Qualitative and Quantitative Analysis of Use of Online Homework for Circuit Analysis

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Abstract

Electric circuit analysis is a critical course in engineering and technology programs for students studying electrical, computer, and mechanical engineering. This study considers the use of online homework in circuit analysis courses for a group of students from diverse academic backgrounds. The effect of homework format on student performance is considered as well as other aspects regarding how homework problems should be authored. Two sections of twenty-four students were presented with the same homework and assessment problems. One section performed the homework on paper and the other used the online WeBWorK platform. How the online problems integrate into scaffolded instruction is discussed at length and student performance for such instruction is considered using the same assessment problems. Student and instructor reception is discussed before conclusions regarding the significance of the results are presented. The preliminary results show little difference in student performance between online and written homework but suggest a modest difference between scaffolded and non-scaffolded instruction. With little change to student performance and an overall positive reception by students and the instructor it is concluded that online homework can be used successfully in circuit analysis courses.

Introduction

As the use of online homework systems becomes more pervasive we, as faculty, must consider the effect of it use on our students as well as the impact it has on how we execute courses. This work considers the use of WeBWorK and the attributes of online assignments as they affect student performance. Student scores from two sections in separate semesters are compared in order to determine how the use of online homework affects student outcomes. Other secondary questions are explored in order to understand how author‘s of online homework can improve the integration of the assignments through scaffolding. Factors such as a student’s chosen major, standardized exam score, and performance on homework are considered in order to understand the significance of variation in performance caused by the mode of homework presentation.

The question of using online homework has been studied by numerous groups across many subjects. Studies covering mathematics[1], physics[2], programming[3], mechanics[4], and thermodynamics[5] have largely concluded that student performance is not significantly affected. Other studies have concluded that the potential benefits are outweighed by challenges such as cost to the student and technical flaws[6]. This result speaks to the need for quality execution of lessons regardless of the means of presentation. A poorly organized slide presentation is the responsibility of the author more than the slide projector. An examination of one aspect, scaffolded instruction, is covered in detail after presenting a number of principles that were followed in authoring the problem used in this study.[7,8,9,10]

WeBWorK itself has gained traction as a platform that addresses these concerns directly due to its low operating cost and flexible evaluation of student answers. A number of recent studies have explored its use in engineering courses.[4,5,11,12,13] Three studies have focused on the use of online homework for circuit analysis courses[14,12,13] two of which made use of WeBWorK.[12,13]

This work begins with the enumeration of attributes used during authoring of the online homework problems for the WeBWorK platform. One such aspect, scaffolded instruction, is presented in detail with examples of non-scaffolded and scaffolded problems as presented by the WeBWorK platform. Student performance for topics taught in the non-scaffolded and scaffolded manner are then compared. The central question of this work is addressed through the comparison of student scores on midterm and final examinations for specific topics and for overall course performance. The two course sections used for this study used identical homework and assessment problems to remove any variation caused by the course material. Instructor workload is considered in the context of the small, undergraduate state university. Subjective student reception is presented and various factors other than the homework format are considered for their effect on the students' performance.

Development of WeBWorK Problems

Any discussion regarding the effectiveness of online homework should include details regarding what attributes lead to better student performance. Just as one can deliver a good lecture or a poor lecture, the effectiveness of online homework is affected by the execution as much as the mode of presentation. A few of the attributes are naturally part of online homework. Immediate feedback is often cited as a benefit, however, care must be taken to provide consistently accurate feedback that speaks to the underlying concept being assessed. WeBWorK allows for both absolute and relative tolerances of student answers though the onus is on the author to find an acceptable balance between accuracy and flexibility.

Online homework may be syntactically rigid or flexible depending on the implementation. WeBWorK allows for the mathematical evaluation of student answers leading to a more forgiving, flexible means of entry. Where other systems perform a simple string comparison to evaluate an answer, WeBWorK allows a number of methods for evaluation. Again, the author must choose the most appropriate means. In this study student answers entered as numeric values or functions are evaluated for mathematical equivalency rather than simple string equivalency.

Two other choices were made in authoring the homework problems for this study. First, the use

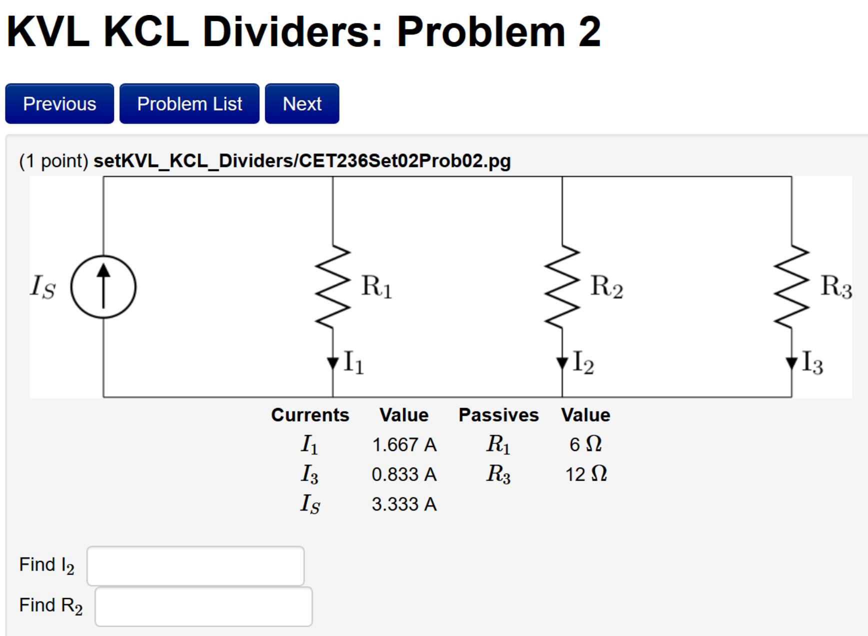

Figure 1: Non-scaffolded problem example

of randomized values for each student serves to change the nature of their collaboration in completing the homework assignments. Rather than sharing answers the students are forced to discuss how the problem was solved. While this does not ensure comprehension of why a method was used, it certainly represents a step in the right direction. Second, the use of units in answer evaluation works to reinforce good engineering practice.

Perhaps the most critical aspect the author of online problems should attend to is ensuring the problems coincide with the methods of instruction used in the class as a whole. The creation and use of online homework is simply not enough to reap the benefits and ensure improved student performance. The author of the homework and instructor of the course should be cognizant of the following attributes of the assignments:

1. Immediate feedback
2. Forgiving syntax, flexible answer entry
3. Randomized values to improve collaboration
4. Use of engineering units in answer evaluation
5. Alignment with course content

All of the online assignments discussed in this study were authored with these principles in mind. One such problem is shown in Figure 1.

Effect of Scaffolding

Scaffolding can be introduced briefly in the context of the metaphor originally introduced by Jerome Bruner[15] and applied to education by Vygotsky[16,17]. The metaphor is that of a master/apprentice relationship where the master slowly removes the support provided as the apprentice progresses towards mastery of the skill being taught. While the idealistic educational setting with a one-to-one student teacher ratio is unheard of in the modern classroom, the concept can be applied to modern instruction.

A portion of the online homework discussed here was structured for scaffolded instruction. Those homework problems covered two methods of analysis: mesh and nodal analysis. The orderly approach to these methods of circuit analysis are taught explicitly in lecture and are reflected in the online homework as a means of reinforcement. The approach is then practiced during recitation sessions and demonstrated by the students during examination. These steps are summarized here:

1. Demonstrated examples during lecture
2. Online homework with intermediate step feedback
3. Traditionally presented textbook problems during recitation
4. Assessment during midterm/final exams

It was stressed during lecture that circuit analysis, and in this case mesh analysis, is a methodical process that can be applied to any circuit. The steps of the method were demonstrated to each section using eight problems prior to the assignment of the online homework. For each lecture problem the methodical approach reflected in the online homework was demonstrated on a whiteboard. This was the first step listed above. If students needed additional support in this form, video lectures were also provided using additional problems.

Upon completion of the demonstrated problems during lecture five and six problems were assigned for mesh and nodal analysis respectively. A problem from the mesh analysis assignment is presented here. Figure 2 shows the initial presentation of the problem the student will encounter. The parts of the problem scaffold are displayed below the circuit schematic. The student cannot progress to a subsequent part until the previous part has been completed. Both mesh and nodal analysis involve the development of a system of equations to be solved. Students often begin writing equations without taking a step back to consider how many and which type of equations they should include in the system. The first part is shown in Figure 3 and is designed to make the student make a plan for their analysis. The second part of the scaffold presents component values for the first time and asks the students to enter the required equations. In this step attention was paid to the flexibility of entry. Student frustration with strict syntax serves as a barrier to successful adoption.[6] To avoid this any valid and equivalent equation is evaluated as correct. Examples of such equations include:

$$-7I_1 + 3I_2 + 4I_3 = -14 \tag{1}$$

$$7I_1 - 3I_2 - 4I_3 = 14 \tag{2}$$

$$14 - 4(I_1 - I_3) - 3(I_1 - I_2) = 0 \tag{3}$$

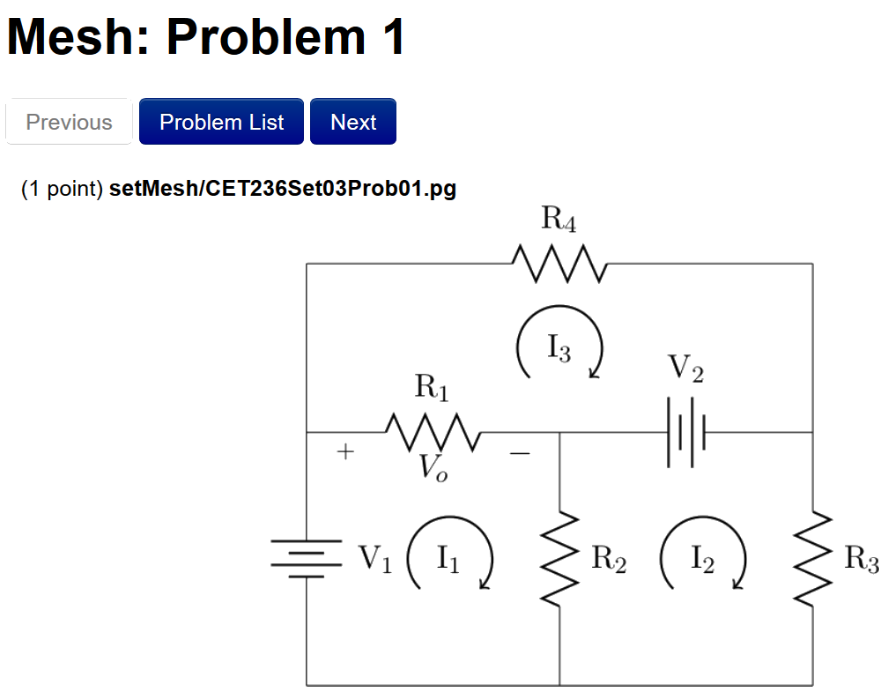

Figure 2: Initial mesh analysis problem presentation

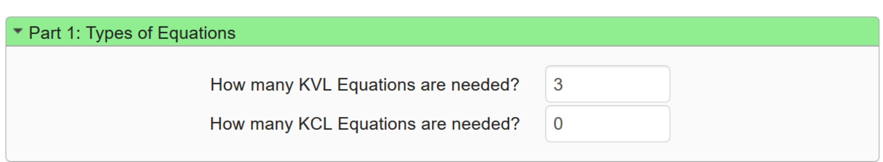

Figure 3: First scaffold part: planning the system of equations

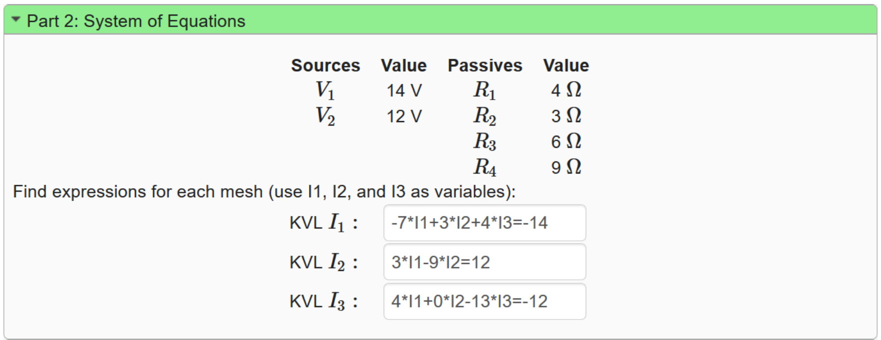

Figure 4: Second scaffold part: developing the system of equations

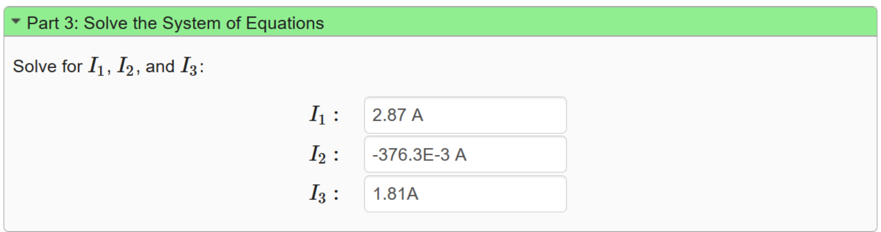

Figure 5: Third scaffold part: solving the system of equations

While equations (1) and (2) offer certain advantages with regards to solving the system, namely ease of use in matrix algebra or row-reduced echelon form, equation (3) is an equivalent equation and therefore is acceptable. Figure 4 shows the display of this part visible to the students after completion of previous scaffold parts. The subsequent parts of the problem are the solution to the system of equations as shown in Figure 5 and the use of that solution to find other values in the circuit as shown in Figure 6.

The instructor presented two of the eight topics in this manner during the semester that used WeBWorK for homework assignments. Mesh and nodal analysis follow a very structured procedure that naturally lends to the scaffolded style of instruction. The instructor presented the remainder of the topics in a non-scaffolded manner. Assessment of the individual topics reflects the students' performance during individual exam problems covering the same topics. Table 1 compares the z-scores of the scaffolded and non-scaffolded topics. The use of z-scores allows for the comparison of evaluations of dissimilar assessment methods as is the case here. WebWork scored the student responses between 0 and 1 with partial credit awarded for individual answers within each problem. The instructor hand-graded the exam questions with scores for each problem ranging from 0 to 10. Again, partial credit was awarded for partially correct

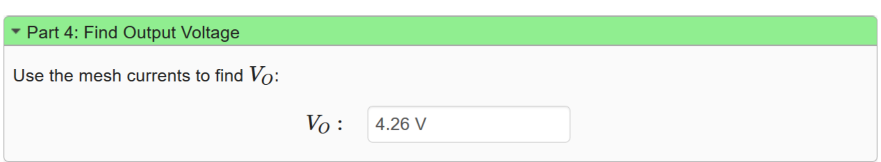

Figure 6: Fourth scaffold part: using the solution to find other values

	Scaffolded	Non-scaffolded
WeBWorK	-0.06968	0.02323
Exam	0.14120	-0.05187

Table 1: z-score assessment averages for problems with scaffolded instruction and without

Topic	Online	Written
Fundamentals	0.00459	0.02433
KVL, KCL, Dividers	-0.26966	0.35152
Mesh Analysis	0.47306	-0.52022
Nodal Analysis	0.16324	-0.15294
Superposition	-0.30820	0.27129
Equivalent Circuits	0.30769	-0.34755
Transients	-0.12025	0.14998
Phasors	0.22467	-0.18546
Overall	0.05939	-0.05113
Math SAT (z-score)	-0.05369	0.05125
Math SAT (mean)	545	551
Homework (z-score)	0.51710	-0.49359
Homework (mean)	92.9%	66.4%

Table 2: Assessment z-score averages for online and written homework course sections

answers. While the performance of the students on the homework showed little variation, the assessment of exam performance gives a preliminary indication that the scaffolded instruction improved the student outcome for those topics.

Student Performance: Online vs. Written Homework

The central question of this work is addressed in Table 2. The exam problems again serve as the means of assessment for individual topics and the overall comparison of online and written homework. The instructor manually graded the exam questions with scores ranging from 0 to 10. Partial credit was awarded for partially correct answers. The z-scores indicate a modest advantage to the online homework though not enough of an advantage to state so conclusively. For comparison, the variation of outcomes for individual topics is far greater. The lack of variation between online and written homework certainly fits with the ethos of “do no harm”. While the change in instructional method did not improve performance significantly it also did not harm performance. With this conclusion, other advantages discussed in the next section can be evaluated without considering any negative effects on the students.

Table 2 also addresses the variation in the populations. The variation in mathematical preparation was examined using the math portion of the SAT exam as a proxy for mathematical ability. Both

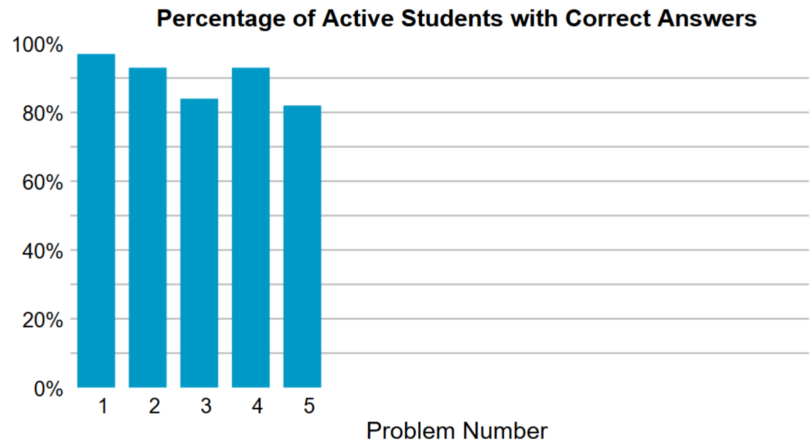

Figure 7: Problem-set statistics available to the instructor as presented by WebWork

the z-scores and mean values of math SAT scores are included in Table 2 and indicate little variation between the populations. The diligence shown by students during the semesters studied was also examined using homework scores. Both the z-scores and mean values of the students homework grades, regardless of delivery method, are included in Table 2. The section taught with online homework out-scored the section taught with written homework. While this may indicate a more dedicated population of students it may also reflect the student's response to the immediate feedback provided by WebWork. This difference in homework scores warrants future study.

The advantage of scaffolded instruction appears in these results as well given the manner of instruction varied between sections. Mesh and Nodal analysis were presented in a scaffolded manner for the online section and in a non-scaffolded manner during the written section. Examining the individual results shows that the largest difference exists for these two topics.

Instructor Workload

The use of WeBWorK has two primary benefits for the instructor. First, it reduces work load with regards to grading and administration. The forty-seven problems assigned to a section of twenty four students required approximately twenty hours of preparation, grading, and entry when performed by hand. Administration of the WeBWorK section, on the other hand, may have taken an hour spread over the entire semester.

Second, the students are not the only recipients of immediate feedback. The use of data can guide the instructor to target review and recitation sessions by indicating where the students under-performed on the homework. Figure 7 shows the statistics available to the instructor regarding an individual assignment. For instance, the data shown above indicates that the students performed worse on problems 3 and 5 of the mesh analysis assignment when compared to the other problems. Familiarity with those problems suggests that not all students are comfortable analyzing a circuit with a dependent supply. The short-term response should be review of the key concepts required for such analysis. The long-term response should include re-evaluation of the instruction regarding dependent supplies for future sections of the course.

Student Reception

Effective methods of teaching can still fail if the students do not accept them. The subjective reception of the homework problems is not only important for student satisfaction but also for student motivation. While a topic-specific survey was not administered a number of students included their opinions regarding the homework as part of the course survey in the semester included in this study. Those comments are included here:

- "*props for moving to online homework*"
- "*The online homework is really weird. Like, REALLY weird.*"
- "*the homework applied the concepts we learned in lecture.*"
- "*The online homework was helpful. If there were more practice problems with different values that would help build speed and confidence for the tests.*"
- "*...all the assignments are fair and worthwhile.*"
- "*His homework is the best though. It's never the same exact circuit from class, which helps for the exams.*"
- "*Possibly give extra homework problems for students to practice online. They don't have to be graded. Just enough extra work for thorough preparation for exams.*"
- "*Online homework is definitely more interesting and exciting to do.*"
- "*Homework is very frustrating. Get reasonable answers on paper, but they do not match up on WeBWorK. I've spent countless hours on the homework to receive a 25%. Partial credit would help considering we are practicing the problems for the first time on our own*"

The majority of the comments are positive. Additional off the record conversations with students have supported many of the positive comments made above. Specifically, the students find the immediacy of feedback useful in studying and would like to see the expansion of WeBWorK's use in this class and others.

The number of student interactions seen by the instructor is another subjective measure of the adoption of the system. In the semester that students completed the homework using WeBWorK, approximately five hundred additional emails were sent to the instructor with specific questions regarding homework problems. While this increased the time spent responding to students the interactions were effectively an extension of instruction beyond the scheduled class times.

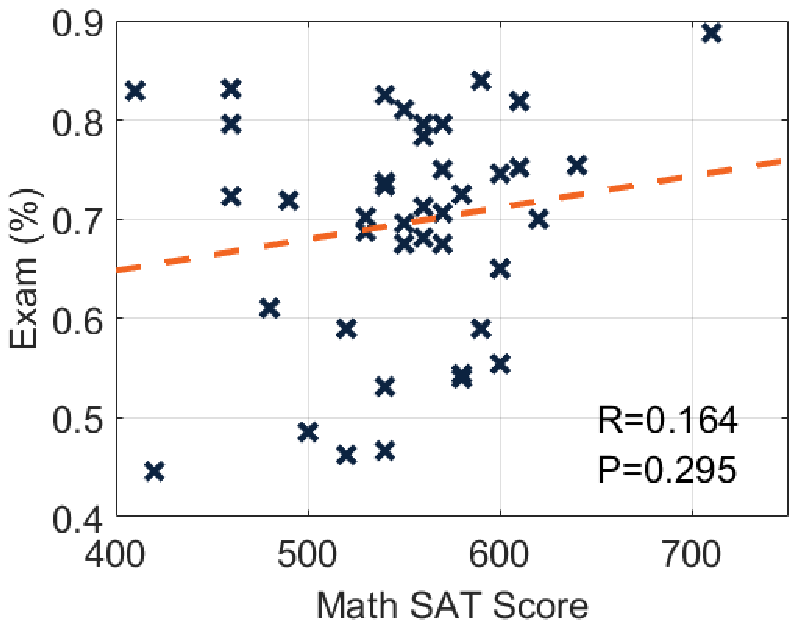

Figure 8: Math SAT Score versus Assessment

Relevant Factors Affecting Student Performance

This section addresses other factors that potentially affect student outcomes. The preparation each student brings to the course is unique but can be classified or measured in a few ways. The diverse background of the student population in this study requires consideration to this end. Two factors considered speak to the students' preparation prior to the class. Another factor speaks to the students' attention to the class during the semester. This section examines the effectiveness of each factor in predicting the individual student's performance.

First, students' mastery of basic mathematical concepts is considered. Each students' comfort level with these fundamental concepts potentially affects their assessment scores more significantly than the means of instruction considered in this study. The students' performance on the mathematics portion of the SAT exam was used as a proxy to measure mathematical ability. The population considered in this study is shown in Figure 8. As expected, there is a positive correlation between the students' SAT scores and their performance regarding circuit analysis. The variance of the residuals of the pictured regression is used to determine the quality of the exam scores as a predictor for assessment. The variance is shown in the summary table at the end of this section.

Preparation prior to the course also varies by student major. Each major is a self-selecting group that may reflect each groups relative comfort with mathematical concepts necessary for the course. Each major group also varies in the courses they have taken prior to the circuit analysis course in this study. For instance, the Mechanical Engineering (ME) students tend to take the course much later in their degree program than the Computer Engineering Technology (CET) students. This difference often means the ME students have been through courses of

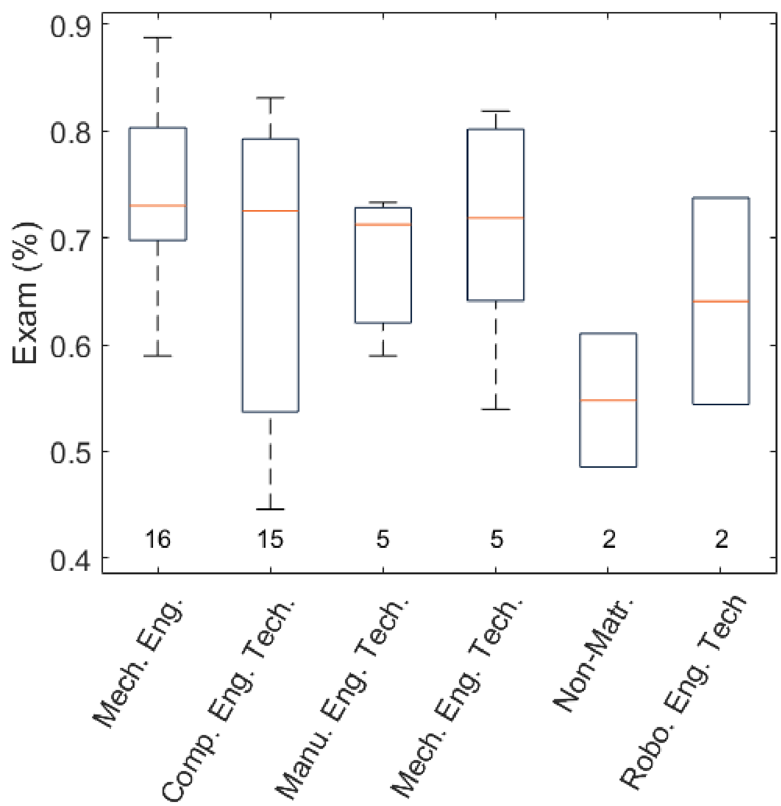

Figure 9: Major versus Assessment

similar or greater mathematical rigor prior to this course. Figure 9 shows the six student majors presented in the studied population. Two of the majors, Robotic Engineering Technology and non-matriculated students, are under-represented in the population and no conclusions are drawn from their performance. The remaining majors are summarized in Table 3. Examination of Figure 9 reveals little variation in the mean of each population. It also reveals that the students that take the course later in their degree programs have a more consistent outcome.

Finally, the students' attention to the course material during the semester is considered. The students homework scores and exam scores were compared to determine whether their background or participation was more significant in their individual performance. The regression of these values is shown in Figure 10. Again, as expected the two values are positively correlated. The variance of the residuals is included in Table 3.

Comparison of the variances of each score or category allows for conclusions to be drawn regarding how relevant each factor is relative to the others. Table 3 shows the variance of math SAT scores, homework grade regardless of format, student majors, and homework format.

The primary question addressed by this study is whether the WeBWorK population was significantly different than the written assignment population. Both populations show comparable variance indicating neither predicts success more accurately than the other. Three predictors show

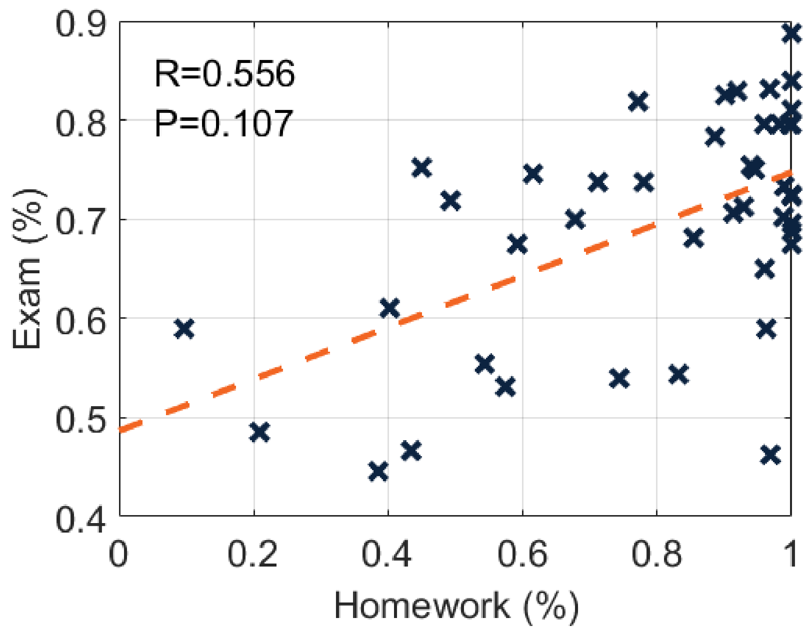

Figure 10: Homework versus Assessment

Factor	Variance
Homework	0.00899
Math SAT	0.01268
Mechanical Engineering	0.00555
Manufacturing Engineering Tech.	0.00603
Mechanical Engineering Tech.	0.01238
Computer Engineering Tech.	0.01994
Written	0.01321
WeBWorK	0.01251

Table 3: Variance of factors under consideration impacting assessment score

better performance than the format of the homework assignments: enrollment in the Mechanical Engineering or Manufacturing Engineering Technology programs and the students score on homework assignments regardless of format. This suggests that prior preparation and diligence during the semester are stronger factors in student performance rather than the homework format.

Conclusion

This work has reported preliminary results regarding the use of the online WeBWorK platform rather than traditional written homework. No significant difference in student performance was found leading to the conclusion that the WeBWorK assignments were similarly effective in teaching the material of the course. This conclusion is similar to other studies performed for online homework assignments in a variety of courses. While no adverse effect is observed in student performance there are subjective benefits for both the students and the instructor. The students appreciated the instantaneous feedback and have requested additional problems in the class and that WeBWorK's use be expanded to other classes. For the instructor, the reduction in workload is an undeniable benefit. Additionally, the use of statistics to guide review and recitations better serves both students and instructors.

The use of scaffolded instruction with WeBWorK was examined as a secondary question. While the sample size prevents a conclusion, preliminary results indicate that students performed better on topics taught in this manner. Further data will be collected regarding this matter as instruction of other topics is modified to be taught in this manner.

Finally, other factors that could predict student performance were considered in order determine the significance of the effect of the change in homework presentation. The data indicates that student preparation and engagement in the course are more significant factors than the presentation format of homework assignments. Data collection will continue in future sections in an effort to gain clarity beyond these preliminary results.

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