eventually enter the correct answer. No partial credit was given.

*Traditional problem activities:* The platform tracked correct completion of multiple answer fields for problems similar to traditional end-of-chapter circuit analysis textbook problems. Students were required to complete all fields for a problem correctly to receive credit. If an incorrect response was submitted for any of the answer fields, students received correct/incorrect feedback, and a complete solution explanation. The student was then allowed to attempt a similar problem with different values, applying what they learned from the previous solution explanation. Students were allowed an unlimited number of attempts, with values changing for each attempt, minimizing students' ability to simply guess the answer. If a student did not successfully complete all fields in at least one of their attempts, no credit was given. It is not known if the students were working out their solutions on paper, on a tablet (which an instructor observed to be common for recent students in general), or some other way, before submitting their answer on the computer. No partial credit was given. Additional information about Group 2 is included in Table 2.

**Table 2. Group 2 participants and zyBook characteristics.**

| **Group 2: zyBook assigned for points** | | | | |
|---|---|---|---|---|
| **Semester** | **Number of students** | **Average total time spent in zyBook in minutes (min.)** | **Number of learning activities in zyBook** | **Number of traditional problem activities in zyBook** |
| Fall 2023 | 41 | 385 min. (229 min. for learning activities; 156 min. for traditional problem activities) Distribution (Distr.): 150 min. to 1180 min. | 66 Animations<br>237 Question Sets<br>(303 learning activities total) | 58 |
| Spring 2024 | 61 | 410 min. (186 min. for learning activities; 224 min. for traditional problem | 69 Animations<br>242 Question Sets | 99* |

| | | | | |
|---|---|---|---|---|
| | | activities) Distr.: 208 min. to 821 min. | (311 learning activities total) | |
| **Total** | 151 | | | |
| *The majority of additional activities compared to previous semester were for chapters not covered in this course, so did not have a significant impact on time spent. | | | | |

The differences between the experience of Group 1 and Group 2 are:

- The content and pedagogical nature of some of the homework activities.
- The timing of the feedback.
- The availability of a solution explanation for immediate remediation after work has been identified as incorrect.
- Ability for students to reattempt (still for credit) after being informed work is incorrect.

The quantity and nature of the practice activities within the zyBook changed over the period of the study as indicated in Tables 1 and 2, but based on ANOVA within the groups, this change did not have a significant impact on student performance.

The following aspects were consistent for all semesters for both Group 1 and Group 2:

- Instructor
- Course grade distribution for activity type:
    - Homework: 15%
    - Lab: 15%
    - Midterm Exams (3): 40%
    - Final Exam: 30%
- Final Exam content

Graders varied from semester to semester, but all approached grading of the paper-based homework similarly.

Graders for the final exam followed a common key for the final exam that specified points credit to be awarded for correctness for the individual parts of each problem.

**Analysis**

The analysis focused on comparing student performance and engagement before and after implementation of the zyBook as part of the course homework grade. The following comparisons were made between the two student groups:

- Performance on final exam
- Engagement with the zyBook
- Survey responses

**Student performance on final exam**

The primary measure of the impact of the zyBook on student learning and performance was based on comparison of results on the final exam. While graded midterm exams were returned to students, and so necessarily changed from semester to semester and may inadvertently differ too greatly to serve as a comparative measure between semesters, the final exam is not returned to students and remains consistent across semesters. So the final exam is a consistent measure of student performance between semesters. The final exam is comprehensive, and covers the following topics:

- Basic Concepts
- Resistive Circuits
- Nodal and Loop Analysis Techniques
- Additional Analysis Techniques
- Capacitance and Inductance
- First- and Second-Order Transient Circuits
- AC Steady-State Analysis
- Steady-State Power Analysis

Partial credit is given, with emphasis on the correctness of each step of the problem.

*Potential confounding variable: lab sessions treatment*

A potential confounding variable for analysis is that the implementation of the lab sessions for the course changed during the time over which the study was conducted. Prior to Fall 2022 (so for Fall 2021 and Spring 2022 for Group 1), the lab component of the course consisted of 14 lab sessions. Beginning in Fall of 2022, a change was implemented to cover the same topics over 10 lab sessions instead of 14 lab sessions. For Group 1, this difference was experienced by students in Fall 2022 and Spring 2023. All students in Group 2 had a consistent lab experience with 10 lab sessions.

The instructor who designed the change from 14 to 10 lab sessions indicated that the lab content was not heavily influenced by the zyBook content, and observed that the lab performance was not significantly different across semesters, and so in turn likely did not have a significant effect on student performance in the non-lab portion of the course. But it must be considered that the reduced student time required with fewer lab sessions may allow students to spend more time and attention on other components of the course. And that the lab session composition changes that accommodated the same number of topics in fewer lab sessions could potentially foster better cross-topic connections and deeper student understanding. Both of these could lead to improved student performance in the non-lab component of the course. Conversely, having fewer lab sessions resulting in fewer repeated topics could also result in comparatively lower learning gains as research has demonstrated value in application of the same knowledge with intervening gaps in time [7]. To control for this variable, in addition to analysis of Group 1 and 2, student performance was also analyzed between students divided into the two following groups: students who experienced 14 lab sessions; students who experienced 10 lab sessions. Analysis for each of the groups follows.

*Grade distribution comparisons*

Grade distribution per group is shown below in Table 3 and Figures 1, 2, and 3. Noticeable positive effect of assigning points for the zyBook is observed in chi-squared test (X-squared = 15.041, df = 4, p-value = 0.005), with the percentage of students who got grades of D and F being reduced from 55% to 43% . The percentages of Cs, Bs, and As were also higher in Group 2 in which the zyBook was assigned for points (increase from 45% to 57%). No effect of the number of lab sessions was observed in the chi-squared test (X-squared = 3.03, df = 4, p-value = 0.55), which means that the difference in grades between Group 1 and Group 2 is likely not due to the change in the number of lab sessions.

**Table 3. Grade distributions for Group 1 and Group 2.**

| | **Group 1: zyBook not assigned for points** | | **Group 2: zyBook assigned for points** | |
|---|---|---|---|---|
| **Grade** | **# of students** | **%** | **# of students** | **%** |
| **F** | 83 | 34.16% | 26 | 25.49% |
| **D** | 51 | 20.99% | 18 | 17.65% |
| **C** | 35 | 14.40% | 18 | 17.65% |
| **B** | 48 | 19.75% | 25 | 24.51% |
| **A** | 26 | 10.70% | 15 | 14.71% |

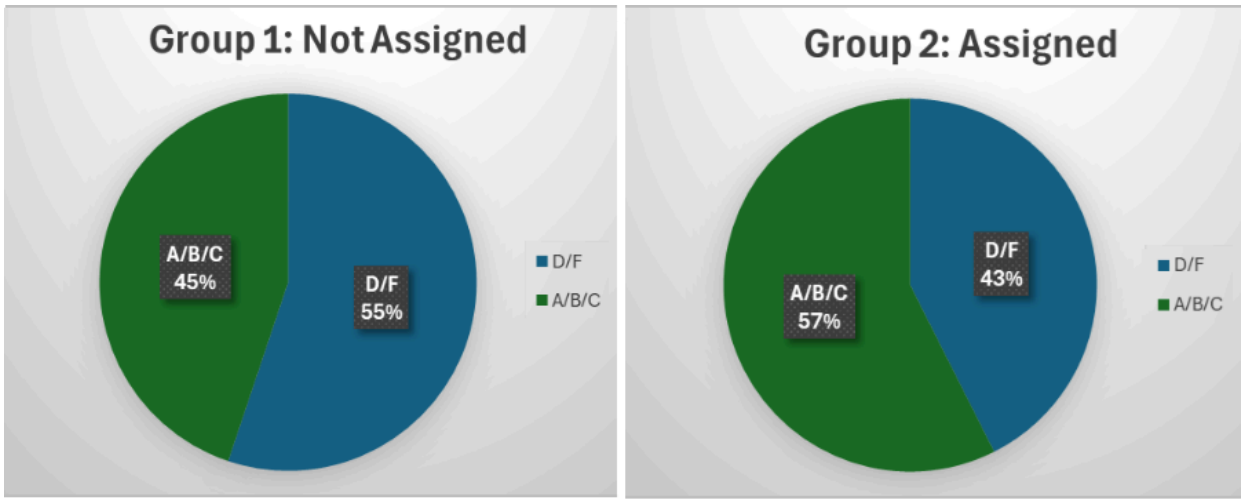


**Figure 1. Grade distribution of A/B/C vs. D/F when the zyBook was assigned vs. not assigned.**

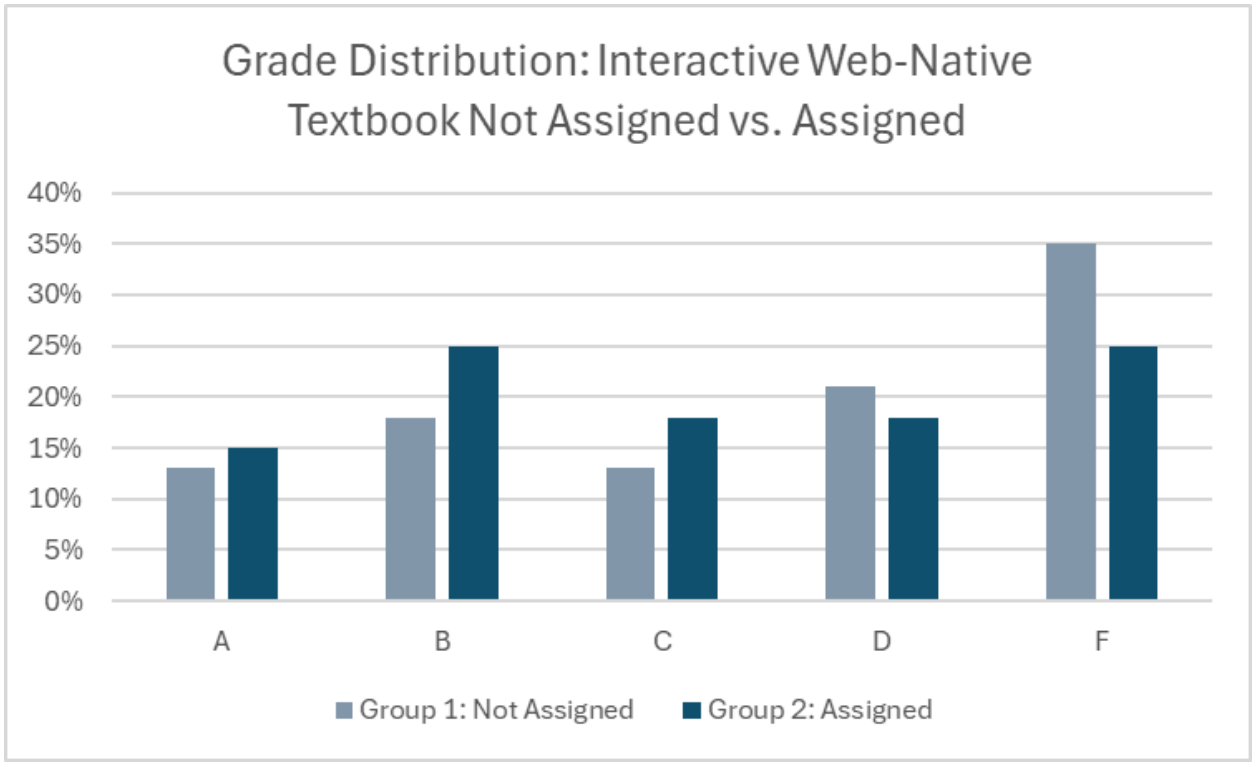


**Figure 2. Grade distributions when the zyBook was assigned vs. not assigned.**

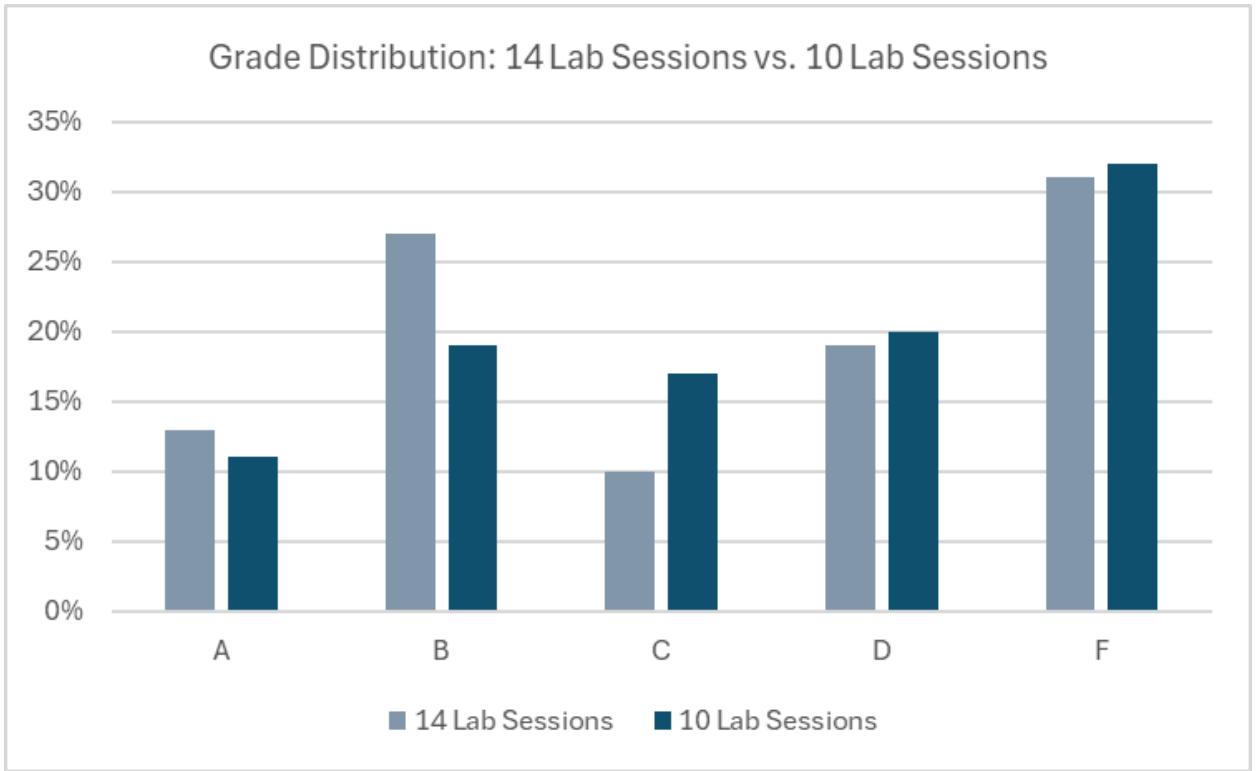


**Figure 3. Grade distributions when lab component had 10 lab sessions vs. 14 lab sessions.**

*Score distributions for 14 lab sessions vs. 10 lab sessions*

A one-way ANOVA did not detect a significant difference between average final exam grades based on the number of lab sessions experienced. There is no statistically significant difference between the average grade of the students who had 14 lab sessions and the average grade of the students who had 10 lab sessions. Meaning this analysis further supports that it is not likely that any difference in grades between Group 1 and Group 2 was caused by the change in number of lab sessions. The box and whisker plots in Figure 4 show the score distributions for 14 lab sessions vs. 10 lab sessions.

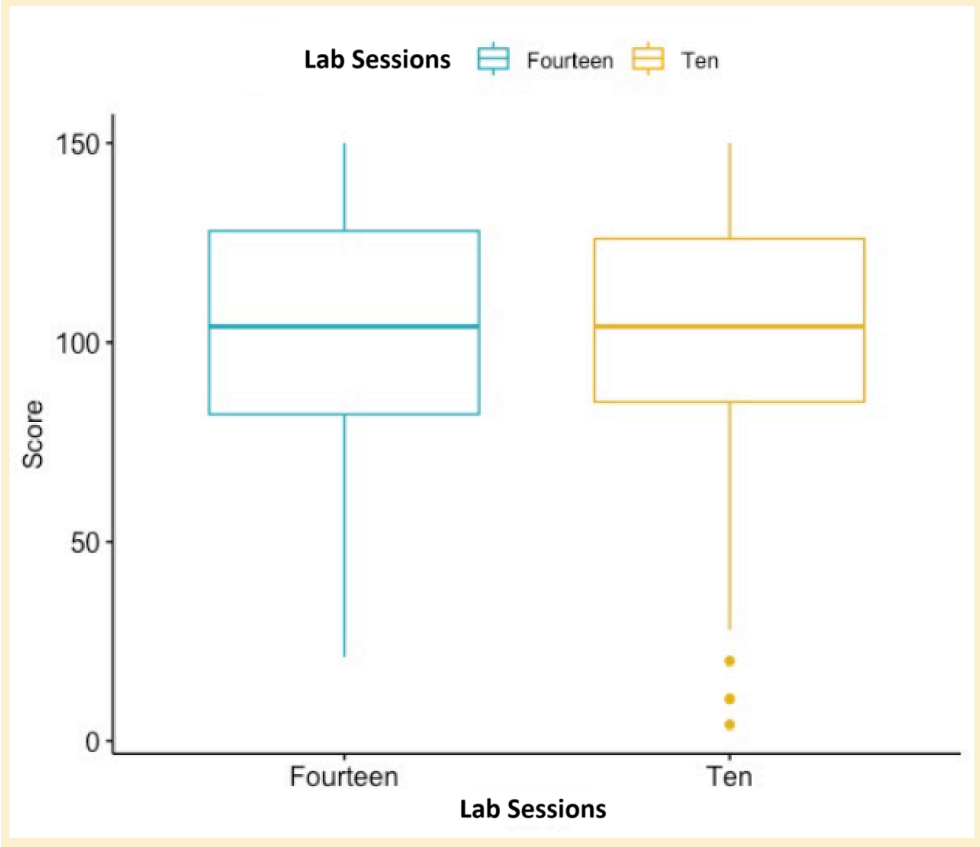


**Figure 4. Box and whisker plots for 14 lab sessions vs. 10 lab sessions.**

*ANOVA within Group 1 and Group 2*

ANOVA was performed on the semesters within Group 1, the semesters when the activities were not assigned. The p-value for the "not assigned" Group 1 semesters is 0.357121. The result is not significant at $p < 0.05$, indicating that there is no significant difference between different semesters when the activities in the web-native textbook were not assigned by the instructor. Table 4 shows the ANOVA results for Group 1.

**Table 4. ANOVA results for Group 1: activities not assigned.**

| Source | SS | df | MS | |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Between-treatments | 164.24 | 4 | 41.06 | F = 1.16186 |
| Within-treatments | 706.8 | 20 | 35.34 | |
| Total | 871.04 | 24 | | |

Another one-way AVOVA was done between the semesters within Group 2 to determine if there are any factors within Group 2 that could have caused a significant grade difference. This ANOVA also indicated that there were no significant differences between the two assigned semesters at p-value of 3.65297 which at $p < 0.05$ indicates a clear lack of significant difference.

*ANOVA Group 1 vs. Group 2*

Subsequently, the semesters were grouped into assigned and not assigned groups with the “not assigned” Group 1 of 243 students and the “assigned” Group 2 of 102 students. The ANOVA results based on assigned and not assigned student group results are shown in Table 5.

**Table 5. Group 1 vs. Group 2 ANOVA results.**

| Source | SS | df | MS | |
|---|---|---|---|---|
| Between-treatments | 1988.1 | 1 | 1988.1 | F = 8.03922 |
| Within-treatments | 1978.4 | 8 | 247.3 | |
| Total | 3966.5 | 9 | | |

The p-value is 0.021968. The result is significant at $p < .05$, indicating that the assignment of the activities in the web-native textbook resulted in a statistically significant difference in the students' average grades on the final exam. With the confounding variables of differences within the groups and the change in labs being accounted for, the conclusion is that the change from not assigning the activities in the zyBook to assigning the activities in the zyBook improved the average of students' grades on the final exam.

**Student engagement with the zyBook**

The level of student engagement (as measured by time spent) with the activities in the zyBook varied greatly between semesters when the activities were assigned as part of the homework compared to semesters when the activities were only recommended. Average total student time spent with activities in Group 1 (when the activities were not assigned for points) ranged from 37 minutes to 83 minutes between semesters. The increase in time spent between the semesters in Group 1 is attributable to the increase in total number of activities available as the zyBook evolved over time. Average total student time spent with activities in Group 2 (when the activities were assigned for points) ranged from 385 minutes to 410 minutes between the two

semesters. That is a five-fold increase in the amount of time spent between Group 1 when the activities were not assigned compared to Group 2 when the activities were assigned for points. This provides additional evidence of the influence assignment for points has on student interaction with activities that has been demonstrated by other research [18].

*Teaching participants' opinions*

The instructor and the lead grader for most of the semesters were asked their opinion about what caused student performance improvement during the semesters that assigned the zyBook for points. They responded that when they assigned the zyBook for credit, it made students actually get into the textbook and learn through the textbook. When they only assigned manually-graded homework problems, students would open the textbook, look at the problem, and try to figure it out. The students were hardly ever going through the examples in the book or looking up the equations. After assigning interactivities in the zyBook, the students went through the sections of the book and learned it one step at a time in the way the book is supposed to be used. The zyBook activities also break concepts down into greater detail, with multiple scenarios, than is possible to cover within the limits of lecture time. For students who are having trouble, the zyBook helps them get through the details of understanding the concepts and trying to make it work out. When students are learning the concepts for the first time, it's very easy for them to get lost in just one misstep. The participants felt the zyBook does a good job of taking the students along slowly, doing things step-by-step, so students can see how the problem goes from start to finish. The animations, learning questions, and homework activities provided the students with another perspective on the foundational ideas of each relevant chapter, rather than the students relying on just the in-class lecture. Assigning these activities for points gave the students more practice, and also increased their familiarity with the textbook itself, making it a more effective option when studying for exams. The perception was that there seemed to be an overall improvement in understanding the basic ideas of the course when the zyBook was assigned for credit.

## Student survey responses and self efficacy

Research has shown that students' self-efficacy [19], their belief in their own competence, how interesting or enjoyable they find tasks, and how much is required of students' time, effort, and emotional resources impacts students persistence in STEM [5]. A student survey was administered to students in the Fall 2022, Fall 2023, Spring 2024, and Fall 2024 semesters. Students who completed the survey were given 5 points extra credit (out of 150) on the final exam, equivalent to 1% of the final grade, and their detailed individual responses were anonymous so as not to bias their response. The extra credit points awarded for survey submission were not included in the final exam grade calculations used to determine the final exam grade distributions examined in this study. Rather, the extra credit points were added during the final accounting to determine course grades, which were not examined as part of this study.

While 209 students completed the final exam, 202 completed the survey, a 92% response rate. Students were asked to rate their agreement with a series of Likert scale items. Although some Likert scale items were added to the survey after the Fall 2022 semester, there were some

statements that were consistent for all semesters, including: *When I got stuck on a problem, the zyBook helped me resolve the issue*; *When reading the zyBook, I usually was able to understand the concepts being taught; I typically read the assigned sections before lecture; I carefully study all of the text in assigned sections;* and *The zyBook increased my confidence in understanding the course material.* On average, the students across all semesters who used the zyBook agreed with all of these statements except for *I typically read the assigned sections before lecture*, for which the average response was Neutral. The Likert scale items that were added to the survey after the Fall 2022 semester included: *The zyBook increased my confidence that I could succeed in this course; The zyBook increased my confidence that I can succeed in my academic program; The zyBook increased my confidence in solving problems; The zyBook increased my confidence that I can apply concepts I learned in my classes to real-world problems;* and *The zyBook increased my desire to become an engineer.* Across the Fall 2023, Spring 2024, and Fall 2024 semesters, students on average agreed with each of the new statements included above, with the statement *The zyBook increased my confidence in solving problems* having an average closest to Strongly Agree.

It's clear that the students using the zyBook even when the activities were not assigned found that using the zyBook helped them answer difficult homework questions, helped them understand the concepts being taught, and increased their desire to become engineers. Using the zyBook also increased their confidence in succeeding in the course, succeeding in their academic programs, solving problems, and applying concepts from class to real-world problems. Although there was not a statistically significant difference in the responses of the groups in which the activities in the zyBook were not assigned compared to when the activities were assigned, the benefit of assigning the activities is that more students completed more activities compared to when activities were not assigned, which resulted in a statistically significant improvement in average student performance on the final exam.

Details of student demographic data from the surveys are included in Table 6.

**Table 6. Student demographics from surveys: year in school and major.**

| | **Fall 2022** | **Fall 2023** | **Spring 2024** | **Fall 2024** | **Semesters combined** |
|---|---|---|---|---|---|
| Total students in survey | 52 | 43 | 62 | 45 | 202 |
| **Year in school** | | | | | |
| Freshman | 0% | 0% | 5% | 0% | 1% |
| Sophomore | 29% | 47% | 68% | 31% | 45% |
| Junior | 58% | 47% | 18% | 64% | 45% |
| Senior | 12% | 2% | 5% | 4% | 6% |
| Other* | 1% | 4% | 4% | 1% | 3% |
| *Fifth-year senior, 2nd undergrad | | | | | |
| **Major** | | | | | |
| Computer engineering | 31% | 28% | 23% | 29% | 27% |
| Electrical engineering | 69% | 70% | 73% | 71% | 71% |

| | | | | | |
|---|---|---|---|---|---|
| Other** | | 2% | 4% | | 2% |
| **Aerospace/chemical/wireless/industrial engineering | | | | | |

## Limitations

*Lack of control group*

This study was not a designed experiment, so lacked a control group. It was advantageous that so many variables remained the same between the semesters studied. This increases confidence that the primary variable influencing the improved final exam performance in Group 1 vs Group 2 was the assignment and resulting increased student engagement with the activities in the zyBook. It would be ideal for a future study to measure the impact across designed groups such as: paper-based homework without access to the zyBook activities; paper-based homework with access to the zyBook activities; computer-graded homework consisting of only zyBook activities; combined paper-based and computer-graded homework with zyBook activities.

*Differing distribution of student demographics in spring semesters vs. fall semesters*

Group 1 is composed of students from three fall semesters and two spring semesters, while Group 2 is composed of students from one fall semester and one spring semester. This course is scheduled in the curriculum to be taken in the spring. The students that are on schedule take the course in the spring. Students taking the course in the fall may be behind schedule, or are retaking it, or are transferring in from another school, all factors which may impact student performance.

*Differing day for final exam*

Final exams at most institutions are often grouped within a single week (the last week of the term) for all courses. The day on which a final exam falls may impact student performance due to the distribution of their other exams, and the resulting stress and time constraints for exam preparation. For Exams 1-3 for all semesters, the instructor set the exam dates to work around exam dates in other courses, so that students would not be overloaded with multiple exams in a short timeframe. For the final exam the instructor did not have control over the schedule during final exam week. For two of the semesters (Fall 2023 and Fall 2024) for which the assigned final exam time was the Friday of final exam week, the instructor elected to administer the final exam during the week prior. For those two semesters, the final exam was split into two parts and the two parts were taken separately during the last two class periods.

**Table 7. Final exam days for Group 1 and Group 2.**

| **Group 1: zyBook not assigned for points** | |
|---|---|
| **Semester** | **Final exam day** |
| Fall 2021 | Monday of final exam week |
| Spring 2022 | Friday of final exam week |
| Fall 2022 | Thursday of final exam week |

| | |
|---|---|
| Spring 2023 | Thursday of final exam week |
| Fall 2024 | Wednesday and Friday: Exam split into 2 parts, with parts taken separately during the last two class periods prior to final exam week. |
| **Group 2: zyBook assigned for points** | |
| **Semester** | **Final exam day** |
| Fall 2023 | Wednesday and Friday: Exam split into 2 parts, with parts taken separately during the last two class periods prior to final exam week. |
| Spring 2024 | Monday of final exam week |

ANOVA was also performed within groups, and no significant difference was found between semesters within groups, which indicates that the above are not impactful factors, and increases confidence that it is the assignment of the zyBook that is causing the improvement in student grades.

**Future work**

In future work, we plan to analyze student struggle metrics such as time spent and number of attempts to identify particular activities in the zyBook for targeted improvement. We'd also like to conduct student interviews and/or working sessions and/or think-aloud recordings of student working sessions to inform implementation of improvements.

We are also seeking to partner with additional instructors using zyBooks in other courses to demonstrate reproducibility (including to other engineering and STEM courses (e.g., materials science, fluid mechanics, thermodynamics, control systems), increase sample sizes to improve the generalizability of the results of the study, and obtain more information about the student participants for additional analyses. We'd like to analyze individual students' time spent in the zyBook relative to their exams and grades outcome to determine impact on individual student results. And analyze student outcomes relative to student demographics such as gender, underrepresented minorities, first-generation students, transfer students, and stronger/weaker prior preparation to evaluate whether different demographic groups experience different levels of benefit from zyBooks assignments. A future longitudinal study could explore students' long-term knowledge retention and application beyond final exam performance by tracking student performance in relevant subsequent courses such as a second circuits course, electronics, analog signals, power systems, and electrical machines. And the impact of broader institutional adoption of zyBooks, and on retention of students in their major.

**Conclusions**

This study demonstrates the significant impact of assigning activities in a zyBook on student engagement and performance in an introductory circuit analysis course. When comparing student engagement as measured by total average time spent on trackable activities in the zyBook, student engagement increased five-fold when the activities were assigned for points compared to when the activities were only recommended. Student performance also improved. The

percentage of students receiving grades of D and F on the final exam decreased from 55% to 43%, while the percentage of students receiving grades of C, B, and A increased from 45% to 57%.

The immediate feedback provided by the zyBook, along with the ability for students to reattempt problems, has been shown to enhance learning outcomes. The results of this study align with previous research highlighting the benefits of immediate feedback and multiple attempts in improving student mastery of course content.

Other than the course implementation of the activities in the zyBook (assigned for points vs. not assigned), most other aspects of the course were unchanged between the groups analyzed. The impact of a potential confounding variable (a change in the number of lab sessions) was evaluated with ANOVA, and was determined to not have a significant impact on student performance. ANOVA was also performed within groups, and no significant difference was found between semesters within groups. This suggests that the observed improvements in student performance on the final exam are primarily attributable to the assignment of activities in the zyBook and the resulting increased student engagement with the activities.

Student survey data from five of the seven semesters provided insights into student perceptions and self-efficacy. The survey results indicated that students generally had positive perceptions of the zyBook. They reported that the immediate feedback and the ability to reattempt problems helped them feel more confident in their understanding of the course material. This increase in self-efficacy is crucial, as it has been shown to positively impact student persistence and performance in STEM courses.

Overall, the integration of the zyBook as part of the homework grade has proven to be an effective strategy for enhancing student engagement, performance, and self-efficacy. Future research could explore the long-term effects of this approach and its applicability to other courses and disciplines.

Key words: circuit analysis, circuits, student performance, interactive textbook, zyBook, homework, grade, autograde, assign, points

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