Comparison of Student Performance Using Web and Paper-Based Homework in College-Level Physics

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Received 25 March 2003; Accepted 21 April 2003

Abstract: Homework gives students an opportunity to practice important college-level physics skills. A switch to Web-based homework alters the nature of feedback received, potentially changing the pedagogical benefit. Calculus- and algebra-based introductory physics students enrolled in large paired lecture sections at a public university completed homework of standard end-of-the-chapter exercises using either the Web or paper. Comparison of their performances on regular exams, conceptual exams, quizzes, laboratory, and homework showed no significant differences between groups; other measures were found to be strong predictors of performance. This indicates that the change in medium itself has limited effect on student learning. Ways in which Web-based homework could enable exercises with greater pedagogical value are discussed. © 2003 Wiley Periodicals, Inc. J Res Sci Teach 40: 1050–1071, 2003

Web-based homework is a rapidly growing educational use of the Internet. At least a hundred thousand U.S. students currently submit their homework for computerized grading over the Web while attending real (nonvirtual) classes, and the practice is also growing rapidly in math, chemistry, and other sciences.[1] In addition to this are students enrolled in on-line courses and those who use on-line practice quizzes and the like. ‘‘Anytime, anywhere’’ computerized systems which instantly mark answers right or wrong and then allow errors to be corrected are replacing traditional paper homework handed in during class, graded by the instructor or an assistant, and returned with marks and comments days to weeks later.

Homework is an important component of introductory physics instruction at the college level. Introductory algebra- and calculus-based physics courses at the college level put a great emphasis on the ability to solve problems. Specifically, these are word problems requiring students to find a numerical quantity using given information and applying one or more physics formulas. All the widely used textbooks devote significant space to examples of how to solve these types of

Contract grant sponsor: Spencer Foundation; Contract grant sponsor: National Science Foundation; Contract grant number: 9714546.
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DOI 10.1002/tea.10120
Published online in Wiley InterScience (www.interscience.wiley.com).

problems and contain a large number of these problems at the end of each chapter for the student to work as exercises. A significant portion of exams in most classes—if not the entire exam—consist of these types of exercises, and many instructors devote a significant amount of class time to demonstrating how to work such problems. The ability to solve these problems requires skills in identifying the physics involved in the particular situation, combining the appropriate physics equations, and working out the math: skills that generally require practice to develop and master. Even reformed courses coming out of educational research continue to give importance to these types of word problems; e.g., between a third and half of the homework questions in the guided-discovery laboratory curriculum *RealTime Physics* (Sokoloff, Thorton, & Laws, 1999) are quantitative problems of the standard type. In a typical physics lecture, students are only in class for 3 hours a week, so the homework component of the course becomes the place in which most students practice solving these exercises. An early implementation of computerized homework in a large physics course (Hudson, 1983) reported a dramatic reduction in the number of dropouts from the course. This is reflected in faculty views of the importance of homework. Interviews with a number of physics instructors (Henderson, 2002) found that they all ‘‘believed that the best way for students to learn how to solve physics problems is by trying to solve physics problems.’’ A discussion thread entitled ‘‘Value of Homework’’ ran from October 31, 2002, to November 6, 2002 on PHYS-L (PHYS-L, 2001), a listserve to which over 600 physics instructors belong. Despite the title, none of the 16 postings questioned the value of homework in physics instruction. Several writers explicitly stated that they view ‘‘homework as essential to learning,’’ and the discussion focused on instructional techniques to get students to complete significant amounts of homework efficiently (from the instructor's perspective). Because homework is one of the most important components of introductory physics instruction, the means of assessing and giving feedback could influence student learning and success.

The type and amount of feedback provided have an important role in learning skills such as physics problem solving. A meta-analysis of many different studies (Walberg, Paschal, & Weinstein, 1985) observed that homework that was graded or commented on had a large positive effect on student learning, whereas homework without feedback had only a small effect on student learning. The most significant pedagogical difference between paper homework and Web-based homework is the type of feedback. In the ideal case, students will turn in paper homework in one class and receive it back from the instructor in the next class session, with each student's solution to each problem evaluated not only for the correct final answer but also for proper use of physics equations, needed diagrams, correct solution method, mathematics, and units, along with written comments and corrections to help students learn from their mistakes. The reality of instructor work loads means that this ideal is usually not achieved: The instructor takes a week or more to return the papers, grading is handed off to a student assistant, few comments are made, only the final numerical solution is checked, and/or only a subset of the problems is actually graded. Web-based homework generally grades only the final numerical answer and only tells the student if it is right or wrong, but it evaluates all problems and responds almost immediately, and students have an opportunity to review their own work and correct a submission. Paper-based homework allows the instructor to require students to provide a complete systematic solution and to evaluate and comment on the process as well as the final number. On the other hand, Web-based homework provides immediate feedback, which could help keep students from practicing incorrect methods, and allows them to work in a mastery mode. The relative merits of the two types of feedback have been a subject of discussion among university physics teachers. In fact, shortly before the first study of this project, the course instructor expressed the belief that writing out complete solutions would lead to better problem-solving skills, whereas the author of the Web homework system expressed the belief that the immediate feedback would be more valuable.

From a pedagogical standpoint, paper and Web-based homework offer a tradeoff between limited but immediate feedback on numerical answers allowing students to learn from their own mistakes, and more complete but delayed feedback on complete solutions allowing students to learn from the instructor's comments and corrections. Of course, there are other potential benefits of using the Web, including using the latest technology for instruction, reducing the grading burden on faculty and assistants, being able to grade all student work, and reducing costs by using computers instead of grading assistants. Subscription to a Web homework service for a large introductory course can cost significantly less than the pay and benefits for a human grader.[2] Potential drawbacks of using Web-based homework include a lack of detailed feedback to students, the danger of multiple submissions encouraging lazy habits, and further impersonalization of the course by replacing a human grader with a computer. The motivation and intended audience of the present study are twofold. First, the change in the nature of feedback that students receive—which has been shown in other areas to be a key factor in the effectiveness of homework for student—could have significant ramifications for student learning in one of the key components of introductory physics courses. Our goal was to compare actual practices carefully in a fairly typical instructional setting, so that the results of this research could be directly applied to the setting of most university-level physics instruction. Many practicing physics instructors have expressed beliefs about the appropriateness of Web homework, and this work will provide data on the subject. Second, the medium of Web-based homework, with immediate feedback, HTML elements, and scripts running on the Web server, opens up a whole realm of different types of homework exercises not possible with paper-based work, such as incorporating multimedia (Christian & Titus, 1998), interactive tutorials (Reif & Scott, 1999), and using artificial intelligence methods for more detailed feedback (Conati & VanLehn, 1999). However, as clearly pointed out by Weller (1996), it is important from a research standpoint clearly to distinguish learning gains due to different pedagogical methods, quality of instructional materials, and time-on-task from learning gains resulting from a change in technology and intrinsically associated practices. By comparing traditional physics courses using traditional physics exercises, we will be able to isolate effects due to the computer interaction and immediate feedback from more innovative uses of these systems. The present work will address the need to evaluate the effect of the change in practice and feedback on student practice in learning problem solving, and provide a baseline to allow future research on innovative uses of Web-based work to distinguish gains due to technology from improvements materials and underlying pedagogy.

This work comparing Web-based homework and paper-based homework in multiple courses at a large state university will focus on student performance and quantitative measures of student learning as a function of how they did their homework. For the purposes of this article, Web-based homework consists of assignments delivered, collected, and graded over the Internet through a Web-based homework system, and which forms the homework component of a standard course. A Web-based homework system is a service that (a) can be accessed from any standard browser and Internet connection, (b) password authenticates the user, (c) delivers assignments to students and receives their answers, (d) grades student work automatically, and (e) keeps a permanent record of student scores which the instructor can access at a later time. A few of the currently available systems that meet this broad definition of Web homework systems include WebAssign, CAPA, Homework Service, OWL, Tychos, WebCT, Blackboard, and WWWAssign (Blackboard, 2001; CAPA, 1999; Hart, Woolf, Day, Botch, & Vining, 1999; Mallard, 1999; Martin, 1997; Moore, 1997; Stelzer & Gladding, 2001; WebAssign, 1998; WebCT, 2000). Computer-based homework is a more general term for any type of homework graded by a computer, including Web-based homework. Paper-based homework is the more traditional method of students working out their solutions on paper, turning these in for grading (perhaps superficially, perhaps in-depth), and, after a delay of a few days to a few weeks, receiving the papers back with written comments. We focused on courses in which the instruction took place in real (nonvirtual) classrooms and where the assignments consisted of standard exercises (i.e., the kind found at the end of the chapter of the physics textbook). Note that the subject of this article is more limited than much of the work in computer-aided instruction (CAI). Here we are dealing with the situation in which instruction is provided by regular classes and/or textbooks, and the computer is simply used for further practice of already learned material. Good CAI is a pedagogical strategy that uses a technological medium, which can be delivered by Web homework systems. However, this work looks at actual practice and compares the effect of the medium using the same pedagogical content and strategy, differing only in aspects intrinsic to the medium—i.e., quality and timeliness of feedback.

In a typical Web-based homework system, students log on using a password through the Internet to a central Web server, select one or more assignments, and receive those exercises. Figure 1 shows a screen shot of such an assignment. In many cases the numerical exercises are randomized, so each student assignment has a unique set of numbers. Depending on the system and the individual, students could work through the exercises while seated at the computer or they may obtain a printed copy of the exercises to work out elsewhere. After determining the answers, students will then submit their solution, which is most commonly a numerical result or one option from a multiple choice list, but could also consist of selecting multiple options in a list, entering a symbolic (algebraic) answer, typing in a word or a short essay, or uploading a file. In most cases, the computer immediately evaluates the answers, gives the student some level of feedback, and may allow reworking and resubmission of the assignment depending on how the instructor has set options. The instructor is able to handle administrative details, create assignments and questions, and review or download student scores and responses. Some systems have additional features such as chat rooms, instructor notes, calendars, and other features. A detailed overview of Web-based homework systems may be found in Titus, Martin, and Beichner (1998).

The roots of computerized homework systems in physics go back at least to the PLATO system (Sherwood, 1971) using then current technology, moving from mainframes with terminals or punch cards (Connell, 1994; Taylor & Deever, 1976) to personal computers and local networks (Abbott, 1994; Milkent & Roth, 1989) to the Internet and World Wide Web (Kashy et al., 1993; Moore, 1997; Raineri, Mehrtens, & Hübler, 1997; WebAssign, 1998). This development has paralleled instructional technology advances in math, chemistry, and engineering (Barker, 1997; Connolly, 1972; Graham & Trick, 1997; Hart et al., 1999; Kohne, 1996; Maron, Ralston, Howe, & Townsley, 1999; Morris, 1982; Porter & Riley, 1996; Spain, 1996; Steinley, 1986; Woolf, Hart, Day, Botch, & Vining, 2000; Yaney, 1971). Studies almost invariably report positive reactions to computerized homework (Connell, 1994; Jones & Kane, 1994; Kashy et al., 1993; Ory, 1997; Taylor & Deever, 1976). Students like the immediate feedback and being able to resubmit assignments, whereas their instructors like not having to grade student work manually. However, research on the instructional effectiveness of computerized collection of student work in physics and other subjects is limited and often inconclusive. Few of the preceding articles mention an evaluation other than an end of semester survey of student opinions. A search was done on the ERIC and Academic Premier databases using the key word *homework* plus various combinations of W*orld Wide Web*, *computer*, *electronic*, *science*, *physics*, and *mathematics*, and then combined with a similar searches on the on-line archives of the *American Journal of Physics* and the publications of the Association for the Advancement of Computing in Education, including *Journal of Computers in Mathematics and Science Teaching*. Combined with a few other papers known to the authors, this resulted in identifying 45 journal and conference papers by other authors describing the use of computers for homework in math, science, and related courses. Of these, 25 were in introductory physics courses, 11 in chemistry, 4 in mathematics, and 5 in engineering. All

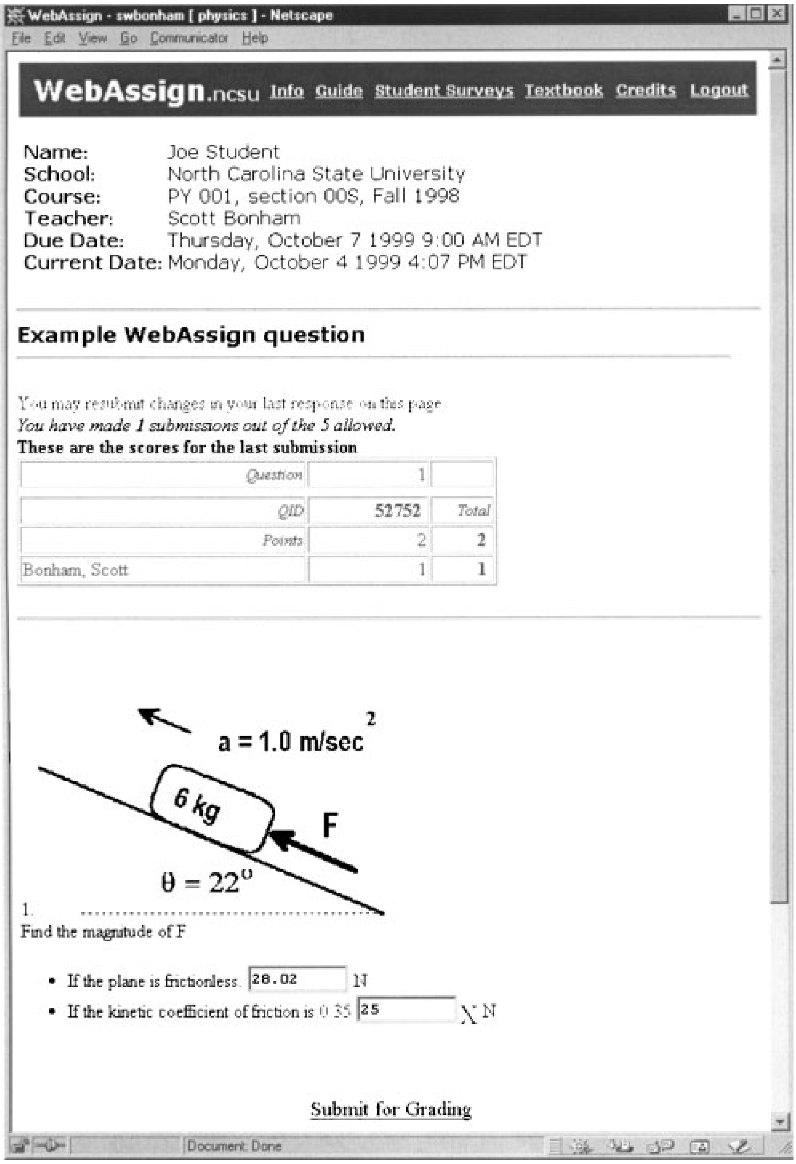


Figure 1. Screen shot of student page in WebAssign. Some numbers, such as the coefficient of friction in this example, are randomized so students get different numbers. This is signaled by the randomized numbers being red (in printed form this appears gray). Assignments usually consist of more than one question.

of the engineering papers merely described a system or included student feedback on surveys. This was also the case for all but one of the mathematics papers. That paper described an introductory statistics course in which a section using a drill program written by the instructor performed better than a section working on standard textbook problems (Porter & Riley, 1996). The program was also used in mastery mode and gave fairly extensive feedback. One of the papers in chemistry compared Web-based work with a built-in tutor to Web-based work without it (Woolf et al., 2000). The rest merely described systems and student responses. Nineteen of the 25 journal or conference papers in physics describe a system and/or include student responses on surveys. Two papers described studies comparing students in a typical classroom to ones using programmed learning CAI to supplement or replace the standard course (Marr, 1999; Weiss, 1971), and one evaluated tutorials using two-way coaching between students and computers (Reif & Scott, 1999). All three reported improved student performance for those using computers, but they also involved differences in pedagogy, significant effort in development of the computer-based materials, and perhaps increased time-on-task between the two groups. One of the remaining three papers found that student performance improved in a course after Web-based homework was introduced (Woolf et al., 2000), although it is not clear how—or if—homework was graded in the non-Web course. A study using large introductory physics lecture sections compared students using the PLATO system with those who did not (Jones, Kane, Sherwood, & Avner, 1983) and found that students using PLATO performed better on the final exam than those who did not. However, other factors were not well controlled because the instructors were different (the lecture for the PLATO section was the author of many of the PLATO modules), the PLATO section received computerized supplemental instruction, and the only PLATO section submitted homework and received feedback on it. The most carefully designed study found compared two physical science classes, about 40 students each, taught by the same instructor (Milkent & Roth, 1989). One section completed homework with a BASIC program developed by one of the authors and the other did the same work on paper. On most measures little or no difference was found between sections. As the reader may be aware, physical science courses are generally survey courses involving limited math and less of the problem solving that is a major part of typical introductory physics courses. In the limited research where there was strict replacement of traditional homework with computerized grading, the effect was not large enough to be significant given the limited statistics, and in the cases where a difference was found it could potentially be attributed to differences in instruction, content, and/or time on-task.

After the initial submission of the manuscript for this article, another significant article on this subject was published (Dufresne, Mestre, Hart, & Rath, 2002). This work compared student performance over several years in large introductory physics courses, including both calculus-based and algebra-based courses, and four different instructors who had taught courses with both paper-based and Web-based homework using the OWL system. The study used an ex post facto analysis of course data and was not a carefully controlled experiment like the present work. Student exam scores for a given instructor in a given course generally improved at a significant level after the introduction of Web-based homework. Before the use of Web-based homework, student homework may have been partially graded (e.g., 3 problems out of 15), worked on in recitation sections, or not collected at all. Students using Web-based homework reported spending significantly more time on assignments than did those using paper homework. The OWL system also works slightly different than the system used in this study; students submitting wrong answers were given feedback that included help with a solution strategy, and then were given a slightly different problem to solve and resubmit.

The current literature does not really answer questions being raised about computerized homework, Web-based or otherwise. Homework is important in technical courses such as introductory physics, where problem solving is a major focus and homework is the main venue for practicing this. Many students struggle to develop problem-solving skills in physics (Maloney, 1994), although directed instruction and feedback has been shown to be effective (Heller & Reif, 1984; Heller & Hollabaugh, 1992). In this article we will look at the following questions:

- Does one medium (Web or paper) lead to better conceptual understanding?
- Does one medium help students develop better problem-solving skills?
- Does one medium lead to differences in other aspects of the course, such as laboratories and seeking out help with exercises?

Method

To answer these questions, we carried out side-by-side comparisons of student performance in multisection, large enrollment introductory physics courses. This investigation was carried out at North Carolina State University (NCSU), a land-grant institution with a large population of engineering students. The research method was a quasi-experimental design in which an instructor who was assigned to teach two lecture sections of the same course agreed to cooperate with the investigators. One of the paired sections received their homework via WebAssign where it was graded by a computer. The other section wrote out solutions to homework exercises on paper. These exercises were turned in and graded by a full-time (15–20 hours/week) graduate student grader. This is a far more thorough grading effort than often provided in large introductory physics classes; before development of the WebAssign homework system, NCSU instructors were provided roughly 5 hours/week of student grading help. This would have been enough to grade one or two problems in an assignment but not all of them. The paired sections met in the same lecture hall in adjacent time slots. Students registered for the two different sections through the standard course registration system and were unaware of the homework method until it was announced the first day of class. During the first few weeks of the semester they were able to switch into other sections if they wished. (There were no reports of anyone switching sections solely because of the homework arrangement.) Students had a 2-hour laboratory every other week which was taught by teaching assistants (TAs) who reported to the laboratory coordinator and not directly to the course instructors. Laboratory sections were not coordinated with lecture sections, so a laboratory section would have students from different lecture sections, and vice-versa. The on-campus Physics Tutorial Center (PTC) offered drop-in tutorial assistance by its staff of graduate and upper-level undergraduate physics students, as well as providing a library of instructional software and videos. The university also provided a peer-instruction program known as Supplemental Instruction sessions, in which an advanced undergraduate student would be assigned to a particular course, would take notes in lectures, and then host regular sessions outside of class where students could get help. We carried out this experiment two times: once in the first-semester calculus-based physics course and then in the first-semester algebra-based physics course. Because the two experiments were very similar in methods and results, we will present them in parallel in their respective sections.

Experiment 1

The first investigation took place in Spring 1999 in the first-semester calculus-based physics, an on-sequence semester for Introductory Engineering students. This course typically has 400–900 students enrolled in any given semester. There are multiple lecture sections of 80–110 students, taught by different instructors. During the semester of the study there were 5 additional sections taught by other instructors, for a total of 7. The population is primarily students in the engineering sequence, and the course covers the topics of kinematics and dynamics, rotational motions, oscillations, and waves. A course coordinator sets the syllabus, makes the default homework assignments (which few instructors change) and writes the common exams for all the students. The textbook for the class was *Fundamentals of Physics, 5th ed.* (Halliday, Resnick, &

Walker, 1997). There were four common tests during the semester, constructed by the course coordinator. These consisted of 15 multiple choice questions and a worked-out problem broken into several parts, accounting respectively for 75% and 25% of the total points. Homework and laboratories each counted 10% of the final course grade, the four mid-term exams combined for 56%, and the cumulative multiple choice final exam for 24%. Nearly all of the assigned homework problems were from the textbook. The Web section received the standard WebAssign homework assignments made by the course coordinator that were given to all the other sections. The department had previously switched to Web-based homework for this course, so in this study the paper section is technically the treatment group, and the Web section the control. The professor, an experienced instructor who makes teaching his main focus, spent the majority of class time working problems similar to homework exercises and material on the exams. Many days there would be a time during class when students worked for 5–10 minutes in self-selected groups on one or more exercises. The classes met Monday, Wednesday, and Friday, with the paper-based section immediately after the Web-based one. The WebAssign section generally had three weekly assignments due at 11:30 p.m. on class days, typically consisting of two or three standard physics problems from the text. The paper section submitted paper homework once a week, usually at the end of class on Friday. These students were asked to write solutions that included (a) identifying the information given in the problem, (b) a drawing, (c) a layout of the solution (the formulas), (d) the solution complete with units and significant figures, and (e) a check for reasonableness. All problems were graded by a graduate student who spent up to 20 hours each week grading, including checking individual parts of problems. Figure 2 gives an example of grading. Homework was returned through drop-off boxes at the PTC, which is located adjacent to the room where the students conducted their laboratory exercises. Most of the exercises on which the two groups worked were the same (or in a few cases, similar) problems from the text and had the numerical answers in the back of the book. The Web section also received via WebAssign an old exam as a practice test before each midterm test. This was not distributed to the paper group but old exams were readily available on the course website and in test packs from the bookstore. The paper group also turned in answers to a few conceptual exercises on each assignment, which the Web students could submit on paper for a small amount of extra credit.

Experiment 2

To test whether the results observed with the calculus-based course could have been influenced by the small difference in assigned exercises, the use of a non-native English-speaking grader, or the particular population, we repeated the experiment in an algebra-based physics class in Fall 1999. The first-semester algebra-based course has approximately 200–400 students per semester, taught in sections of 60–90 students by multiple instructors. It covers the same topics as the calculus-based course and is predominantly populated by biology and allied health science students. Unlike the calculus-based course, there were no shared exams, common syllabus, or homework for all sections of the algebra-based course. In addition to the paired sections that participated in this study, there were three other sections of the course taught by other instructors, which will not be discussed here. As in the first experiment, students registered for the course with no knowledge of the homework policy, which was announced the first day of class. Students were able to register for a different open section if they chose to do so. The Web and paper sections met during adjacent class periods on Tuesdays and Thursdays. Most weeks there was a quiz given in class with one or two problems similar to a homework exercise, on which complete written out solutions were required. These quizzes were open book and open notes. Students were able to recover up to half the points lost on the quizzes by going to the PTC to rework the quiz and

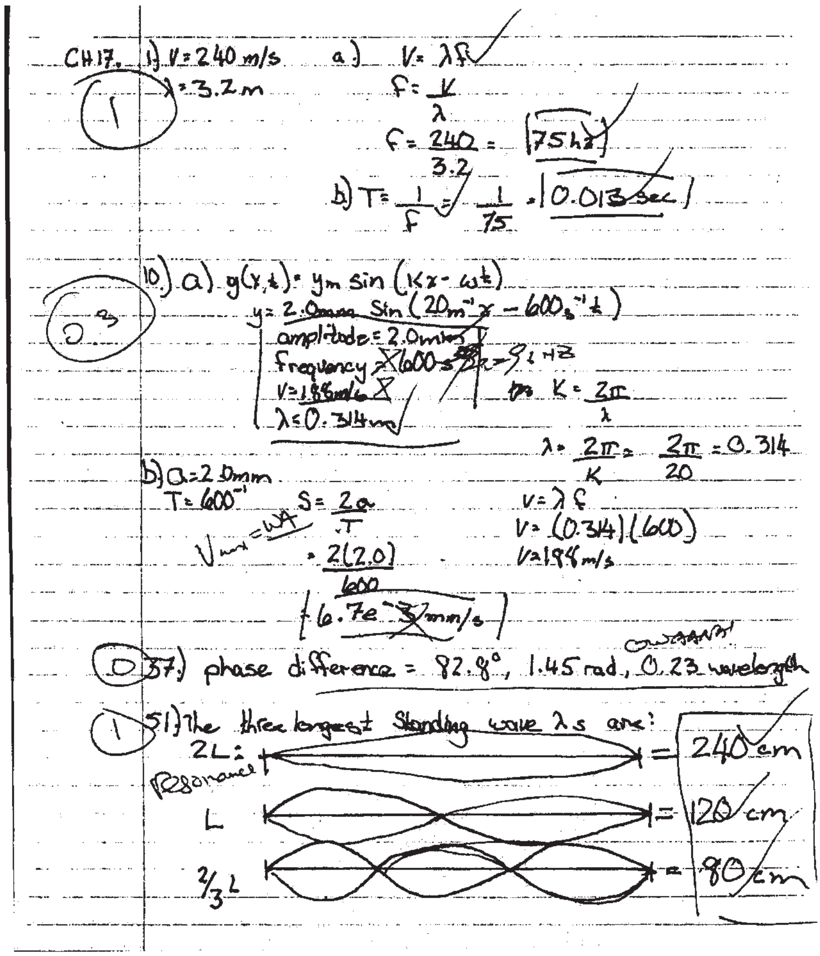


Figure 2. Example of grading from calculus-based course. The grader checked different parts but did not write a lot of comments. (English was not his native language.)

complete several additional problems. Three multiple choice exams during the semester were written by the instructor. Quizzes counted for 40% of students' grade, laboratories for 10%, homework for 9%, tests for 40%, and 1% for simply logging into the instructor's fairly extensive website. The main focus of the instructor's activity during the lectures was working through the assigned homework problems, frequently leaving the final numerical calculations for the students. Although the department had designated *College Physics* (Serway & Faughn, 1999) as the official text, the instructor chose not to tie the course closely to any particular textbook, and so wrote all of the homework exercises in the style of typical end of chapter problems. The assignments consisted of 10–12 exercises each week, and usually several of the problems were multistep. Most of the problems were numerical but some multiple choice and essay questions were also used. An example of one of the problems can be seen in Figure 1. Assignments were made available to all students through the course website, delivered via WebAssign to the Web section, and handed out in printed homework packets-one problem per page-during class in the paper section. Both sections received the same weekly assignments (e.g., Figures 1 and 3) which were due once a week

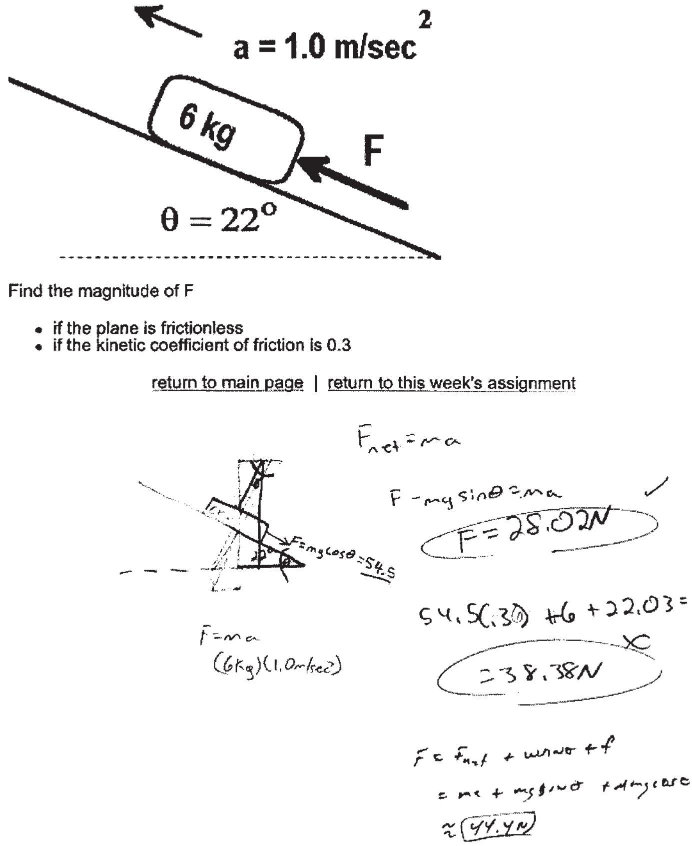


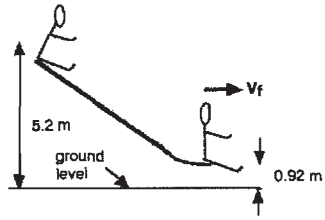
Figure 3. Example of grading from algebra-based course. This grader gave more feedback. In this case, it appears that the student made a calculation error. Note that this is the same exercise as Figure 1.

at nearly the same time. For a number of years this instructor had not collected homework in either electronic or paper form because of a lack of grading help. Difficulties with the Web system at the beginning of the course caused the due time for the assignment to be pushed back several times in the first few weeks, finally being fixed at 9 a.m. Thursday morning for both sections. Students in the paper section were required to show work on the paper assignments, which were graded by hand and returned in class 1–2 weeks later. The TA for this section was an American physics graduate student who did a thorough job of grading, including giving positive as well as negative feedback. Figure 3 shows an example of grading. At the beginning of this particular semester the WebAssign service experienced technical difficulties which made the system sluggish and unresponsive for several weeks. There were also some errors in coding the answers to the instructor-written problems owing to the short lead-time available, so the first students to work the problems sometimes found exercises marked incorrectly before the problem was discovered and fixed. As a result, the instructor and many of the Web homework students developed a negative attitude toward the system over the course of the semester. Although not done deliberately, the circumstances of the two investigations span a range of implementation scenarios, with the calculus course possibly biased more favorably toward the Web-based section while the algebra course ran much smoother for the paper-based section (Fig. 4).

Show your work in the spaces provided. Start calculations with equations in symbols, substitute numbers with units and box your answers. No credit is given for answers without justification.

Part I. A child of mass 50 kg slides down a playground slide starting from rest. Treat the child as a particle.

(A) Calculate her initial gravitational Potential energy at the top. Take the zero of PE at ground level.



(B) Calculate her final gravitational potential energy at the bottom. Take the zero of PE at ground level.

(C) State the principle of conservation of mechanical energy **in symbols** and **write out** the meaning of each symbol used.

(D) Use conservation of mechanical energy to calculate her final speed, V_f, neglecting friction.

Part II. Supposed that with friction, her final speed is 6.1 m/s.

(E) Calculate her **final mechanical energy** at the bottom and determine the **work done by friction.**

Figure 4. Complete exam problem. Student solutions on Part II were analyzed for differences in solution style.

Results

Experiment 1

We collected data on test performance, homework scores, laboratory scores, a pre/post conceptual test, use of the PTC, and in-class survey and interviews. Scores and responses on the multiple choice part of the test were obtained from the course coordinator and worked-out problems such as shown in Figure 4 were photocopied before they were returned to students. The Force and Motion Concept Exam (FMCE) (Thornton & Sokoloff, 1998) was administered to all students in the course—including those in this study—in their laboratory sections at the beginning and end of the semester. Students received extra credit for participating but it was not required; most students participated at the beginning and about half of all students participated at the end. The multiple choice FMCE probes conceptual understanding of physics, particularly the degree to which students hold to Newtonian as opposed to non-Newtonian beliefs. The values reported here are raw (percent correct) scores on this test. The university registrar provided grade point average (GPA) and scores on the Scholastic Aptitude Test math section (SATM). The FMCE pretest provides a measure of previous physics understanding from formal or informal learning, the GPA a measure of general academic achievement, and the SATM a measure of mathematics skills. Improvement between pre- and posttests provides a measure of conceptual learning, whereas test homework scores provide measures of problem-solving ability. In this work we will primarily use the simple, traditional definition of problem-solving ability: the ability to obtain the correct answer to a standard physics problem by any legitimate means.

Data from the different sources were compiled together, and students who did not complete the course were removed. Completing the course was defined as those who received a final grade

Table 1
Comparison of background and performance measures in the calculus-based physics course

Measure	Web Section			Paper Section			*t* Test	
	N	Mean	*SD*	*N*	Mean	*SD*	Score	*p*
GPA (A = 4.0)	110	3.11	0.61	108	3.01	0.68	1.16	.25
SAT math score	111	639	81	109	632	69	0.68	.50
FMCE pretest (%)	98	26.5	15.8	95	26.1	16.2	0.02	.99
Homework average[a]	117	87.9	22.7	112	72.7	32.5	4.13	<.0001
Test average	117	75.4	13.1	112	73.3	13.9	1.18	.24
No. MC questions correct	105	11.7	2.0	105	11.2	2.3	1.53	.13
Written question points[b]	105	20.2	3.7	105	18.9	4.2	2.21	.03
FMCE gain (%)	60	18.9	24.3	38	20.1	28.6	0.06	.95
Lab average	117	84.9	17.2	112	84.3	14.2	0.23	.78

Note. Mean, standard deviation, and results of two-tailed *t* test assuming unequal variances. GPA, SAT, and FMCE data were not available for all students. Conflict exam data are included in test average but not MC questions and written questions.
[a]Score on final submission for Web section, only submission for paper section.
[b]The two sections had different graders for the written part of the exam.

(did not withdraw) and took at least one exam. There were a total of 117 students (35 women) in the Web section and 113 students (20 women) in the paper section. Table 1 summarizes the comparison between the Web and paper sections, using two-tailed *t* tests. Because not all background information was available for all students, the *N* is smaller for some items. GPA, SATM, and FMCE pretests give background information on the students and allow us to judge how well-matched the paired sections were. From these measures, we can see that the section doing Web-based homework entered at a slightly higher academic level, but in no category was the difference significant at the $p < .05$ (95% confidence) level, so the sections were relatively well-matched.

The remaining portion of Table 1 compares student performance data. Homework average is the actual homework score obtained divided by the total possible points. The Web students were allowed to resubmit problems without limit until the deadline, and their score represents their final (not necessarily best) submission. The paper students were able to submit only once but their score includes partial credit. The Web students in the calculus section also had three short assignments a week; the paper group had a single, longer assignment. It is therefore not surprising that in the calculus course the Web students had a higher homework score. The calculus course had four midterm tests and a cumulative final. The tests had 15 multiple choice questions and a multipart written question that was graded by graduate students. The final was entirely multiple choice. The majority of the questions were one-step or two-step physics calculation problems with some conceptual problems mixed in. The average reported here is the average of the four tests and the final, with the final having twice the weight of a midterm test. MC questions are the average number of multiple choice questions a student got right on the regular midterm exams. (Makeup exams for students who could not attend the common exam time were scored differently and were not available.) Written questions are the average score on the written section of the regular midterm exams. There is a statistically significant difference between the treatment and control groups on the written questions at $\alpha = .05$, which will be explored further below. The astute reader may notice that the *t* test statistic for both the MC questions and written questions is higher than the statistic for the test average. The difference between the two sections on the final, which is not included in the first two items, was small. In the calculus course the FMCE was given again at the end of the semester (as part of a different study) and about half of the students participated. A gain ratio can be calculated (Hake, 1998) for students with both pre- and posttest scores:

$$g = \frac{\text{Posttest} - \text{Pretest}}{100\% - \text{Pretest}}.$$

Because the principle difference between the sections was feedback on numerical problems, which do not always correlate well to conceptual understanding, we did not expect a significant difference, as is seen. We also did not expect significant differences between student laboratory scores because this grade was based on laboratory reports, as is also seen. The only measure that may indicate a significant difference between the groups is the written questions, which we will look at further here.

To see whether this difference resulted from differences in instruction, a regression analysis was carried out on written question scores, which were worth 25 points. We performed a hierarchical regression, first using the background factors of GPA, SAT math scores, scores on the FMCE pretest, and whether the student had paper homework (the treatment). Table 2 summarizes this analysis. GPA, SAT, and FMCE were strong predictors of performance on the written questions, accounting for nearly half the variance and with p values of $<.0001$, whereas homework method was insignificant. In a second step, homework scores, gender, and minority status were added in. Of these additional factors, only homework average made a significant contribution, but even so its contribution to the model, as measured by the standardized coefficient β, was much less than that of GPA, SAT, or FMCE. Table 3 shows a similar result for the average number of multiple choice questions correct on a test. This shows us that the difference seen in the *t* test results for the written questions is attributable to preexisting differences between the groups—e.g., math skills, previous knowledge of physics, and general academic level of student—and not from the difference in how homework was done.

An additional question is whether there were differences in skills related to problem solving not reflected in the exam scores. One concern about computer-based homework is that it further

Table 2
Summary of hierarchical regression analysis for variables predicting score on written part of exam in the calculus-based course

Measure	*B*	*SE B*	β	*p*
Step 1				
Intercept	−0.45	2.08	−0.02	.83
GPA	2.57	0.39	0.41	$<10^{-9}$
SAT math score	0.016	0.003	0.53	$<10^{-6}$
FMCE pretest	0.063	0.015	0.25	$<10^{-4}$
Paper class	−0.16	0.44	−0.01	.71
Step 2				
Intercept	−1.26	2.15	−0.05	.56
GPA	1.73	0.42	0.28	.00005
SAT math score	0.016	0.003	0.51	$<10^{-5}$
FMCE pretest	0.069	0.015	0.28	$<10^{-5}$
Paper class	0.30	0.44	0.01	.49
Homework average	0.04	0.01	0.16	$<10^{-4}$
Male	0.11	0.52	0.00	.83
Minority[a]	−0.87	0.86	−0.03	.31

Note. $N = 172$. For Step 1, $R^2 = 0.47$ ($R^2_{adj} = 0.46$). For Step 2, $R^2 = 0.53$ ($R^2_{adj} = 0.51$).
[a]A member of an underrepresented minority: African American, Hispanic, or Native American.

Table 3
Summary of hierarchical regression analysis for variables predicting score on multiple choice part of exam in the calculus-based course

Measure	*B*	*SE B*	β	*p*
Intercept	−1.96	1.01	−0.13	.05
GPA	1.28	0.21	0.34	$<10^{-8}$
SAT math score	0.011	0.002	0.59	$<10^{-10}$
FMCE pretest	2.97	0.72	0.20	$<10^{-4}$
Paper class	0.28	0.22	0.02	.20
Homework average	0.017	0.005	0.12	<.0005

Note. $N = 172$; $R^2 = 0.60$; $R^2_{\text{adj}} = 0.59$.

reduces the incentive for students to write systematic solutions to communicate clearly and avoid mistakes: work step by step, write explanations, work algebraically, keep track of units, and so forth. Could the paper-based group, because of the extra practice in writing complete solutions on homework, have developed better habits in the mechanics of writing solutions that did not make a significant difference on these particular exams? One way to measure the mechanics of a solution would be simply to count the number of key elements of each. Every mathematical step will almost always involve writing an equal sign, so the number of equal signs would be a measure of the number of mathematical steps written down in the solution, as would the number of numbers and variables. Similarly, the number of words written is a measure of how much written explanation is given, the number of variables a measure of the amount of algebraic work, and the number of units a measure of use of units.

Photocopies of all solutions to the written part of the exams were available, so we could look for differences in the mechanics of student solutions. We decided to analyze Part E of the written section of the second exam quantitatively. This exercise is reproduced in Figure 4. This exercise was chosen because it is a multistep exercise and involves core ideas of velocity, force, and energy, so a well-organized solution can be helpful in solving it successfully. Furthermore, this was the second exam, so students were already familiar with the exam format. The number of words, excluding words appearing as a subscript of a variable, were counted as well as the number of equation signs. Also counted were the total number of variables written, number of numbers (excluding obvious arithmetic calculations in margins), and number of units. Students were explicitly instructed to box the two final numeric solutions, so number of answers boxed or circled were also counted (Table 4). We observed no significant differences at $\alpha = .05$ and only boxing the

Table 4
Comparison of numbers of elements in student solutions to last written exam question on second midterm test

Count of	Web Section		Paper Section		*t* Test	
	Mean	*SD*	Mean	*SD*	Score	*p*
Words	2.6	4.5	2.3	5.0	0.41	.68
Equation signs	7.4	3.7	7.5	3.3	−0.20	.84
Variables	11.7	6.8	12.2	6.4	−0.53	.60
Numbers	11.4	4.8	12.0	4.7	−0.08	.42
Units	5.5	3.6	6.1	4.8	−0.88	.38
Answers boxed	1.1	0.9	1.3	0.8	−1.68	.09

Note. Solutions where nothing was written or student did not take the regular midterm test were excluded, leaving a total of 82 solutions from the Web section and 78 solutions from the paper section.

answer was significant at $\alpha = .10$, arguably the least important part of the solution. Even being required to write out complete solutions every week did not appear to have changed paper-based students' solution habits.

In summary, the only measurable differences in quantitative performance measures between students working their homework on paper and those working their homework in the Web-based computer system are directly attributable to differences in the populations themselves and not to the treatment. The only exception is homework score, but the difference in the number of times they were able to submit their work means that this measure is not really comparable between groups. The substitution of human-graded paper homework for computer-graded Web homework made no measurable difference in student learning.

Experiment 2

Most of the same data were collected in the algebra-based physics course. Data were collected from the instructor on student performance on quizzes, exams, homework, and quiz makeups. Selected background data on students were obtained from the university registrar. On two of the homework assignments, students were also given a short survey about homework, and augmented data on use were obtained from the PTC. No coursewide FMCE testing was done that semester. Students not completing the course were removed from the analysis, leaving 64 students (37 women) in the Web section and 56 students (35 women) in the paper section. Table 5 summarizes these data. As in the case of the calculus-based course, the Web-based section had higher GPA and SAT math scores. We cannot tell to what extent the tendency of better students to be in the Web section was due to the type of homework, to being scheduled earlier in the day, or to random fluctuations.

The algebra course had three (noncumulative) tests during the semester which were entirely multiple choice, and weekly open-book quizzes consisting of written problems closely related to the homework exercises for that week. The same grader marked quizzes in both sections in the algebra course. Quiz reworks refers to the number of times students used the policy that they could rework quizzes with additional exercises to earn half of the missed point on a particular quiz. The t test comparisons showed a significant difference ($p < .05$) in the test scores but not in the quiz scores. As was done in the first experiment, this will be further explored to determine whether this

Table 5
Comparison of background and performance measures in the algebra-based physics course

Measure	Web Section		Paper Section		*t* Test	
	Mean	*SD*	Mean	*SD*	Value	*p*
GPA[a]	3.19	0.79	2.96	0.49	1.52	.13
SAT math score[a]	596	76	571	64	1.9	.06
Homework	65.0	26.8	62.5	20.1	0.57	.57
Test average	84.2	17.5	77.3	14.3	2.35	.02
Quiz average	6.3	2.0	5.8	1.1	1.57	.12
Quiz reworks	2.3	2.2	2.9	2.4	−1.61	.11
Lab[b]	81.6	13.9	81.7	15.0	−0.04	.94

Note. Mean, standard deviation, and results of two-tailed t test assuming unequal variances. Except as noted, $N_{web} = 64$ and $N_{paper} = 56$.
[a]Data not available for 6 students, so $N_{web} = 58$.
[b]One student was exempt from lab, so $N_{web} = 63$.

difference is directly attributable to the instructional method. It is also noteworthy that, unlike the experiment in the calculus-based physics course, the homework scores did not differ significantly in this case. A number of factors may have contributed to this lack of difference: Both sections had a long homework assignment each week, the instructor substantially worked many of the homework problems in class before they were due, and Web students experienced technical frustrations with the system.

As in the case of the calculus-based course, a linear regression analysis was performed on the test and quiz performance data from the algebra class. We undertook a hierarchical analysis for test performance, first including GPA, SAT, and type of homework. In the second step, homework average, gender, and minority status were included (Table 6). Once again, GPA and SAT math scores were strong predictors of performance, whereas type of homework and minority status were insignificant. Table 7 summarizes a regression analysis on quiz scores. As seen in the first experiment, student ability as demonstrated by GPA and SAT math scores was a strong predictor of test and quiz scores. Homework average made a smaller contribution, and the homework medium did not make a significant difference.

Discussion

We have carried out a detailed study comparing the use of paper and computer homework in two different introductory physics courses. The two quasi-experiments involved two different populations of students, one consisting of primarily engineering students of whom a majority were male, and the other largely allied health majors and other sciences, of whom a majority were women. The experiments also involved 2 different instructors and 2 different graduate student graders. Performance on tests, quizzes, conceptual tests, and written solutions were analyzed. The student background, as measured by GPA, SATM, and FMCE pretesting, were significant predictors of student performance on the different measures, but homework method was insignificant in both experiments. There was no difference attributable to homework method in conceptual learning as measured by gains on the FMCE, in problem solving as measured by

Table 6

Summary of hierarchical regression analysis for variables predicting score on tests in the algebra-based course

Measure	*B*	*SE B*	β	*p*
Step 1				
Intercept	−8.99	10.58	−0.09	.40
GPA	13.06	2.21	0.5	$<10^{-7}$
SAT math score	0.086	0.018	0.69	$<10^{-5}$
Paper	−1.55	2.32	−0.02	.51
Step 2				
Intercept	2.50	11.49	0.03	.83
GPA	12.81	2.51	0.51	$<10^{-5}$
SAT math score	0.068	0.020	0.54	<.001
Paper	−1.39	2.28	−0.01	.54
Homework average	0.058	0.056	0.06	.31
Male	5.91	2.41	0.06	.02
Minority[a]	−4.11	4.28	−0.04	.34

Note. $N = 110$. For Step 1, $R^2 = 0.48$ ($R^2_{adj} = 0.46$). For Step 2, $R^2 = 0.51$ ($R^2_{adj} = 0.49$).
[a]A member of an underrepresented minority: African American, Hispanic, or Native American.

Table 7
Summary of hierarchical regression analysis for variables predicting score on quizzes in the algebra-based course

Variable	B	$SE\ B$	β	p
Intercept	−1.44	1.00	−0.14	.15
GPA	0.94	0.24	0.38	<.0002
SAT math score	0.005	0.002	0.42	<.005
Paper	−0.08	0.22	−0.01	.73
Homework average	0.025	0.005	0.25	$<10^{-5}$

Note. $N = 110$. $R^2 = 0.52$, $R^2_{\text{adj}} = 0.50$.

exams, or in other parts of the course such as laboratories. Even looking at elements of written solutions on exams, we found no significant differences at $\alpha = .05$. Thus, we conclude that we have established the null hypothesis that, in the case of introductory university-level physics with standard lecture sections using typical end of chapter problems, there is no significant difference in student course performance between Web-based homework with computer grading and homework written out on paper and graded by hand. Comparison with recently published work of (Dufresne et al., 2002) is instructive. In that study, the introduction of Web-based homework generally increased amount of homework that was graded and student time on-task, and gave students some assistance in solving problems when errors were made. This suggests that the medium of Web-based homework is not intrinsically more effective that traditional paper-based homework, but doing homework in general has pedagogical value, and that additional support and feedback enabled by the medium may be of real value.

It is perhaps not surprising that the difference in homework method has such limited effect on student performance. First, similar or identical end of chapter–type problems were used, so there was no real difference in pedagogical content. The differences between the two homework methods are completeness required and feedback. The paper students were required to work out the entire solution and show their work, whereas the Web students needed only to submit the final numerical answer. The paper students received more detailed information but after a time delay, whereas Web students received immediate feedback on whether their answers were correct. However, the calculus-based paper students could check their answers with those in the back of the book and rework their solutions, whereas the Web students could correct answers marked wrong by the computer and then resubmit. Furthermore, study practices of many students may tend to reduce these differences further. Many Web students usually printed out assignments, worked them out on paper—sometimes thoroughly—and then returned to the computer to submit them. Thus, many of the Web students actually worked out their solutions on paper just as those in the paper section, simply using the computer as a means to check their answers and receive credit. On the other hand, many of the students in the paper section did not spend much time reviewing the returned homework, viewing it as not important or not helpful, and so did not derive as much benefit as they might have from the written grading. Both of these student habits tended to reduce the effect of the differences further between homework methods. The instructor and lecture style probably has little effect on this phenomena because it has been observed that in the lecture-style classroom that still dominates most college-level physics, teaching style and experience of the instructor have limited impact on student learning (Hake, 1998; Halloun & Hestenes, 1985).

This result also raises deeper questions that are beyond the scope of this article about the value of traditional physics instruction, what the tests are actually measuring, and the pedagogical value of standard textbook exercises. As noted above, homework score has less predictive power (as measured by the standardized coefficient β) of performance on both multiple choice and written questions than does GPA, SAT, or FMCE pretest. In the algebra course, homework does not make a significant contribution to the model for test score. Even on quizzes, where the problems were similar or occasionally even identical to homework problems and students could refer to their homework solutions if they had already worked them out, both SAT and GPA have larger β coefficients than homework. One possible explanation is that success in traditional physics courses depends primarily on preparation and academic ability of students. In the study mentioned above (Henderson, 2002), traditional instructors expressed the view that students practicing solving problems was the most important aspect of learning. This would suggest that primary characteristics leading to success would be math skills and the discipline and self-knowledge to work on physics until mastering the knowledge and skills, whether that was less or more work than the assigned homework. Good students with a rigorous physics background may not put a lot of effort into the homework—and thus do not receive good homework scores—because they realized that they did not need to do the homework to do well on the tests. One student described this to the lead author but it is difficult to say how widespread this practice is. A second possible explanation is that these types of exams evaluate as much general study and test-taking skills as they assess physics knowledge. Like the SAT, the exams consisted primarily of timed multiple choice tests. A third explanation might be that traditional end of chapter homework exercises are not particularly effective exercises to help students learn.

Many researchers have questioned how effective they are in helping students develop real understanding (Heller & Hollabaugh, 1992; Sweller, 1988; Sweller, Mawer, & Ward, 1982). Research indicates that students can develop the ability to get the correct answers on typical physics problems without developing real understanding of the underlying physics (Halloun & Hestenes, 1985), and novice problem solvers tend to classify problems by surface features such as springs and ramps as opposed to physical principles involved (Dufresne, Gerace, Hardiman, & Mestre, 1992). Because they often do not mentally organize problems they are familiar with in a useful, systematic manner, it would be unlikely that feedback on problems would be mentally stored in a useful manner, either, so that feedback in any form would have limited impact on subsequent problem solving. In that case, the differences in feedback given by human graders and by computer systems would have little effect on student learning.

Web-based homework systems have the potential to make a difference in this area. The physics textbook problem is a literary form that has been developed over many years and has become a central part of physics instruction. Although not all textbook problems have all of them, typical characteristics are: a short story problem, application of concepts from a single topic, all the needed numerical quantities (and no extraneous ones) included in the problem statement, and clear instructions to calculate a specific quantity. They represent a collective effort to teach students to apply physics concepts (third level in Bloom's Taxonomy) to describe reasonably realistic physical situations, much as professional physicists do to more complex situations. The means of distributing and grading work puts some powerful constraints on the types of exercises that could be used, however, and this has certainly influenced the form they have developed. Inclusion in textbooks requires problems to be verbally described and encourages problems to be self-contained and take minimal space (minimum of graphs and pictures). Because students usually get only one submission on paper-based work, they need to have a good chance of getting it completely correct on the first submission, discouraging problems involving multiple topics, any ambiguity in what to solve for, confusion owing to extraneous or missing information, or complex mathematical solutions. To make grading as fast as possible, problems with final numerical answers are preferred while discouraging ones involving many steps, significant writing, creative solutions, or variation in numerical inputs, such as initial estimations or personal data.

Web-based homework does not have many of these restrictions and could be used for exercises that encourage physics understanding. A proven method to teach both understanding and problem solving is to use fairly complex problems that require conceptual understanding and a systematic attack and to explicitly teach and coach good problem-solving strategies (Heller & Hollabaugh, 1992). A related approach is to use simulations in the presentation of the exercise, so that the student must make decisions about what information is needed and make measurements, instead of simply finding the formula that uses exactly the given numerical values (Christian & Titus, 1998). The use of multiple representations, such as verbal and graphical as well as mathematical, is another valuable tool (van Heuvelen, 1991). Because these sorts of exercises are often more challenging than textbook problems, in many cases support needs to be built in for the student. One way is to break a complex problem into multiple steps with the student submitting intermediate values, which can provide a form of scaffolding. Another approach is seen in the Tycho Web homework system's Socratic-like help which provides as needed a series of questions to lead students through a problem they do not understand (Stelzer & Gladding, 2001). Another innovative approach is using interactive Web-based tutors, such as the PAL system (Reif & Scott, 1999). The authors currently use some Web-based exercises with integrated simulations and one is developing ways to incorporate student drawing of graphs and diagrams into Web-based work. Web-based homework offers a variety of ways to move beyond the standard physics textbook problem to exercises that are of greater pedagogical value, although much research will be needed to determine the most valuable avenues to pursue. This work indicates that there are no clear pedagogical reasons to not switch to Web-based homework. However, future research and development work will be needed to realize the potential benefits of Web-based homework.

Web-based homework is a rapidly growing use of the Internet and is becoming a major component of instruction in physics and other subjects, replacing delayed feedback from a human grader with instant but limited feedback from a computer. Web delivery and grading of traditional textbook-type questions is equally effective as having students write them out for hand grading, as measured by student performance on conceptual and problem-solving exams. This was true for both calculus-based and algebra-based physics and with different instructors, and is consistent with the limited research that has appeared on this subject. We conclude that the change in the medium itself and in the type of feedback provided does not have significant pedagogical consequences in introductory physics. Replacement of hand-graded homework by computer work could improve student learning by freeing time and economic resources for more effective instructional methods, and it could be a medium that allows widespread use of exercises with greater pedagogical value.

The authors thank the Spencer Foundation for the grant that made this work possible, and the National Science Foundation for the fellowship that supported the lead author under Grant 9714546. People who helped make this work possible include Phillip Alexander, Qunyi Chin, John Hubisz, Louis Hunt, Larry Martin, George Parker, Nikhil Phansalkar, Brian Pittman, Elizabeth Reig, and John Risley.

Notes

[1]WebAssign currently serves about 100,000 students (John Risley, personal communication, October 2003). Another system, Homework Service, states on their website (http://hw.ph.utexas.edu/hw.html) that they process 150,000 answers a week; at 5–10 questions/student, this works out to 20,000–50,000 students. In addition to this are schools using CAPA, OWL, WebCT, and other systems.

[2]A hundred-student section would need a half-time (20 hours/week) grading assistant; for a science or engineering graduate student this would cost $5,000–7,000 a semester, plus tuition and benefits. WebAssign offers a hosted service with a large database of textbook problems and a price of $75–125 per instructor per semester plus a charge of $8.50 per student. This is <$1,000 per semester for the same course, and students can be directly charged most of the cost. A different system, Homework Service, is a free, volunteer-based operation.

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