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An Expanded Study to Assess the Effect of Online Homework on Student Learning in a First Circuits Course

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Introduction

To meet the needs of today's students and to maximize efficient use of faculty resources, electronically delivered homework is becoming ever more popular in higher education. The authors' institution has considerable experience with the open-source, freely available homework delivery tool WeBWorK. WeBWorK's use in mathematics has been well-established, with it now being employed at over 1000 institutions worldwide.

As part of a currently funded National Science Foundation (NSF)-funded project, our team is expanding the use of WeBWorK to engineering courses. Specifically, we have targeted the development of homework problems for three core semester-long, sophomore-level engineering courses: Statics and Mechanics of Materials, Electrical Engineering and Circuits I, and Thermodynamics. Following sufficient debugging and testing, these problems have now been submitted to the National Problem Library maintained by WeBWorK, with the support of the Mathematical Association of America (MAA) and the NSF. Other electrical engineering WeBWorK problems have been developed by Northern Arizona University and North Carolina State University.

The effects of online homework in engineering have only been explored to a limited degree by the engineering education community. Therefore, our project team is also studying the effect of online engineering homework on student learning. The project team has designed a homework assignment process to establish a control group and then assess homework affects. For example, suppose two sections of an introductory circuits course are taught in a given term. For a particular homework assignment that is a fairly isolated topic within the course, one section is required to do only paper homework, namely the instructor's printed WeBWorK assignment. The "paper only" homework section is not given access to that homework assignment in WeBWorK. The other section of the course completes homework on WeBWorK as usual. Following the homework assignment submission, the same in-class quiz is administered to both sections of the course and graded according to a common rubric. The groups then switch roles three times over the duration of the course. All other homework for the course is based in WeBWorK, with instructors also collecting a notebook at the end of the quarter containing all of the homework problems worked out in a typical engineering format. The homework notebook is graded on the formatting of problem statements and solutions but not on the correctness of the solution itself.

This paper is based on two quarters of data, specifically from the Spring 2015 and Fall 2015 terms. This study analyzes the results from the common quizzes to determine the level of knowledge attainment on the topics and to determine if statistically significant differences exist between the two populations of "paper only" homework and online homework only. The statistical analyses are based on introductory circuits courses taught over two terms, amounting to eight quizzes taken by 116 students.

Faculty Impact

From the administrative side, WeBWorK uses resources efficiently. WeBWorK implementation requires modest physical resources, and it is relatively simple to keep up to date over time. Once problem sets are implemented, it is easy to use them 1) between different sections of a course, 2) with different teachers, 3) for an indefinite period of time, 4) even with changes in textbooks. That is, once problem sets are created, it is not necessary to update the sets from one term or year to the next or when a publishing company releases a new edition of a textbook. Instructors also have the flexibility to change textbooks entirely without the need to entirely recreate their course's homework sets. In this situation, usually only a reordering or regrouping of problems is necessary so that assignments would correspond to sections in the newly chosen text. All of the software required to run WeBWorK is available at no cost because it is open-source. The program does require an appropriate web server, but no special computing equipment is needed by any of the faculty or students who are involved with WeBWorK. All of the additional day-to-day activities involved can be done through any web browser. Moreover, WeBWorK reduces the amount of paper grading by instructors. When the solution process or format of the submission accounts for part of the homework grade, there may still be a need for modest paper grading by the instructor. An instructor may even choose to assign open-ended projects to assess conceptual skills and understanding of processes that cannot be ascertained through online homework assignments. Overall, the implementation of WeBWorK gives faculty the opportunity to redirect their time towards other efforts that improve student learning as well as other university responsibilities. One faculty comment, in particular, summarizes our observations,

> *"As we no longer have funds for graders, I would give much less (perhaps even no) homework if I did not have Webwork. With Webwork, and in particular with its instant feedback, I am able to assign homework for every class period."*

Homework Problem Development

WeBWorK problems are written in a parameterized fashion. A pseudo-random number generator is used to create different problem sets for each student. Students may work together to solve their homework because the problems have the same structure. It is fully expected that students will discuss the WebWorK problems in groups, practice their skills by doing, and solidify their understanding by teaching one another. In this aspect, WebWorK is similar to conventional homework delivery methods. However, students cannot simply copy answers from their classmates. Thus, completing homework assignments in WeBWorK will lead students to become more effective problem solvers. While attempting problems, they are not able to look at the "answer in the back of the book" until they have discovered it through learning how to do the problem. This leads a student to feel more responsible for their own learning in a course because they are required to understand the material so they can answer their individual questions. An early WeBWorK study found that the immediate feedback feature was the most strongly endorsed benefit by students[4]. WeBWorK also supplies direct communication with the instructor via email from *inside* any WeBWorK homework problem, through an "Email the instructor" link contained in each problem, and allows access to discussion boards. A sample problem written for Circuits is shown in Figure 1.

One important note is how calculated answers with roundoff errors are entered into WeBWorK. Each problem has an error tolerance that is specified by the problem coder. Students should be instructed to maintain several decimal digits throughout their calculations to avoid excess roundoff errors. The default error tolerance for numerical comparisons is 0.1%. However, the coder may also adjust the acceptable error tolerance for individual problems or for an entire course to be more forgiving or more stringent, depending upon the specific situation.

Learning Impacts from Prior Studies

There are numerous benefits to using WeBWorK over traditional paper-graded homework, from the perspective of student learning as well as regarding faculty and administrative resources. WeBWorK offers students real-time feedback on each problem by telling a student-user whether their response is correct or incorrect. Research has shown that prompt feedback enhances student learning [1]. Students may also be given the opportunity of attempting a problem multiple times at the discretion of the instructor. One WeBWorK study found a correlation between student attempts and problems solved of 0.944, "suggesting that once students began a problem they persisted until they had solved it" [2]. Providing students the opportunity and encouragement to "continue working on a task until it is completed and accurate" also enhances student learning and achievement [3].

Studies on student performance and online/offline tutorial services indicate a correlation between online tutoring and student success. Data from one study conducted at Louisiana Tech in 2008 revealed that students utilized online tutoring far more often than traditional tutoring programs. This information suggests a student preference to online technology [4]. A meta-analysis conducted by the Department of Education found that, "on average, students in online learning conditions performed modestly better than those receiving face-to-face instruction" [5]. Similar results were found in a study of college algebra students at a community college [6]. Specifically, online homework was found to be "just as effective as textbook homework in helping students learn college algebra and in improving students' mathematics self-efficacy," as measured by the Mathematics Self-Efficacy Scale. Further, it was observed that "online homework may be even more effective for helping the large population of college algebra students who enroll in the course with inadequate prerequisite math skills." Some universities report that students perform better on exams when using WeBWorK thus boosting student performance [7]. In most cases, the improvement was small, but nonetheless statistically significant compared to classes without WeBWorK [2].

One study found that student preferences for online homework over traditional homework transcended gender, academic rank, and learning style, suggesting a diverse group of students may react positively to and benefit from online homework [8]. Another study related to middle school mathematics students found that "females expressed stronger opinions on the fact that instant scores and feedback helped them overcome difficulties in mathematics problem solving" [9]. An NSF-funded global experiment, involving students and faculty from three continents, extended WeBWorK usage into Computer Science [10]. Student and faculty response was been positive, barring lack of consistent access to internet and computers, with the authors noting that "Systems such as WeBWorK offer the potential to transfer knowledge and teaching practices from one country to another."

In our first study of implementing WeBWorK in circuits, an analysis of the quiz data indicated that the online homework is at least comparable to paper homework for student learning (add citation after review to avoid identification). The authors acknowledge that some of the quiz scores in this study may have been skewed higher due to the professors going over homework questions prior to the quizzes. To strictly assess the impact of the differences in homework format, the current study is based on data obtained when administering the quizzes prior to answering any homework questions.

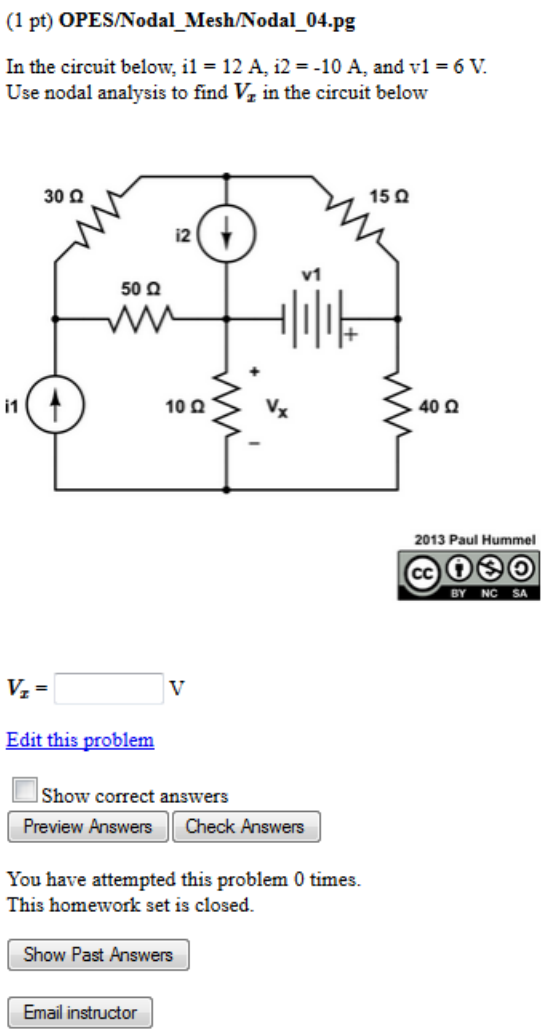

Figure 1: Sample Homework Problem from Circuits Course

Current Study from Introductory Circuits

The objective of the study was to investigate the effectiveness of homework done through WeBWorK on student development and learning, as opposed to traditional homework practices. Multiple studies have been done in the area of mathematics, but this experiment expanded it to the discipline of engineering. The course chosen for the study was an introductory circuits

course—Electrical Engineering and Circuits I (ENGR 221). This course is a requirement for all engineering students at Louisiana Tech and covers such topics as the following: fundamental concepts (like current, voltage, and resistance), units and laws; network theorems and network simplification; phasors and AC solution of circuits; and power and electronic applications.

This study was performed over two academic quarters. Two sections were studied in the spring quarter of 2015 and the fall quarter of 2015. The two sections of the course offered will henceforth be referred to as Sections 001 and 002. During both terms, Section 001 was taught at 10:00 a.m., and Section 002 at 12:30 p.m. The sections were each taught by different professors; however, all the material—notes, tests, assignments, labs—were all identical. This ensured that each student was given equal information and evaluation across both sections.

To assess the student learning impact of WeBWorK, a control group was established through the following process. For a particular homework assignment that was a fairly isolated topic within the course, one section was required to do only paper homework, namely the instructor's printed WeBWorK assignment. The "paper only" homework section was not given access to that homework assignment in WeBWorK. The other section of the course completed homework on WeBWorK as usual. During the class period when the homework assignment was due, the same quiz was administered to both sections of the course.

The distribution of paper homework versus WeBWorK alternated between the two sections for each different topic. When one section offered paper homework, the other section offered the standard WeBWorK set. This process would switch for the next topic. Each student was given the same amount of time and resources to complete the homework. The primary difference between the paper homework and WeBWorK was the students' ability to receive immediate feedback on the correctness of a problem. On the virtue of paper homework, a student had little feedback to determine if they completed the proper steps to arrive at the correct solution. All other homework for the course was based in WeBWorK, with instructors also collecting a notebook at the end of the quarter containing all of the homework problems worked out in a typical engineering format. The homework notebook was graded on the formatting of problem statements and solutions but not on the correctness of the solution itself.

For this study the quizzes covered four fundamental topics from introductory circuits – Nodal Analysis, Mesh Analysis, Thévenin Equivalents, and Operational Amplifiers. That is, each topic was covered for an entire lecture, homework was given the same day, and then a quiz was given the following lecture.

Quiz Guidelines

The quiz was administered (closed book/closed notes) at the start of class before any lecture or homework review. Each student was given approximately 10 minutes to complete analysis on a single circuit that covered the topic at hand. At the conclusion of this timeframe, the quizzes were collected. No solution for the quiz was ever covered or discussed in class.

Each of the quizzes were collected between the two sections and sorted based on the quiz topic. Among the participants in the course, only the students who had completed all three quizzes

were calculated in the evaluation process. This comprised 116 entrants in the review. A common grader was assigned to grade all of the quizzes using a common rubric. The statistics from these quizzes were tabulated and analyzed.

In order to compare differences in performance due to WeBWorK access, a fair comparisons had to be made across multiple quizzes that naturally varied in difficulty. In an attempt to normalize the scores across the variability in difficulty in the different quizzes, the raw scores for each quiz were first converted to z-scores using the mean and standard deviation from the full dataset of all quizzes. The z-score would normalize the quiz difficulty to allow the quiz scores to be comparable to each other. The z-scores for each quiz could then be equally averaged to compare students with WeBWorK versus students with paper homework.

Results

In the spring 2015 quarter, the two course sections started with 42 students each. Throughout the quarter, not all of the students were in attendance to take each of the quizzes. To make a more equitable comparison of quiz results, only students who were able to attend all 4 quizzes were used. This reduced the sample size to 29 and 26 for the two sections respectively.

The average z-score for each section on each quiz is shown in Table 1 below. The quizzes are highlighted to show which of the two sections received paper based or WeBWorK based homework. Section 001 is highlighted in blue and Section 002 is highlighted in red.

	Quiz 1	**Quiz 2**	**Quiz 3**	**Quiz 2**	***Avg***
Paper	0.05240	0.20329	-0.10826	0.24441	**0.09110**
WeBWorK	-0.05845	-0.18226	0.12075	-0.21913	**-0.09110**

Table 1: Quiz Z-Score Averages by Section and Homework Type for Spring 2015

Looking at Table 1 the average scores for both WeBWorK and traditional paper homework have little separation showing a similar performance on the quizzes. The paper homework students appeared to perform slightly better than those with WeBWorK. To gain a perspective on the significance of that difference, the z-scores for all quizzes is averaged for each section.

Section 001	**Section 002**
-0.1143	0.1275

Table 2: Quiz Z-Score Averages by Section for Spring 2015

The difference in quiz scores between the two sections is greater than the difference between homework types. Section 002 performed better, on average, on the quizzes than section 001 regardless of what type of homework they were given. This would lead to the conclusion that WeBWorK, while maybe not improving the learning, is not hindering the learning compared to traditional paper homework. The difference in homework types was less significant than the instructor or class.

In the fall 2015 quarter, the two course sections started with 47 and 50 students respectively. Just like in the spring quarter, students who did not take all 4 quizzes were removed, reducing the sample size to 29 and 28. As before, the average z-score for each section on each quiz is shown in Table 3 below. Section 001 is again highlighted in blue and Section 002 is highlighted in red.

	Quiz 1	**Quiz 2**	**Quiz 3**	**Quiz 2**	***Avg***
Paper	0.21181	-0.12699	-0.37768	-0.22279	**-0.12967**
WeBWorK	-0.20498	0.13122	0.36550	0.23022	**0.12967**

Table 3: Quiz Z-Score Averages by Section and Homework Type for Fall 2015

The fall quarter shows students administered homework via WeBWorK performing better than those with traditional paper homework. The difference is more pronounced, but still worth comparing to the difference in performance between the two sections.

Section 001	**Section 002**
0.0489	-0.0473

Table 4: Quiz Z-Score Averages by Section for Fall 2015

The fall quarter had less discrepancy in scores between the two sections, and the difference between homework types was larger than the difference between sections. In the fall, the Students with WeBWorK performed better, on average, than those with paper homework regardless of which section they were in.

Finally, both quarters are combined to create a larger dataset. The combined dataset was still broken into two groups defined as Section 001 and Section 002 with each group having a sample size of 59 and 57 students respectively. Table 5 below shows the z-score averages for each section as show before. Section 001 is again highlighted in blue and Section 002 in highlighted in red.

	Quiz 1	**Quiz 2**	**Quiz 3**	**Quiz 2**	***Avg***
Paper	0.10232	0.02849	-0.24412	0.00035	**-0.02898**
WeBWorK	-0.10591	-0.02753	0.25269	-0.00033	**0.02898**

Table 5: Quiz Z-Score Averages by Section and Homework Type for Spring and Fall 2015

Not surprisingly the differences between WeBWorK and paper homework are marginal. There appear to be no statistically significant difference between the students who were assigned WeBWorK and those who were assigned paper homework. Again both sections can be averaged to compare to the difference by homework type.

Section 001	**Section 002**
-0.042415	0.043904

Table 6: Quiz Z-Score Averages by Section for Spring and Fall 2015

The difference between the two sections is greater than the difference between homework assignment types, meaning the instructor had a larger factor on quiz performance than the type of homework assigned. This reinforces our conclusion that WeBWorK can perform at least equally well to traditional paper homework.

Student Reactions to WeBWorK

Our institution has been using WeBWorK in mathematics courses for nearly ten years. Students have become quite accustomed to its usage in engineering courses as well. While new student users may complain about the input of answers into WeBWorK, when pressed for an opinion, they typically comment on the value of WeBWorK's features like the email instructor option on each problem, immediate problem feedback, and the ability to attempt a problem numerous times.

As part of this project, the authors have collected student opinion data through pre- and post-surveys administered in ENGR 220 (statics and mechanics of materials) and ENGR 221 (circuits). The summary reported here is based on student opinion from the Fall 2014 and Winter 2014-15 quarters. Data from the exact terms when the quizzes studied here were administered is not yet available. Pre-surveys were administered at the beginning of these terms. A total of 211 students completed surveys in Fall 2014, while 185 students completed the Winter 2014-15 pre-survey. The pre- and post-surveys contain thirteen common questions related to student identity and self-efficacy. The questions and tally of student responses is shown in Table 7.

	Fall 2014 % Agree or Strongly Agree		**Winter 2014-15 %Agree or Strongly Agree**	
Question	**Pre (n=211)**	**Post (n=99)**	**Pre (n=185)**	**Post (n=50)**
I have friends in engineering.	95%	93%	94%	96%
I belong in engineering.	95%	88%	94%	94%
I am good at solving engineering problems.	88%	83%	88%	98%
I excel in my engineering studies compared to my peers in engineering.	55%	60%	56%	62%
I will be an excellent engineer.	86%	76%	85%	92%
I can have a fulfilling career in engineering.	90%	77%	90%	96%
I am comfortable working in an online environment.	83%	83%	91%	94%
I am comfortable using a computer to solve engineering problems.	90%	87%	92%	98%
Homework problems are a critical part of the learning process in engineering classes.	96%	90%	96%	96%
The amount of effort I put into solving the homework problems will affect how much I gain from the course.	92%	84%	89%	92%
The amount of effort I put into solving the homework problems will affect my grade in this course.	95%	85%	94%	96%
My grade in this course will be affected by the amount	81%	87%	81%	84%

of effort I put into this course. (reversed scaled)				
I will not gain the same amount of knowledge from this course regardless of the amount of effort I put into this course. (reverse scaled)	81%	85%	79%	84%

Table 7. Student identity and self-efficacy survey responses

The data indicates that students *begin and end* their WeBWorK courses feeling comfortable in their choice of an engineering major, developing in identity as an engineer, and believing they will have a fulfilling career as an engineer. The students are comfortable operating in an online environment for their homework submission, and they understand the impact of their homework efforts on knowledge attained and course grade. Students are a little less sure that they excel in their engineering studies when compared to their peers.

Post-surveys were administered at the end of the Fall 2014 and Winter 2014-15 quarters. A total of 99 students completed post-surveys in the fall, while a total of 50 students completed the Winter 2014-15 post-survey.

The post-survey contains 18 additional statements for which students are asked to rate their level of agreement. Some differences were seen between the Fall 2014 post-survey and the Winter 2014-15 post survey. In both cases more than half of the students reported that their previous experience with WeBWorK had been positive (68% Fall and 80% Winter). However, fewer than 75% of students (62% Fall and 69% Winter) reported being more comfortable using WeBWorK than submitting pencil and paper homework. Only 17% of Fall respondents and 14% of Winter respondents Agreed or Strongly Agreed that they didn't like WeBWorK because it was too difficult to submit their answers. Difficulty submitting answers electronically does not seem to be a problem for these students. Overall, students who completed the post-survey in Winter 2014-15 were more positive about the use of WeBWorK than were students who completed the survey in Fall 2014. A summary of these post-survey results is contained in Table 8.

Statement	**Fall 2014 % Agree or Strongly Agree**	**Winter 2014-15 %Agree or Strongly Agree**
Make better grades	56%	63%
Prefer WeBWork to other methods	58%	71%
Better prepared for exams	62%	78%
Know immediately if answer correct	96%	100%
Feedback more useful than traditional	52%	66%
Get more out of class	54%	70%
Prefer WeBWork because know homework has been graded	58%	72%

Table 8. Unique post-survey question summary

Students were most positive about WeBWorK because it told them immediately if their answer was correct. For all other statements about the value of WeBWorK to students, less than 75% of the students Agreed or Strongly agreed that they felt that WeBWorK was valuable to them for that reason. However, only 20% (Fall 2014) and 10% (Winter 2014-15) report that they did not like WeBWorK because they had had difficulty using the program. At the same time, 56% (Fall 2014) and 36% (Winter 2014-15) report that they did not like WeBWorK because even though the answer they entered was correct, the program counted it wrong. Slightly more than half of respondents (56% Fall and 68% Winter) believe that WeBWorK problems are more difficult than traditional paper and pencil problems. At the same time, almost half of the students (58% Fall and 48% Winter) report that they often get frustrated and give up on a WeBWorK problem because of its difficulty.

The reduction from fall to winter in feelings that WeBWorK was improperly marking answers wrong was likely due to two reasons. A few of the problems were deployed in the fall for the first time, and contained occasional inaccuracies that were not discovered until after they were assigned. While the issues were resolved quickly, the seeds of doubt had been planted. When some students hear about this occurring once or twice, they tend to doubt the system even though the vast majority of problems report answers correctly. The second reason for the decline is due to the makeup of the class in the fall versus winter quarter. The fall quarter is typically comprised of more first-time takers of the course compared to the winter. Because of the relatively high rate that students have to retake this course, more students in the winter had seen the problems previously. The decline in students getting frustrated and giving up on a problem is probably also related to this class makeup difference.

Conclusions and Future Directions

In this work we have reported the results of a study to determine the impact of online homework when compared to traditional “paper” homework on student learning in an introductory circuits course. The data suggest that the online homework, administered through the open-source WeBWorK, is at least comparable to paper homework for student learning. This is consistent with what other studies involving online homework in mathematics have revealed. Finally, the authors are looking to implement WeBWorK in higher level electrical engineering courses, so future educational studies to assess the impact of online homework on student learning in these courses will likely occur. A similar study has been conducted for a first statics course and is planned for a sophomore thermodynamics course. Data for these studies continues to be collected to increase the sample size for improved statistical analyses.

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