Enhancing the Mathematics Skills of Students Enrolled in Introductory Engineering Courses:
Eliminating the Gap in Incoming Academic Preparation

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Abstract

Several studies strongly support the relationship between mathematics performance and retention of engineering students. There is also substantial evidence that nationally almost half of college freshmen could benefit from some mathematics remediation. The purpose of this study was to determine whether the use of WeBWorK as an instructional technology enhanced the mathematics skills of students enrolled in introductory engineering and engineering technology courses. Differences in mathematics performance of three intact groups were investigated with predicted freshman year grade point average as the covariate. Results suggest that WeBWorK helped eliminate the gap in incoming academic preparation between engineering and engineering technology users. Feedback from students indicates that WeBWorK is a valuable tool for refreshing basic mathematics skills and enhancing mathematics self-confidence.

Several studies strongly support the relationship between mathematics performance and retention of engineering students. However, there is substantial evidence that nationally almost half of college freshmen could benefit from some mathematics remediation. Although gaps may exist in other subject areas, “the transition in mathematics is by far the most serious and the most problematic” (Kajander & Lovric, 2005, p. 150). Research conducted in the mid-1980s revealed that roughly 46% of college students required mathematics remediation (Adelman, 1999; Dell-Amen & Rosenberg, 2002). A decade later Wieschenberg (1994) found that 40% of approximately 600,000 students in his study failed their first attempt at freshman calculus. A more recent study conducted in 2004 by Bahr (2010) found similar results: 40–46% of college students required some sort of remedial work, primarily in mathematics and English. Clearly, the problem has a history that spans decades with little evidence of amelioration.

The issue of mathematics preparation is especially problematic for engineering majors. For example, Brannan and Wankat (2005) found that almost three-fourths (73.4%) of the 49 institutions that participated in their study considered mathematics to be an area of weakness for their entering engineering students. According to Graff and Leiffer (2005), a “disturbing number of [engineering] students” (p. 13231) are not ready for calculus when they enter college, and the mistakes they make in subsequent courses are not due to deficiencies in their ability to do calculus but rather in their ability to do algebra. Increased reliability on calculators has also resulted in students’ inability to manipulate numbers, do simple calculations in their heads, or estimate and gauge the appropriateness of their answers. However, Dunham and Dick (1994) found that American high school students who used graphing calculators performed as well as other students on standardized exams. Their research was replicated by Burrill et al (2002).

Buechler (2004) attributes the deficiency in mathematics to instruction received in high school or in former institutions and to lack of retention of material caused by poor study skills and/or time elapsed between instruction and application. He suggests that urban universities with relatively low admission requirements are particularly vulnerable to the issue of inadequate mathematics preparation of engineering students.

Several studies strongly support the relationship between mathematics performance and retention of engineering students. For example, Budny, Leuwerke, and Bjedov (1998) found that a major reason students leave engineering is because of difficulty with mathematics courses. Leuwerke, Robbins, Saywer, and Hovland (2004) found an interaction between low achievement in mathematics and student retention in engineering majors. Two studies conducted by Sami Fadali and colleagues (2000; 2001) revealed that students dropped out of engineering due to their lack of competency in mathematics. Furthermore, they found that even after completing Calculus students continued to make errors that hindered their problem solving skills, primarily due to poor study habits and their inability to transfer knowledge between mathematics and engineering problems.

Socio-economics status, gender, race, and parental education are among a number of factors which can influence the mathematics preparation and, therefore, the performance and retention of engineering students (Hagedorn, Siadat, Shereen, Nora, & Pascarella, 1999). Regardless of the reasons for the continued high percentage of students requiring remediation, the mathematics skills of university freshmen are unsatisfactory and educators “can no longer expect that the incoming students will know this material" (Kajander & Lovric, 2005, p. 149). Collectively, these studies and others like them, along with substantial anecdotal evidence, beg the question: *How can the problems in student transfer from secondary to tertiary mathematics be ameliorated?*

Research indicates that the transfer to university level mathematics can be eased by the use of computer based strategies. For example, as early as the 1970s Cornelius (1972) found that students were concerned with the transition to collegiate mathematics, particularly the pace and rigor of the lectures and work. According to Kajander and Lovric (2005), many high school students develop a "surface learning" (p. 157) of mathematics that is insufficient at the university level. They note that a developmental course or expanded bridge program may be effective in easing the transition. They also suggested that prior preparation via online mathematics refreshers can be effective. More recently, Taylor (2008) noted that computer based remediation allows students to control the process and pace of learning. Properly constructed, computer based assignments can be an effective scaffolding technique for students as it provides concepts and offers immediate feedback, correcting the students while errors are still fresh in the mind (Parsons, Croft, & Harrison, 2009; Ross & Bruce, 2009). Scaffolding techniques guide students from simple to more complex material beginning with a range of expert support and culminate in student self-sufficiency in the topic (Chaiklin, 2003).

Many institutions have relied on the use of technology to remediate students' lack of mathematics preparation. North Carolina State University, for example, used WebAssign to provide additional support in an Applied Differential Equations course (Levy, Shearer, & Taylor, 2007). Although students reported that they spent only 30–90 minutes each week on WebAssign homework, more than 90% indicated that the technology helped refresh their mathematics skills and approximately one-third indicated that it helped them catch up despite their initially being unprepared for the course. Other institutions have developed their own web-based review courses. For example, lower-tier students who participated in Clarkson University's web-based summer math course earned a higher number of As in Calculus I compared to students who completed a remedial course at a community college or who participated in their alternative boot camp course (Turner, 2008). The success of these online tools may be explained by Wong (2001) who found that students who used computer-based drill and practice homework achieved better results than students who used paper-based homework problems. In addition to providing immediate feedback, computer-based homework systems often provide online assistance when students encounter difficulties in problem solving. Consequently, the use of such technologies may lessen students' anxiety, improve their proficiency, and enhance their confidence in their mathematics skills.

The purpose of this study was to determine whether the use of WeBWorK (2010a) as an instructional technology enhanced the mathematics skills of engineering and engineering technology students. WeBWorK provides individualized homework problems and immediate feedback regarding correctness of answers. Assignments can be structured to facilitate heuristic problem solving. Heuristics are "methods and rules of discovery" (Polya, 1945/2004, p. 112) to help students problem-solve when they get stuck. For example, more complex problems can be broken into several steps. Hints can also be added with a point penalty if used.

Setting

The study was conducted at a large, urban research institution in the Southeast during the fall of 2008. Students enrolled in Introduction to Engineering (ENGR 1201) and Introduction to Engineering Technology (ETGR 1201) courses composed the sample (N = 346). Both courses are designed to build basic knowledge and skills relative to the various disciplines within the profession, project management, engineering design, teamwork, technical communications, and engineering mathematics. Collectively, about 750 students enroll in ENGR/ETGR 1201 each year. The two-credit-hour courses meet twice a week. Section sizes are limited to about 30 students to facilitate student-student and student-faculty interactions and to engage small groups of students in three hands-on projects.

During the fall semester enrollment in both courses is restricted to College of Engineering students only. Other majors may enroll during the spring semester. Calculus I is a co-requisite for ENGR 1201 while College Algebra is a co-requisite for ETGR 1201. Historically, about 30% of engineering majors cannot take ENGR 1201 during the fall semester of their freshman year because they are not eligible to enroll in Calculus I due to their performance on the mathematics placement exam, which is administered during summer orientation. These students typically take the course in the spring semester after having successfully completed Pre-Calculus. Historically, about 90% of engineering technology freshmen place into College Algebra, making them eligible for ETGR 1201 during their first semester of college.

All sections of ENGR 1201 and ETGR 1201 share a common curriculum, including lecture materials, projects, assignments, grading rubrics, and tests. In addition, the five faculty who teach the courses meet weekly to develop content, plan delivery strategies, review student learning outcomes, and identify opportunities for improvement. These meetings and the use of a common curriculum help reduce inconsistency among the sections. Learning outcome data collected over the last several years revealed that students struggle with the basic engineering mathematics taught in the courses, primarily consisting of algebra. As a result, more mathematics was introduced in Fall 2006.

Research Questions

The purpose of this study was to determine whether the use of WeBWorK (2010a) as an instructional technology enhanced the mathematics performance of students enrolled in ENGR/ETGR 1201 during the fall of 2008. WeBWorK is an internet-based, open-source software application developed by the University of Rochester. Students complete individualized homework problems online and receive immediate feedback regarding the correctness of their answers. Assignments can be structured to facilitate heuristic problem solving.

Although WeBWorK is used extensively in mathematics courses and in many science courses at institutions of higher education across the country, its use in engineering courses is relatively limited (WeBWorK, 2010b). The software has been used in the Department of Mathematics and Statistics at this institution since 2006 and is believed to have contributed to a reduction in the percentage of students who earn a final course grade of D or F or who withdraw from a course. Thus, the study was designed to answer the following research questions:

1. Is there a difference in the mathematics performance of students who use WeBWorK compared to students who do not use the instructional technology?
2. Is there a difference in mathematics performance of engineering and engineering technology WeBWorK users?
3. Is there a difference in mathematics performance of engineering WeBWorK users and engineering non-WeBWorK users?

Research Design

Students enrolled in ENGR 1201 and ETGR 1201 during the fall semester of 2008 composed the sample for the study. Selected sections were assigned to either the treatment or the control group. The use of a common curriculum and weekly instructor meetings helped reduce inconsistency relative to course content and delivery. Therefore, the primary pedagogical difference between the intact treatment and control groups was the use of WeBWorK. Group assignments were made to further minimize variability associated with instructor delivery styles and/or to facilitate within-group comparisons. Engineering students enrolled in selected sections of ENGR 1201 composed the control group ($n = 106$). The treatment group ($n = 240$) was composed of engineering technology majors ($n = 86$) enrolled in all sections of ETGR 1201 and engineering majors ($n = 154$) enrolled in selected sections of ENGR 1201. ETGR 1201 was assigned to the treatment group because historical data consistently demonstrated that engineering technology students enter college less academically prepared than their engineering peers based on SAT Math scores, freshman year predicted grade point averages (PGPA), and performance on the mathematics placement test. Thus, group assignments also afforded an opportunity to evaluate differences between engineering and engineering technology WeBWorK users and between engineering students who used WeBWorK and those who did not use the technology.

Students in the treatment group completed three WeBWorK assignments not given to students in the control group. These assignments were designed to refresh students' skills in basic mathematics as a means of preparing them for more rigorous engineering mathematics taught in ENGR/ETGR 1201. The first assignment was on fractions, the second was on exponents, and the third was on algebraic equations, with each including about 15–20 problems. They were due on the second, third, and fourth Fridays of the fall semester, respectively, and all were completed online using WeBWorK. Subsequently, three additional mathematics-specific assignments were given to all students in both the treatment and control groups: (1) A standard 1201 mathematics problem set, (2) a circuits problem set, and (3) a structural beam problem set. Unit conversions were included in all three problem sets. The treatment group completed the problem sets using WeBWorK while the control group used hard copies. Two tests and the final exam included selected problems used to evaluate students' performance in engineering mathematics.

Bias associated with incoming academic preparation was reduced by controlling for group differences in PGPA, which predicts the cumulative grade point average at the end of the spring semester of the freshman year. PGPA takes into account prior academic achievement such as high school GPA, high school rank, and SAT score. It is used to make decisions regarding students' eligibility to the university and/or specific academic programs. Studies conducted by the College of Engineering consistently indicate a significant and moderate relationship between PGPA and freshman year academic performance. The PGPA calculations are routinely subjected to statistical testing by the university's Department of Mathematics and Statistics.

Per Institutional Review Board (IRB) requirements, each instructor recorded and maintained his/her students' identifying information and scores on the selected test problems to ensure confidentiality. At the end of the semester, each instructor forwarded the information to Institutional Research (IR) so that it could be integrated with demographic and academic data stored in the university's data warehouse. Identifying information was deleted from the original dataset and replaced with IR codes prior to returning it for analysis to ensure anonymity per IRB requirements. Although differences in group performance were evaluated for two tests administered during the semester, the course final exam was considered the omnibus test.

Participants

At the time of the Fall 2008 census, 472 students were enrolled in ENGR/ETGR 1201. Students for whom PGPA data were not available, such as transfer and international students, were excluded from the study (total n = 106). In addition, students who withdrew from the courses prior to taking the first test were deleted from the dataset (n = 12). Finally, eight other students were excluded from the study because their PGPA was below 2.0, the minimum required for admission to the college. These students often have special circumstances, such as a documented learning disability, that warrant an exception to the admission requirements. Consequently, a total of 346 students composed the sample for this study.

Approximately two-thirds (69.4%) of the participants were in the treatment (WeBWorK) group and almost one-third (30.6%) was in the control (non-WeBWorK) group. The treatment group comprised students from both courses: 64.2% were engineering majors and 35.8% were engineering technology majors. ENGR 1201 sections were assigned to both treatment and control groups: 59.2% of the engineering majors were WeBWorK users and 40.8% of the engineering majors were non-WeBWorK users. All (100%) of the students enrolled in ETGR 1201 were in the treatment group.

Descriptive statistics by grouping are provided in Table 1. Values of *skewness* and *kurtosis* indicate that the assumption of normality was satisfied for all variables. Although box plots revealed evidence of outliers, all cases were retained in the dataset since scores fell within expected ranges. The mean PGPA for all participants was 2.75 (SD = 0.38) with group means ranging from 2.55 to 2.84 (SD = 0.36, 0.38). The minimum PGPA equaled 1.99 and the maximum PGPA equaled 3.79. Consistent with historical data collected by the college, engineering technology students entered college with a lower mean PGPA (M = 2.55, SD = 0.36 versus M = 2.82, SD = .36, respectively) which suggested that they were less academically prepared than their engineering peers. In addition, mean scores for both tests and the final exam indicate that, on average, engineering students performed better than engineering technology students. The mathematics problems on the first and second tests were worth a total of 19 and 50 points, respectively. Some students failed to answer any questions correctly while others answered all questions correctly. The final exam problems were worth a total of 60 points. Scores on the final exam ranged from 5–60 for all participants. Only 311 students took the final exam. Of the 35 students who did not take it, 27 had officially withdrawn from the course.

Method

Analysis of covariance (ANCOVA) is a statistical technique used to reduce systematic bias and within-group or error variance using a covariate or control variable (Stevens, 1999; Tabachnik & Fidell, 2007). Systematic bias occurs when groups differ on a key variable that is related to the outcome or dependent variable. ANCOVA adjusts the group means of

	N	*Mean*	*SD*	*Skew*	*Kurtosis*	*Min*	*Max*
PGPA							
All Participants	346	2.75	0.38	0.40	-0.33	1.99	3.79
WeBWorK Users (ENGR/ETGR)	240	2.71	0.38	0.44	-0.24	1.99	3.79
Non-WeBWorK Users (ENGR only)	106	2.84	0.37	0.39	-0.46	2.05	3.71
ENGR 1201 WeBWorK Users	154	2.80	0.36	0.54	-0.15	2.06	3.79
ETGR 1201 WeBWorK Users	86	2.55	0.36	0.47	-0.66	1.99	3.38
*Test 1 Score (19 pts. Max.)**							
All Participants	335	5.59	4.74	0.66	-0.50	0	19
WeBWorK Users (ENGR/ETGR)	229	4.50	4.29	0.84	-0.28	0	17
Non-WeBWorK (ENGR only)	106	7.92	4.84	0.33	-0.77	0	19
ENGR 1201 WeBWorK Users	144	5.89	4.53	0.44	-0.90	0	17
ETGR 1201 WeBWorK Users	85	2.15	2.49	1.02	-0.09	0	8
Test 2 Score (50 pts. Max.)							
All Participants	316	30.85	13.07	-0.25	-0.86	0	50
WeBWorK Users (ENGR/ETGR)	213	29.85	12.76	-0.09	-0.97	0	50
Non-WeBWorK (ENGR only)	103	32.93	13.51	-0.60	-0.41	0	50
ENGR 1201 WeBWorK Users	142	32.11	12.93	-0.35	-0.82	0	50
ETGR 1201 WeBWorK Users	71	25.31	11.19	0.33	-0.61	5	50
Final Exam Score (60 pts. Max.)							
All Participants	311	38.20	13.64	-0.36	-0.69	5	60
WeBWorK Users (ENGR/ETGR)	208	37.50	13.64	-0.31	-0.81	5	60
Non-WeBWorK (ENGR only)	103	39.61	13.61	-0.46	-0.37	5	60
ENGR 1201 WeBWorK Users	139	38.99	13.76	-0.40	-0.79	10	60
ETGR 1201 WeBWorK Users	69	34.49	12.98	-0.24	-0.77	5	60

Table1. Descriptive Statistics by Grouping

the dependent variable to what it would be if all groups started out equal on the control variable. Random assignment is the best way to eliminate systematic bias within sampling error. Therefore, ANCOVA can reduce but does not completely eliminate systematic bias when using intact groups because participants may be different on other variables not considered. The reduction in error term produced by ANCOVA increases the sensitivity of the *F* test used to evaluate main effects and interactions. In ANCOVA, the covariates are first regressed onto the dependent variable and then group differences relative to the dependent variable are evaluated using a statistical technique similar to an analysis of variance (ANOVA) on the residuals (Garson, 2010; Maxwell, Delaney, & Manheimer, 1985).

Group differences in mathematics performance on selected problems for each of the two tests and the course final exam were evaluated using ANCOVA with PGPA as the covariate. Since three tests were conducted for each group, a Bonferonni adjustment was made to reduce the risk of a Type I error, i.e. $\alpha = .05/3 = .017$. Prior to the analyses, independent *t*-tests with $\alpha = .05$ were used to determine whether there was a significant difference in group means relative to PGPA.

In addition to normality and outliers, data were screened for bivariate linearity, bivariate correlations, homogeneity of variance, homogeneity of regression, and other assumptions germane to ANCOVA (Stephens, 1999; Tabachnick & Fidell, 2007). Correlations between the covariate and each set of grouping variables were evaluated to ensure independence of treatment. Within-group correlations and scatter plots for PGPA versus each outcome variable were examined to ensure appropriate use of the covariate. Levene's test was used to assess the tenability of homogeneity of variance in both the t-tests and ANCOVAs. The assumption of homogeneity of regression was satisfied if the group x covariate interaction was insignificant. Effect sizes for *t*-tests were calculated using standardized mean differences (Cohen's *d*). Effect sizes for ANCOVA were determined using measures of association [partial eta squared (η^2)], which represents the proportion of variation in the outcome that is explained by the covariate or grouping factor. The overall variance explained (R^2) by the corrected model and confidence intervals were also reported for statistically significant group differences. All analyses were conducted using SPSS v. 16.0.2.

Results

Correlations between the covariate, PGPA, and each of the three independent grouping variables were either insignificant (*ps* > .05) or weak (*r* < .31). In general, within-group correlations between covariate PGPA and each of the outcome variables were significant at the .01 level, albeit weak, as coefficients ranged from *r* = .23 to *r* = .33. The only exception was in the case of ETGR 1201 WeBWorK users, where the relationships between PGPA and test 1 and between PGPA and the final exam were not significant (*p* > .05). The assumption of bivariate linearity between the covariate and each of the dependent variables was tenable based on examination of within-group scatter plots. Collectively, these results suggested that the use of PGPA as a covariate could be useful in reducing "noise," i.e. removing extraneous variability, in some but perhaps not all cases.

Research Question #1: Is there a difference in the mathematics performance of WeBWorK and non-WeBWorK Users?

Prior to running the ANCOVA, a *t*-test was conducted to determine whether there was a significant difference in incoming academic preparation between the treatment (*n* = 240) and control (*n* = 106) groups. The mean PGPA for WeBWorK and non-WeBWorK users was 2.71 (*SD* = .38) and 2.84 (*SD* = .37), respectively. The assumption of homogeneity of variance was satisfied based on Levene's test (*p* = .74). On average, there was a significant difference in incoming academic preparation between the groups: *t* = 3.04, *p* = .003, *df* = 344; CI = .05; .22. However, the effect size was small based on Cohen's *d* = .35, which indicates that the difference in group means was equal to about one-third of a standard deviation.

As indicated in Table 2, the assumption of homogeneity of regression was tenable for all three dependent variables based on insignificant group x PGPA interactions (*ps* > .017). Results of Levene's test provided in Table 3 indicate that the assumption of homogeneity of variance was tenable based on an adjusted alpha of 0.17.

Results of the ANCOVA revealed no significant difference in adjusted means on test 2 or the final exam (*p* = .24 and *p* = .54, respectively). However, there was a significant difference in performance on test 1 after controlling for PGPA: *F* = 33.16, *df* = 1, *p* < .01, and partial η^2 = .09. WeBWorK users (unadjusted *M* = 4.50,

Interaction Effects	*Type III Sum of Squares (SS)*	*Degrees of Freedom (df)*	*Mean Square (MS)*	*F Statistic*	*Level of Significance (p)*
Test 1: Group x PGPA	0.34	1	0.34	0.02	.89
Test 2: Group x PGPA	0.87	1	0.87	0.01	.94
Final Exam: Group x PGPA	32.40	1	32.40	0.19	.66

Table 2. Homogeneity of Regression: WeBWorK Users vs. Non-WeBWorK Users

Dependent Variable	*F Statistic*	*Between Group Degrees of Freedom (df1)*	*Within Group Degrees of Freedom (df2)*	*Level of Significance (p)*
Test 1	4.09	1	333	.04†
Test 2	0.38	1	314	.54
Final Exam	0.22	1	309	.64

Table 3. ANCOVA Homogeneity of Variance: WeBWorK Users vs. Non-WeBWorK Users

SD = 4.29) scored significantly *lower* on the first test than non-WeBWorK users (unadjusted M = 7.92, SD = 4.84). PGPA was a significant covariate: F = 31.41, df = 1, p < .01, and partial η^2 = .09. Overall, the model explained 19.0% of the variance in test 1 performance (adjusted R^2 = 18.5%).

Research Question #2: Is there a difference in the mathematics performance of engineering versus engineering technology WeBWorK users?

Results of the t-test revealed a significant difference in mean PGPA between engineering and engineering technology WeBWorK users: t = 5.11, p < .01, df = 238; CI = .15, .34. Levene's test was not significant (p = .93). The mean PGPA of engineering WeBWorK users (M = 2.80, SD = .36) was significantly higher than that for engineering technology WeBWorK users (M = 2.55, SD = .36). The effect size was moderate as evidenced by d = .69.

As indicated in Table 4, the assumption of homogeneity of regression was tenable for all three dependent variables based on insignificant (ps > .017) group x PGPA interactions. Levene's test associated with ANCOVA revealed that the assumption of homogeneity of variance was tenable for test 2 and the final exam based on an adjusted alpha of 0.17. However, the assumption was violated for test 1 as p < .01 as indicated in Table 5.

Heterogeneity of variance inflates Type I errors—that is, rejection of the null hypothesis when it should be retained. Stevens (1999) suggests that the F statistic is robust to unequal variance if the ratio of the largest/small group size < 1.5. In this case, however, the ratio is equal to 1.69 (144/85). When the large variances are associated with the large group, as is also the case here, the F statistic is conservative and, therefore, violation would not be of great concern to many researchers despite a concomitant decrease in statistical power (Stevens, 1999). A conservative F statistic means that the actual α is less than nominal α. However, given Levene's p < .01 and a stringent alpha level of .017, an independent t-test was also run, assuming unequal variances, to evaluate the difference in group means on the first test.

Results of the ANCOVAs revealed a significant difference in adjusted means on test 1 (F = 32.95, df = 1, p < .01, partial η^2 = .13). PGPA was a significant but weak covariate (F = 10.49, df = 1, p = .001, partial η^2 = .04). The latter finding was not unexpected given the insignificant within-group correlation between the covariate and the dependent variable for engineering technology WeBWorK users. However, 21.4% of the variance in performance on test 1 was explained by the model (adjusted R^2 = 20.7%). On average, ENGR 1201 WeBWorK users (unadjusted M =5.89, SD = 4.53) scored significantly higher on the first test than ETGR 1201 WeBWorK users (unadjusted M = 2.15, SD = 2.49). The t-test with unequal variances supported these results: t = 8.05, df = 266.1, p < .01; CI: 2.82, 4.65. The effect size was large as the difference in group means was more

Interaction Effects	*Type III Sum of Squares (SS)*	*Degrees of Freedom (df)*	*Mean Square (MS)*	*F Statistic*	*Level of Significance (p)*
Test 1: Group x PGPA	14.13	1	14.13	0.97	.33
Test 2: Group x PGPA	2.04	1	2.04	0.01	.91
Final Exam: Group x PGPA	62.09	1	62.09	0.37	.55

Table 4. Homogeneity of Regression: ENGR 1201 WeBWorK Users vs. ETGR 1201 WeBWorK Users

Dependent Variable	*F Statistic*	*Between Group Degrees of Freedom (df1)*	*Within Group Degrees of Freedom (df2)*	*Level of Significance (p)*
Test 1	39.37	1	227	< .01
Test 2	4.37	1	211	.04†
Final Exam	0.09	1	206	.77

Table 5. ANCOVA Homogeneity of Variance: ENGR 1201 WeBWorK Users vs. ETGR 1201 WeBWorK Users

than one standard deviation (*d* = 1.07).

There was also a difference in group performance on test 2 ($F = 7.00$, $df = 1$, $p < .01$). On average, engineering WeBWorK users (unadjusted $M = 32.11$, $SD = 12.9$) outperformed engineering technology WeBWorK users (unadjusted $M = 25.31$, $SD = 11.12$). However, the proportion of variation in test 2 performance accounted for by the grouping factor was small (partial $\eta^2 = .03$). PGPA was a significant albeit weak covariate: F = 18.76, df = 1, p < .01, partial $\eta^2 = .08$. Overall, the model accounted for 14.0% of the variance in test 2 performance (adjusted $R^2 = 13.2\%$). There was no difference in group performance on the final exam ($p = .25$).

Research Question #3: Is there a difference in mathematics performance of engineering WeBWorK users and engineering non-WeBWorK users?

There was no significant difference ($p = .34$) in mean PGPA which meant that engineering majors in the treatment ($n = 154$) and control ($n = 106$) groups entered college with similar incoming academic preparation. Levene's test was not significant ($p = .91$).

As indicated in Table 6, the assumption of homogeneity of regression was tenable for all three dependent variables based on insignificant group x PGPA interactions. Homogeneity of variance associated with ANCOVA was tenable for both tests and the final exam based on *ps* > .05, as shown in Table 7.

Results of the ANCOVA revealed a significant difference in adjusted means on test 1 ($F = 10.65$, $df = 1$, $p = .001$) but the effect size was small (partial $\eta^2 = .04$). Engineering majors in the control group outperformed engineering majors in the treatment group. The unadjusted mean score for non-WeBWorK users was 7.92 ($SD = 4.84$) compared to an unadjusted mean of 5.89 for WeBWorK users ($SD = 4.53$). PGPA was a significant but weak covariate ($F = 14.74$, $df = 1$, p < .01, partial $\eta^2 = .06$). Overall, only 9.9% of the variance in performance on test 1 was explained by the model (adjusted $R^2 = 9.1\%$). There were no differences in adjusted group means for either test 2 or the final exam ($p = .83$ and $p = .90$, respectively).

Discussion

Research Question #1: Is there a difference in the mathematics performance of WeBWorK and non-WeBWorK Users?

Non-WeBWorK users entered college better prepared academically than their peers in the treatment group based on PGPA. This difference was also evident from results of test 1, which indicated that non-WeBWorK users significantly outperformed students who used the instructional technology. However, the continued use of WeBWorK throughout the semester, including the three refresher assignments given at the beginning of the semester, did not significantly improve the mathematics performance

Dependent Variable	*Type III Sum of Squares (SS)*	*Degrees of Freedom (df)*	*Mean Square (MS)*	*F Statistic*	*Level of Significance (p)*
Test 1: Group x PGPA	2.80	1	2.80	0.14	.71
Test 2: Group x PGPA	34.86	1	34.86	0.22	.64
Final Exam: Group x PGPA	35.55	1	35.55	0.21	.65

Table 6. Homogeneity of Regression: ENGR 1201 WeBWorK Users vs. ENGR 1201 Non-WeBWorK Users

Dependent Variable	*F Statistic*	*Between Group Degrees of Freedom (df1)*	*Within Group Degrees of Freedom (df2)*	*Level of Significance (p)*
Test 1	0.37	1	248	.54
Test 2	0.43	1	243	.84
Final Exam	0.26	1	240	.61

Table 7. ANCOVA Homogeneity of Variance: ENGR 1201 WeBWorK Users vs. ENGR 1201 Non-WeBWorK Users

of students in the treatment group. Their performance on test 2 and the final exam was not significantly different from non-WeBWorK users even after controlling for PGPA.

Despite these findings, WeBWorK did provide students an opportunity to hone their mathematics skills prior to transferring knowledge to engineering applications. It also facilitated heuristic problem solving as students were required to step through individualized problems and get real-time feedback regarding the correctness of answers. Therefore, it is quite possible that using WeBWorK helped to eliminate the gap in incoming academic preparation between students in the treatment group, approximately one-third of whom were engineering technology majors, and students in the control group, all of whom were engineering majors. Further investigation is needed to determine whether the comparable performance was due to the use of the software as an instructional technology and/or the fact that WeBWorK users were required to complete three refresher assignments.

Research Question #2: Is there a difference in the mathematics performance of engineering versus engineering technology WeBWorK users?

On average, engineering technology majors entered college significantly less prepared academically than their engineering peers based on PGPA. The deficit in incoming academic preparation was also manifested as significant differences in mathematics performance on tests 1 and 2. However, the gap in group performance was reduced after the first test. By the time of the final exam, there was no significant difference in mathematics performance between engineering and engineering technology WeBWorK users. These findings and those associated with research question #1 suggest that the use of WeBWorK may have helped eliminate the gap in incoming academic preparation between engineering and engineering technology majors. They also suggest that WeBWorK may be a viable strategy for all students who could benefit from mathematics remediation.

Research Question #3: Is there a difference in mathematics performance of engineering WeBWorK users and engineering non-WeBWorK users?

The incoming academic characteristics of engineering students in the treatment and control groups were, on average, comparable. On test 1, engineering majors who did not use WeBWorK actually outperformed engineering majors who used the technology, but the difference was too small to be practically meaningful. There was no significant difference between the groups on either the second test or the final exam despite the treatment group's continued use of WeBWorK. These findings indicate that the use of WeBWorK did not enhance the mathematics performance of the engineering majors who participated in this study.

Students' Perceptions of WeBWorK

Four questions related to use of WeBWorK were added to the end-of-semester course survey. Students rated their responses to each of the following items using a Likert scale where 5 = Strongly Agree and 1 = Strongly Disagree.

1. Using WeBWorK helped me refresh my mathematics skills in fractions, exponents, and algebra.
2. Using WeBWorK helped me develop mathematics skills necessary to analyze electrical circuits and beams.
3. WeBWorK is a useful tool for developing engineering mathematics skills.
4. I am more confident in my mathematics skills as a result of using WeBWorK.

Ratings of 4 and 5 (Agree and Totally Agree) were combined to evaluate positive responses. More than half (54%) of the students indicated that WeBWorK helped them refresh basic mathematics skills. More than half (53%) also felt that the instructional technology was useful in developing mathematics skills required to analyze electrical circuits and beams. Almost half (47%) believed that the tool was useful for developing engineering mathematics skills and one-third (33%) of students were more confident in their mathematics skills as a result of using WeBWorK. Thus using WeBWorK may have heightened students' awareness of the gap between their existing level of competency and that required for success in the major.

Limitations of the Study

The most serious limitation is the fact that intact groups were used; that is, students were not randomly assigned to treatment and control groups. In addition, group sizes were unbalanced and the use of PGPA as a covariate was limited in terms of reducing systematic bias and within-group variability. Despite weak correlations ($r < .35$) between the covariate and independent grouping variables, some relationships were greater than the .20 threshold recommended by Stevens (1999). Some covariate-dependent variable relationships were also insignificant.

There was a steep learning curve associated with the use of WeBWorK, both for the instructor who created the assignments and for the students who used it. Initially, answer tolerances were set too low so that unless the answer was within the specified range it was rejected despite the fact that the problem may have been worked correctly. Ultimately, the situation was resolved, but not before it caused considerable frustration among the students.

Some of the instructors offered students extra credit on the first test. Although original performance scores were considered in the analyses reported here, the additional mathematics practice is considered a confounding variable that could have contributed to enhanced performance that helped minimize group differences. In addition, both tests and the final exam included non-mathematical problems, such as concepts and applications related to the engineering design process and project management. The placement of the mathematics problems used as the basis for this study differed on each of the tests. In one case they were at the beginning of the test; in another, they were in the middle of the test. While this may not have unduly influenced performance, future tests will be similarly structured as much as possible to ensure consistency in test-taking. This will help minimize the likelihood of missing or incorrect answers due to test anxiety and/or fatigue.

Four of the five sections that composed the control group were reserved specifically for students who participated in the College of Engineering Freshman Learning Community (FLC). FLC students live in a common residence hall, take classes and study together, and, of course, socialize. Previous studies have shown that although FLC students are more likely to be retained in the major after their first year of college than their non-FLC peers, the academic performance of the two groups is comparable. Therefore, it is not clear what role, if any, participation in the FLC may have had on results of this study.

Finally, a conservative adjustment to alpha was made to reduce the risk of a Type I error (i.e. rejecting the null hypothesis when in fact it should be retained). Such an approach has the adverse effect of increasing a Type II error due to reduced power (i.e. failing to detect a difference in group means when in fact one may exist). Power is also a function of sample size. Examination of p values in Tables 2–7 indicates that levels of significance (p values) exceeded .05 in all but two cases, in both of which p = .04. Consequently, a less stringent alpha level would not have produced different results unless $\alpha > .04$.

Next Steps

Enrollment in ENGR/ETGR 1201 during the fall semesters is traditionally more homogeneous than during the spring semesters. In the fall, enrollment is restricted to College of Engineering majors who are also enrolled in the co-requisite mathematics courses. The majority of the class is composed of traditional-age new freshmen matriculating from high school. In the spring semester, however, enrollment is open to new freshmen, new transfer students, and non-College of Engineering majors who enroll in the co-requisite mathematics courses. College of Engineering majors who were not eligible to take the course in the fall because they did not satisfy the mathematics co-requisite and students who have to repeat the course because they did not earn a grade of C or better also register for the course in the spring. Thus, a follow-up study using spring semester enrollment is planned. Further investigation is also needed to determine whether use of WeBWorK as an instructional technology and/or the refresher assignments contributed to improvements in the mathematics skills of less academically-prepared engineering technology majors.

Conclusions

The purpose of this study was to investigate differences in mathematics performance of three intact groups of students: WeBWorK users versus non-WeBWorK users, engineering WeBWorK users versus engineering technology WeBWorK users, and engineering WeBWorK users versus engineering non-WeBWorK users. By the end of the semester, there was no significant difference in mathematics performance between treatment and control groups and between engineering WeBWorK users and engineering non-users. However, results suggest that WeBWorK helped eliminate the gap in incoming academic preparation between engineering and engineering technology users. Feedback from students also indicates that WeBWorK is a valuable tool for refreshing basic mathematics skills and for enhancing mathematics self-confidence.

The literature substantiates the critical relationship between students' beliefs about their mathematics performance and their persistence in the major. This study found that deficiencies in mathematics skills can be ameliorated through the use of WeBWorK. Thus the technology may be a viable strategy for reducing mathematics anxiety, improving proficiency, enhancing mathematics self-confidence, and improving retention of college freshmen.

Finally, the open-source software may be adapted to individual course needs. Once a bank of tested WeBWorK problems is available, there is minimal cost associated with its continued use. The technology allows problems to be structured to facilitate heuristic problem solving. It also allows students to complete individualized homework problems and receive immediate feedback regarding the correctness of their answers. Therefore, from a pedagogical and fiscal perspective, there is sufficient justification for its continued use in ENGR/ETGR 1201 and in other College of Engineering courses, particularly since typical online course management systems do not have the functionality to generate individualized assignments.

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