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# A Comparison of Web-Based and Paper-and-Pencil Homework on Student Performance in College Algebra

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# A Comparison of Web-Based and Paper-and-Pencil Homework on Student Performance in College Algebra

**Abstract:** College algebra fulfills general education requirements at many U.S. colleges. The study reported here investigated differences in mathematics achievement between undergraduates in college algebra classes using one of two homework methods: *WeBWorK*, an open-source system for web-based homework (WBH), or traditional paper-and-pencil homework (PPH). We assessed learning for 439 students in 19 college algebra classes at a large public university in the United States. Twelve classes used WeBWorK and seven had traditional paper and pencil homework. Analysis of covariance revealed no significant differences in algebra performance or achievement gain by homework group, ethnicity, or gender when statistically controlling for previous mathematics achievement. Results support the conjecture that WeBWorK is at least as effective as traditionally graded paper and pencil homework for students learning college algebra in moderately sized lecture-based classes.

**Keywords:** computer algebra systems, college algebra, web-based homework

## 1 INTRODUCTION

Web-based homework is an internet-based accessory to mathematics and science learning that is gaining popularity in the U.S. To date, the most growth in, and research on, web-based homework systems at the college level has been in large lecture-based courses [8, 9, 27]. As in an earlier report, in this study the focus was on smaller lecture-based settings, moderately-sized college algebra classes of 30 to 40 students [14].

Key factors in learning include mastery of pre-requisite skills, quality of instruction, and amount of academic instructional time - including time spent on homework [16]. The importance of homework, especially for the advanced cognitive development expected in high school and college mathematics, has already been established by many individual and meta-analytic studies [5, 6, 17, 39]. However, it is clear from the research that homework is necessary, but not sufficient, for achievement on exams [28, 29]. To examine the potential for shifting skill-building from traditional paper and pencil homework assignments to web-based homework, this study compared college algebra achievement gains, measured by common exams, in two randomly assigned groups: web-based homework and paper and pencil homework.The web-based tool used was WeBWorK.

## 2 THEORETICAL FRAMEWORK

The educational perspective behind the development of WeBWorK, and this study, is constructivist: understandings are mental structures assembled, linked, and modified by a learner. Such construction is generated by interaction with information, ideas, and processes. The "constructing" involves acquiring knowledge of conventions (e.g., facts), concepts, and the relationships among them [37, 38]. Web-based homework may facilitate acquisition and structuring. However, we acknowledge that web-based homework is only a support tool. By no means is homework a replacement for interactions between teacher and student or peer and near-peer group work. What WeBWorK does do is replace the unevenly implemented pedagogical interaction of graded homework with simple and rapid feedback.

Within the liberal arts tradition at U.S. colleges, the primary purpose of homework in college algebra is to foster development of a robust collection of algebra skills and concepts. The method for achieving this goal has customarily been through separate practice with facts and concepts. Exercise sets in most college algebra textbooks offer drill practice with facts followed by practice with application and synthesis of concepts.

In many texts an exercise set ends with mildly non-routine problems aimed at generating cognitive disequlibrium and encouraging deeper reflection on concepts and their relationships. For a variety of reasons, from pressure to "cover" certain chapters to the personal epistemologies of students and instructors, the practice in college algebra teaching in the U.S. is to assign problems mostly from the first two categories (drill and application). Though there are efforts to rewrite college algebra textbooks along the lines of the reform of calculus in the U.S. [18], this study was situated in a traditional setting and investigated a web-based perturbation to that traditional setting.

Given the research on achievement differences related to ethnicity, gender, and class status in the U.S., it may be that students from family cultures or socio-economic situations where computers are less common might be at a disadvantage if web-based homework is substituted for paper and pencil homework [3, 4, 33, 36]. Our analysis made use of the available proxy variables in registrar data to explore this idea. Also, educational research on student affective issues, particularly mathematics anxiety, suggests that attention be directed towards these concerns in designing, collecting, and analyzing data. Finally, the role of the instructor in achievement differences is an important consideration [1, 39]. The results reported here are from the quantitative analysis of categorical variables: homework group, ethnicity, and gender. A phenomenological report on instructional style and student perceptions and reactions to the use of web-based homework has been published elsewhere [14]. A limitation of the study is that no socio-economic classification data were collected, though in the phenomenological study we did investigate a proxy measure: student access to and comfort with computers and the internet.

## 2.1 Research Questions

In this quantitative-focused investigation of the impact of the web-based homework interface WeBWorK on college algebra learning, we asked the following questions:

1. Did students in both the web-based and paper and pencil homework groups have a statistically significant gain from pre- to post-test score? That is, did the students in both groups learn college algebra in ways effectively measured by the instrument?
2. When statistically controlling for pre-test scores, were there significant main effect differences in post-test scores depending on homework group, ethnicity, or gender?
3. Were there any interaction effects between or among homework group, ethnicity, and gender on scores (pre, post, and gain)?

## 2.2 *WeBWorK*

WeBWorK is an open-source, non-proprietary web-based homework interface developed and refined at the University of Rochester [9, 32, see also webwork.maa.org]. It uses problem libraries to generate similar but individualized problems for each student. Course management capabilities of the program include: (a) detailed statistical information on individual student and whole-class progress, (b) adjustable due dates for individuals and groups, (c) group email lists for a class, and (d) exporting of grade data to spreadsheet programs. In the semester of this study, instructors incorporating WeBWorK into their courses rarely used (a) - (c) but did make use of grade exporting. None of the instructors modified items or added WeBWorK activities beyond the assigned homework (e.g., none used authoring features in WeBWorK to import or create items).

For students, WeBWorK provides immediate "correct" or "incorrect" feedback. The WeBWorK interface as used in this study did not correct a student's errors or give hints. It only let users know whether or not they had submitted a correct answer. WeBWorK program defaults for the study allowed students to try again (offering a prompt to try a similar problem). Students were encouraged by instructors and the information on the WeBWorK site to seek help from a fellow student, a tutor, or the instructor when stuck on a problem. They could do this in person or by email (there was a feedback button to generate email built into the WebWorK interface - see Figure 1).

It is possible to program into WeBWorK the capacity to give hints based on the type of wrong answer. However, for the college algebra classes discussed here, the question of interest was whether or not "correct"/"incorrect" feedback accompanied by the retry option were sufficient to achieve the goal of reducing instructor homework grading load while still encouraging student homework efforts and maintaining course achievement.

Students signed on to the WeBWorK server from any internet-connected computer. They could download and print out the full assignment problem set. Students entered their solutions into WeBWorK through a text window using standard computer algebra software syntax (see Figure 1). After the

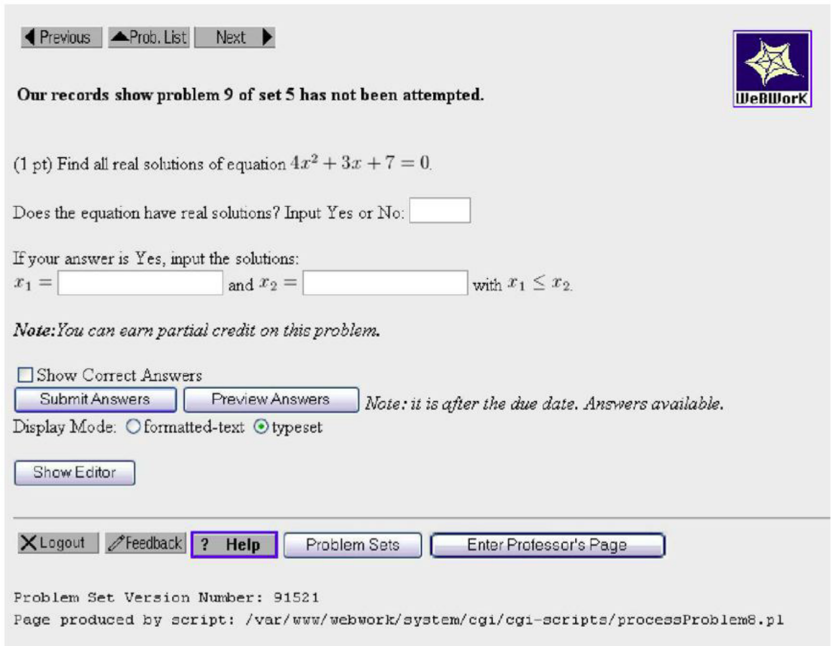


**Figure 1.** Screen shot of a homework problem on solving a quadratic equation requiring mathematical notation in the second part of the answer.

due date, students could go back and review their submitted homework and view correct answers. Students could also re-work old assignments as a form of review for exams.

## 3 METHODS

Every semester the college algebra course at the site of the study, we'll call it Big Public University (BPU), enrolls between 600 and 800 students in moderately sized class sections of fewer than 40 students each. An additional 200 to 300 students enroll in large lecture sections of 100 or more students each (not included in this study). The moderately sized class sections are taught by lecturers with advanced degrees (Ph.D. or master's) or by Graduate Teaching Assistants who are working towards master's degrees in mathematics.

One of BPU's primary missions is the preparation of schoolteachers. Overall, the university student body is 64% women and 36% men though the first-year class in the year of the study was 70% women and 30% men. Made up mostly of first-year students, the college algebra enrollments in this study were close to this balance at 69% women and 31% men.

In the semester of this study, 644 students enrolled in 19 moderately sized college algebra sections. Of these students, 532 (84%) completed the course while the other 112 (16%) dropped or withdrew. Of the 532 who finished the course, 378 passed it with A (19%), B (28%), or C (24%). Another 59 students (11%) had D grades. That is, of the 644 who originally enrolled, 378 had a grade of C or better, a 59% pass-rate. Though slightly higher than the national average pass-rate in college algebra of 57%, this pass-rate was typical of the institution (Mathematical Association of America, 2004). Due to late additions, absences, and drops, complete data were available for a sample of 439 students, 83% of those who finished the course. By homework group, students' scores were available for 302 (84%) of the WBH and 137 (81%) of the PPH students who completed the course. Although the sample contained more women (72%) than men (28%), this may be attributed to the institution's entering class averages.

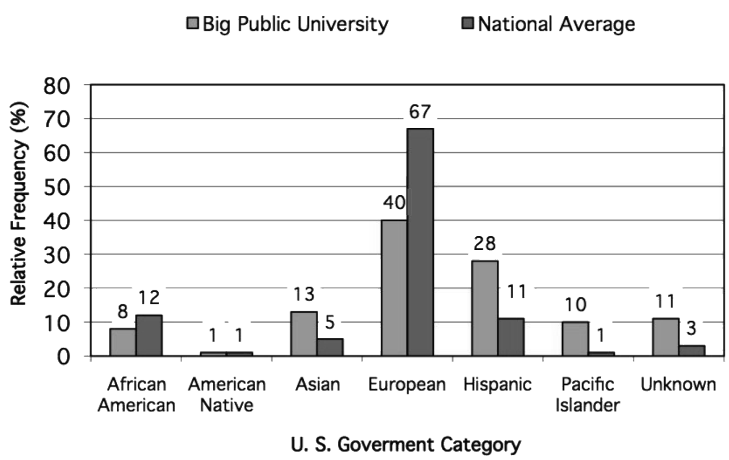


**Figure 2.** Percentage of enrollments by U.S. government assigned demographic groups.

### 3.1 Student Participants

The population of students at U. S. public universities is diverse. The light bars in Figure 2 show the distribution of students in this study at BPU by U.S. government identification category (these percentages are also representative of university-wide enrollment trends at BPU). For comparison, the dark bars give U.S. national enrollment percentages [25]. Though the student population at BPU was more diverse than the national average, the BPU distribution was representative of the projected U.S. post-secondary demographics for 2060 [7].

### 3.1.1 Instructor Participants

Two years after WeBWorK was first introduced at BPU, and one year after a pilot study, the current study began. Assignments among the 19 moderate-sized sections of college algebra (taught by 15 different instructors) were initially random with 10 WBH and 9 PPH classes. However, within the first two weeks of the term two instructors switched to WBH. Nonetheless, each of the three instructors who taught multiple sections of the course had at least one PPH section and one WBH section In the end, 12 WBH sections were taught by 11 instructors and enrolled 408 students. For PPH, 7 sections were taught by 7 instructors and enrolled 236 students. Four of the 15 college algebra instructors were Graduate Teaching Assistants (GTAs) working on their master's degrees in mathematics (1 man, 3 women) and had little to no college teaching experience. Nine were instructors with master's degrees who already had some experience teaching college algebra (7 men, 2 women), and two were male Ph.D. lecturers in mathematics. Table 1 summarizes the preparation and experience of the instructors in the study (all names are pseudonyms).

**Table 1.** Profile of WBH and PPH Class Instructors.

| **WBH only** | Degree at start of the study | Years Teaching College | Years Teaching Algebra |
|---|---|---|---|
| Ms. Degree | M.S. | >10 | >5 |
| Mr. Ellipse | M.S. | >10 | >5 |
| Dr. Functional | Ph.D. | >10 | 3-5 |
| Mr. Graphic | M.S. | >5 | 3-5 |
| Mr. Helix | M.S. | 3-5 | 3-5 |
| Mr. Inch | GTA | 3-5 | 3-5 |
| Ms. Join | GTA | <1 | <1 |
| Ms. Kite | GTA | <1 | <1 |
| **WBH & PPH** (#sections) | | | |
| Mr. Angle (1W, 1P) | M.S. | 3-5 | 3-5 |
| Mr. Basis (2W, 1P) | M.S. | 3-5 | 1-3 |
| Ms. Cone (1W, 1P) | GTA | <1 | <1 |
| **PPH only** | | | |
| Dr. Radian | PhD | >10 | >5 |
| Mr. Saddle | M.S. | >10 | >5 |
| Ms. Torus | M.S. | >10 | >5 |
| Mr. Undo | M.S. | 1-3 | 1-3 |

## 3.2 Data Gathered

The primary data forming the basis of this report were pre- and post-test scores, and registrar-supplied student preparedness information (SAT-Math and SAT-Verbal scores), demographic information, and course completion information. Data were for all moderate enrollment college algebra classes at

BPU in the Fall term of the study year.

A 25 item multiple-choice paper and pencil test over college algebra content was administered in the first and last weeks of the term in all 19 classes. The same test was used both times. Students recorded their choices on digitally scanable answer sheets. The BPU course coordinator for college algebra and the WeBWorK implementation supervisor developed the test. A panel of five expert college mathematics instructors established its face and content validity and the test was piloted in the Fall term in the year before being used for this study.

For the WBH group, WeBWorK itself stored an impressive collection of data on the homework done within the program. These included which problems were attempted, how often, with what level of success, over what time span. Analysis of the try-retry data for web-based homework sessions is the topic of another study.

### 3.3 Procedure

The college algebra problem library programmed into WeBWorK for the study was made up of exercises selected from the textbook used by all sections of the course [35, permission was obtained from the author and publisher]. Advanced WeBWorK functionalities like animations and multiple graphs were not used. The college algebra course coordinator determined a list of suggested homework exercises, organized by textbook section, and provided it to the PPH and WBH instructors and to the WeBWorK problem library programming team. The focus of the study was direct replacement. The problem sets were offered to instructors as pre-sets to minimize the effect of instructor learning about making assignments in WeBWorK. This is a notable condition of the study - we did not attend to instructor-learning for using WeBWorK "from scratch." Many pre-selected WeBWorK problem sets that are aligned to particular textbooks are available in WeBWorK, though their use varies and instructors often trim or enhance the sets to personalize to their own classroom context.

The problems that students had for homework were essentially the same across the two groups. Instructors did report spending some time in WeBWorK (for most instructors, less than 30 minutes per week) assigning problems. Most WBH instructors chose the default set of items that had already been identified, just as most PPH instructors used the coordinator-provided list. In some weeks, some WBH instructors edited the set (reducing the the number of items) just as PPH instructors edited the coordinator-provided list, choosing fewer items for their own instructional reasons. This study did not investigate this decision-making on the part of instructors.

Each WBH and PPH instructor used at least 80% of these problems in assignments that were due weekly on a day and at a time determined individually by each instructor. Though no data was collected from PPH students on their homework practices, we did gather information from PPH instructors about homework completion and found that the majority of homework was done outside of class time and, among instructors who collected homework papers, an average of 75% of PPH students regularly turned in their paper and pencil homework assignments . Students in WBH courses completed their

WeBWorK outside of class on a home computer or at one over 500 computers available on-campus in labs and in the library. According to the WeBWorK audit-trail, 78% of students regularly did their WeBWorK assignments.

### 3.4 Analysis

To answer the research questions, data analyses were conducted using SPSS, a common statistical software package. A paired $t$-test was conducted for each homework group (WBH and PPH) and for the combined sample to answer the first research question about whether the test indicated college algebra learning had occurred. The hypothesis was that the students in each group (WBH and PPH) would have significantly higher scores on the post-test compared to their pre-test scores. A three-way Analysis of Covariance (ANCOVA) was conducted to answer the second research question about differential learning gains between WBH and PPH groups when controlling for a variety of demographic variables. We generated several null hypotheses for the analysis related to the three research questions, these are presented in Table 2; numbering indicates the related research question. The mathematics education and homework literature offers justification for each of these hypotheses. For $H_1$ and $H_{2a}$ the driving reason was Cooper's [5] call for ensuring relative comparability of treatment and control groups. Concern about the influence of societal factors, particularly those aspects encoded in data as ethnicity and gender, prompted the choice and wording of $H_{2b}$, $H_{2c}$, and $H_3$ [33].

**Table 2.** Null Hypotheses Tested.

| | |
|---|---|
| $H_1$: | Student achievement was the same (no gain) from pre- to post-test regardless of homework group (WBH or PPH). |
| $H_{2a}$: | Statistically controlling for pre-test scores, student score gain as measured from pre- to post-test was the same regardless of homework group (WBH or PPH). |
| $H_{2b}$: | Statistically controlling for pre-test scores, student score gain was the same regardless of ethnicity. |
| $H_{2c}$: | Statistically controlling for pre-test scores, student score gain was the same regardless of gender. |
| $H_3$: | Statistically controlling for pre-test scores, there were no significant interactions among homework group, ethnicity, and/or gender. |

## 4 RESULTS

Before conducting the primary analyses to answer the research questions, we examined the attrition between the two homework groups. Due to late additions, absences, and drops, of the 532 students completing the course there were 464 (87%) pre- and post-test pairs composed of 291 (86%) WBH students' data and 173 (89%) PPH students' work. Though the drop-rate in the WBH courses (13%) was slightly lower than in the PPH courses (18%), the difference was not statistically significant ($z = -0.39$, $p = .348$).

A thorough investigation of the relationship between homework and achievement should control for preparedness [5]. Students in the two groups were statistically equivalent in terms of previous preparation as measured by SAT mathematics and verbal scores.

### 4.1 Did students in both groups learn algebra? Yes.

We used paired $t$-tests to answer the first research question, regarding the increase in student achievement after instruction in college algebra. Analysis consisted of the paired $t$-tests for the WBH and PPH groups as well as the combined sample, the results are presented in Table 3. There were significant differences between pre-test and post-test scores for each analysis: $t(302) = 17.41$, $p < .0005$ for the WBH group, $t(137) = 11.86$, $p < .0005$ for the PPH group, and $t(439) = 21.09$, $p < .0005$ for the combined group. Therefore, $H_1$ was rejected. That is, each group scored significantly higher on the post-test than on the pre-test. These results indicate that achievement in college algebra was significantly higher after the course than as students entered the course, which was expected.

**Table 3.** Paired $t$-test Results for Performance Differences by Group.

| | | Pre-test | | Post-test | | |
|---|---|---|---|---|---|---|
| Group | $N$ | $M$ | $SD$ | $M$ | $SD$ | $t$ |
| WBH | 302 | 10.59 | 4.03 | 15.23 | 4.30 | 17.41* |
| PPH | 137 | 9.50 | 3.11 | 14.16 | 5.08 | 11.86* |
| Combined | 439 | 10.25 | 3.80 | 14.91 | 4.43 | 21.09* |

* $p < .0005$

### 4.2 Was score gain different between the two groups? No.

A comparison of mean scores by ethnicity indicated some differences among demographic subgroups, but additional three-way ANCOVA tests indicated they were not homework-group dependent (Table 4). That is, there was a large mean difference between the scores of students identified in registrar records as belonging to "Asian/Pacific Islander" demographic categories (e.g., student self-reported Chinese, Japanese, Korean, Hawaiian, Filipino, Samoan, and/or Vietnamese affiliation) and those identified as "Hispanic" (e.g., student self-reported Chilean, Mexican, and/or Puerto Rican affiliation), but this difference also existed within homework groups.

The ANCOVAs summarized in Table 4 were conducted to answer the research questions regarding differences in student achievement based on demographic information. The variables in the analyses were the three independent variables (a) homework group (PPH or WBH), (b) ethnicity, and (c) gender, along with the covariate (pre-test scores), and the dependent variable (post-test scores).

The statistically significant result for the pre-test in Table 4, $F(1, 415) = 70.92$, $p < .0005$, indicates that the pre-test is a viable covariate of the post-test in the analysis. However, there were no significant main effect differences on post-test scores after statistically controlling for pre-test scores for homework group, ethnicity, and gender. Thus, analysis resulted in failing to reject $H_{2a}$, $H_{2b}$, and $H_{2c}$.

**Table 4.** Three-way Analysis of Covariance by Group, Ethnicity, and Gender; Statistically Controlling for Pre-test Scores.

| Source | *SS* | *df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|
| Pretest | 1178.47 | 1 | 1178.47 | 70.92 | .000 |
| Group | 38.12 | 1 | 38.12 | 2.29 | .131 |
| Ethnicity | 163.78 | 5 | 32.76 | 1.97 | .082$^{\dagger}$ |
| Gender | 8.05 | 1 | 8.05 | 0.48 | .487 |
| Group×Ethnicity | 105.29 | 5 | 21.06 | 1.27 | .277 |
| Group×Gender | 0.35 | 1 | 0.35 | 0.02 | .885 |
| Ethnicity×Gender | 470.48 | 5 | 9.50 | 0.57 | .722 |
| Group×Ethnicity×Gender | 23.15 | 5 | 5.79 | 0.35 | .845 |
| Error | 6896.35 | 415 | 16.62 | | |

It should be noted in Table 4, for testing hypothesis $H_{2b}$ on ethnicity, results approached significance ($p < .10$). For the most part this was due to the large mean difference, noted above, between students identified in "Asian/Pacific Islander" categories and those in "Hispanic" categories.

### 4.3 Was there interaction among group, ethnicity, and/or gender? No.

As is noted above and summarized in Table 4, we explored for possible interactions among the three independent variables on post-test scores when controlling for pre-test scores. ANCOVA results showed no significant interactions and we failed to reject $H_3$. These results indicate that achievement in college algebra was statistically significantly higher post-course than pre-course, regardless of demographic or homework group variables.

## 5 DISCUSSION

### 5.1 Influence of WeBWorK in College Algebra Learning

The main result of the study in comparing post-test achievement between WBH and PPH groups was that there was no significant difference in performance. The two homework groups began in essentially the same place with no significant differences in scores between homework groups on the pre-test, and ended, as groups, about the same. As a result, web-based homework appears to be at least as effective as paper and pencil homework for students in moderately sized lecture-based sections of college algebra.

It is important to point out that no statistically significant interaction of ethnicity by group or gender by group was found, indicating that any ethnicity- or gender-correlated differences in performance were independent of the student's being in a particular homework group. That is, it seems that whatever may be culturally biased in the structure or processes of college algebra, the use of WeBWorK does not appear to significantly exacerbate or diminish it.

### 5.2 Benefits and limits of WeBWorK

Unlike internet auto-tutorials, discovery learning modules, or electronic communication by instructors about individually graded homework, the web-based homework of WeBWorK investigated here does not openly conflict with traditional direct instruction or lecture methods of classroom teaching nor does it take a large amount of instructor time [11, 24, 27, 41]. This is both good and bad. The simplicity of WeBWorK is good in that the likelihood of its adoption by traditional college instructors is increased. This is particularly so if it is seen as a tool to eliminate the grading of large numbers of undergraduate mathematics homework papers. It may be bad, however, in that WeBWorK does nothing explicitly to challenge the notion widely held by many undergraduates and instructors that learning, particularly in college algebra, is a matter of habituation in skill practice rather than construction of personal knowledge structures rich in conceptual connections to previous learning [19, 20].

It is clear from work to date on human-computer interactions that computers have a mediating effect on learning, particularly in mathematics, different from that of other learning environments [15, 21]. What is also clear from the results presented here is that substituting WeBWorK for paper and pencil homework in lecture-based college algebra instruction does not appear to hinder student performance (as measured by the common paper and pencil tests). While it would be beneficial if web-based homework actually improved student performance, the simple use of the interface for this study is unlikely to lead to such a result. Nonetheless, WeBWorK may be used by college instructors to make their grading load more manageable and it appears to be at least as effective as paper and pencil homework for most students.

One shortcoming of web-based homework is that though student and teacher can know quantitatively how the student is doing from their WeBWorK score, there is no qualitative information for the instructor to use in helping a student construct conceptual understanding. WeBWorK does not have a qualitative feedback mechanism (it just is not designed that way) that provides what other evaluation methods can.

### 5.3 Learner-centered use of instructor grading time

While it is true that computer-based learning environments can act as catalysts for change in the perceptions students have of themselves as learners, such change is by no means automatic or persistent after a single semester course [27, 41]. The benefit of delegating the masses of skill practice for which homework is viewed useful to a web-based interface is that it allows instructors the flexibility to spend what would have been homework grading time on alternative forms of feedback that may be more beneficial to students. An instructor can choose additional formative and summative assessments to support the growth of students' intellectual autonomy in learning mathematics. If understanding is constructed by learners, then such construction can be facilitated through interaction and co-evolution of both the skill-practice available through an interface like WeBWorK and through assignments that help students build rich conceptual scaffolding to give context to their skills [30]. Some possible alternative methods for instructional interaction with students reported in the literature are projects [10], concept-based quizzes [31], and writing exercises of various types [2, 12, 13, 34]. We note here that instructors in our companion qualitative study demonstrated effective use of concept-based quizzes [14].

### 5.4 Future work

Several areas of research around web-based homework hold great promise. First and foremost, replications of the study reported here are necessary. Additionally, qualitative exploration of student and instructor views in the context of web-based homework is needed. The authors have made a first step in this direction [14]. As with any curricular innovation, it is important to discover how the intended curriculum is implemented, received, and activated for students. That is, what happens in classroom and other instructional interactions as the innovation is used? How is student engagement affected? Is student learning, performance, or persistence in mathematics modified? How? Investigation of these questions at other levels (e.g., secondary school) would also be valuable since web-based technology is likely to become ubiquitous in K-12 schools.

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