

A Comparison of the Effectiveness of Web-based and Paper-based Homework for General Chemistry

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Abstract: An instructor compares typical use of paper-based homework and Web-based homework using two different sections of general chemistry. Analysis of student performance data suggests that Web-based homework is as effective as paper-based homework for student learning. Time spent grading, recording, and returning paper-based homework is greatly reduced with a Web-based system, although initial use of the Web-system requires some time for setup. The Small Group Instruction Diagnosis (SGID) technique [1, 2] is used for collection of student affective data. Students appreciate the usefulness of both paper-based and Web-based homework as a preparation for quizzes and examinations. Advantages unique to typical use of Web-based homework include instantaneous feedback and ability to resubmit assignments.

Background

Not all learning takes place in the classroom or laboratory. Instructors traditionally rely on the assignment of homework to motivate and guide student learning in the hours between meetings. Indeed, although the effectiveness of homework is sometimes called into question, large scale reviews of educational research show that in all subjects and at all grade levels homework has a positive impact on student learning outcomes [3]. It should be noted that this positive effect is largest for older students and that in the youngest elementary grades the effect is statistically significant but very small [4].

For many instructors of general chemistry, however, there remains uncertainty about how to go about using homework. Assigning, collecting, and grading weekly problem sets places high demands on the instructor's time. This difficulty approaches impossibility at some universities where class sizes near 300 students or more. Faced with this situation many instructors assign "suggested problems" without collecting them, but conventional wisdom says that students will be less likely to complete homework if it will not be collected.

Web-based delivery of homework offers a possible solution. With Web-based homework, students must submit their solutions to homework problems online. And although there is some time cost to instructors setting up the system and in downloading grades, the time spent with red pen and stacks of students' papers is largely eliminated.

Still, there remain questions regarding how the use of Web-based homework could affect students and instructors who are accustomed to paper-based homework. This study addresses the following three research questions:

1. Research question: given typical usage, are learning outcomes as good for Web-based homework as for paper-based homework?

2. Research question: how much time does the instructor save using online homework versus collecting and grading paper-based homework?

3. Research question: is there a difference in how students perceive the helpfulness of Web-based homework versus hand-written homework?

Some chemists have reported on their use of Web-based homework in general chemistry. In some cases, students perceive that the Web environment has a positive impact on their learning [5–10], in another case students were split on this issue [11], and in another case students didn't "like" the Web environment [12]. Of course, the details of how the Web was used varied, and so it is not surprising that there was not just a positive or just a negative student opinion. Of the studies that tried to measure the impact of Web-based homework on quantifiable student learning of content, one found no measurable effect [8] but admits that the study was flawed because the control "paper" group had access to the Web-based homework as well. One other study [13] found a positive correlation between "extra" quizzes taken on the Web-based system but did not have a control group and did not control for incoming student ability.

Researchers in physics education have also studied the effectiveness of Web-based homework delivery. Similar to chemistry students, many physics students feel that working homework on a computer is helpful for learning [14,15]. One study suggests that computer-assisted assignments can encourage collaboration between physics students and facilitate an increase in conceptual understanding [15]. Three studies specifically compare Web and paper-based homework for preparing student for physics examinations [16–18]. Two of these studies find that Web-based homework does as well as, but not better than, paper-based homework [16, 17]. The third study finds that one of four participating instructors realized a statistically significant gain in exam scores after switching to Web-based homework while the other three instructors found no significant difference [18]. Pascarella conducted an in-depth qualitative study and found that online systems can actually have a negative effect where physics students will "game" the system by working less carefully and using the computer to check this careless work [19]. This strategy increases the likelihood that students who were

successful paper-based problem solvers will revert to novice-like problem-solving strategies. This lack of consensus highlights the need for further investigation.

This study examines the effect typical use of Web-based versus paper-based homework for general chemistry students. Students who turned in paper homework experienced a two-day delay in receiving their hand-graded homework back again while the students who submitted their homework online received their grades with feedback instantaneously. The data from this experiment are both quantitative and qualitative. The quantitative data is consistent with previous research in that it shows a statistically significant correlation between homework scores and student learning outcomes for both paper and Web-based homework. There is no statistically significant difference, however, between the correlations from the paper and Web-based homework groups. A timesaving advantage for the instructor of using Web-based homework delivery was significant after the initial setup. An additional timesaving advantage was realized during class time because there was no need to return papers. Qualitative data indicates that students recognize the benefit of homework in both cases and appreciate the immediacy of feedback available and the ability to resubmit work facilitated by Web-based homework.

Methodology

The author collected weekly homework scores from two of his sections of general chemistry students ($N_{\text{paper}} = 44$ and $N_{\text{Web}} = 45$). Additionally, for both sections, a short but comprehensive exam was developed for use as a pretest/posttest. This test was given on the first day of class as a pretest and on the final day of class as a posttest.

To obtain qualitative data, the technique of Small Group Instructional Diagnosis (SGID) measured the students' perceptions of the usefulness of paper/online homework. The SGID technique was originally developed as an alternative to traditional "fill in the bubble" course evaluation forms [1]. In this technique a trained facilitator, typically an on-campus faculty development expert, meets with the faculty member to discuss what issues they feel are important for effective teaching and learning in their classroom. Together they settle on a small set of questions to solicit feedback from the students. Typical questions might be [20]:

1. What aspects of the course help you learn?
2. What does not help?
3. What do you suggest to improve your learning?

The faculty member then decides on a date (preferably within the first half of the term) for the facilitator to conduct the diagnosis. The diagnosis typically takes 25 to 35 minutes, and is conducted during normal class time but in the absence of the instructor. The students are given a sheet with the questions on it and are given approximately 10 minutes to write individually. They are then assigned to small focus groups (3 to 5 students) and asked compile a list of answers that they feel best represent their collective perspective. Each group reports out their compiled list and the facilitator writes each answer on the board at the front of the room. Once all of the groups have reported out, the facilitator leads a whole class discussion to a verbal consensus on what answers are universally held as the most important. The facilitator then constructs an anonymized, typewritten report of the students' comments and discusses the results with the faculty member in a follow-up meeting.

Research provides evidence that the SGID technique is a more effective way for students to evaluate a course as compared to typical end-of semester evaluation forms [21, 22]. Instructors can readily use the data from the diagnosis in a formative way for the improvement of instruction [21]. Students feel that their voices are heard and prefer the SGID technique to traditional evaluation forms [22]. Although the SGID technique has itself been studied and found valid in a variety of settings (including science classrooms [21]), it is typically used as a tool to gather feedback for instructors rather than as a research tool [1]. This is the first instance that we are aware of in which SGID has been used to gather qualitative data in a chemistry classroom specifically for chemical education research.

For the purposes of this research, in addition to the three questions suggested by Bennett [20], the subjects were also asked:

"How is your use of WebCT homework impacting your learning in this class?"

or, in the case of the paper-based section:

"How is the use of homework impacting your learning in this class?"

The comments for each group are reported verbatim in the supporting materials to this article. These comments have been further categorized thematically by the author and will be discussed in the results section.

In summary, the data have four components:

1. weekly homework scores,
2. pretests to measure incoming knowledge on the first day of class,
3. posttests (identical to pretests) to measure outgoing knowledge on the last day of class,
4. SGID reports (qualitative).

Instrumentation

The author assigned both groups of students weekly problem sets (8 total over the course of an academic quarter) of approximately 10 problems each. For both groups, the problems were taken from the end-of-chapter problems in the textbook [23]. The majority of the problems assigned were quantitative in nature.

For the paper-based group, students were required to individually turn in hand-written solutions. Realizing that it is rare for instructors of general chemistry to thoroughly grade student work, the author mostly graded the students' work for completion with some credit given for correctness of solutions. Up to 6 points were given for completion of the assignment if the instructor judged that all problems were worked through. Up to 4 additional points were given based on the correctness of two problems chosen at random (a student volunteer would roll a ten-sided die). For these two problems, brief written comments were given by the instructor to explain the assigned grade. Additionally, a complete key was scanned and posted online for student viewing after the graded homework was returned. An example of a typical question, graded response, and key are shown in Figure 1. Each homework point corresponded to a very minor (0.1%) portion of the final course grade.

For the Web group, the problems from the paper group were adapted to an HTML format and placed on the Web using WebCT software [24]. Because most of the problems were quantitative, students were required to type in their final

Problem 3.36

A 1.547 gram sample of wet copper (II) sulfate is heated carefully to drive off the water. The white crystals of CuSO_4 that are left behind have a mass of 0.989 grams. How many moles of water were in the original sample?

3.36
 $1.547 \text{ g} \left(\frac{\text{mol}}{18.01 \text{ g}} \right) = 0.8587 \text{ mole H}_2\text{O}$ (circled 1/2)
 MUST SUBTRACT DRY CuSO_4 FIRST!

KEY

3.36 $\text{CuSO}_4(\text{wet}) \rightarrow \text{CuSO}_4(\text{dry}) + \text{H}_2\text{O}$
 1.547g 0.989g 1.547g - 0.989g = 0.558g

$0.558 \text{ g H}_2\text{O} \times (1 \text{ mol H}_2\text{O} / 18.01 \text{ g H}_2\text{O}) = 0.0310 \text{ mol H}_2\text{O}$

Figure 1. Typical problem, graded student solution, and posted key.

Question 1 | (1 point)

A 1.736 gram sample of wet copper (II) sulfate is heated carefully to drive off the water. The white crystals of CuSO_4 that are left behind have a mass of 1.072 grams. How many moles of water were in the original sample?

Student response: .03686
 Correct answer: 0.0369
 General feedback: The water evaporates, so figure out the MASS that left by subtraction. Then you must convert that mass to moles. Try problem 3.35 in your text for additional practice.
 Score: 1/1

Figure 2. Typical Web-based problem, student response, and feedback.

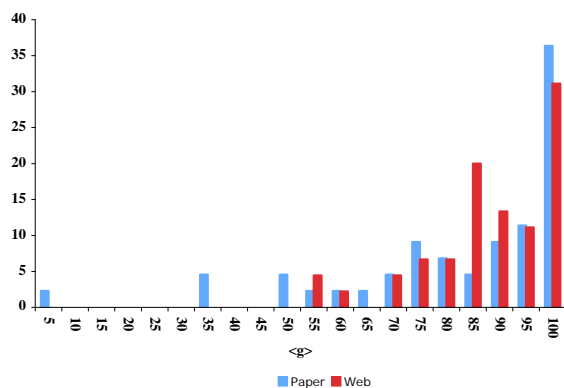


Figure 3. The distribution of normalized gains (percent posttest gains relative to maximum possible gains above pretests) for the paper and Web groups.

(numerical) answer. As is typical with Web-based homework, after submission the homework was automatically graded by computer and available for student viewing within seconds. For each problem, general feedback was supplied which ranged in detail from describing mistakes that students typically make to giving detailed hints on how one could solve the problem. Each quantitative problem used random number generators for quantities given in the problem. In this way each time a homework set was accessed the correct answers would change. This feature, common to many Web-based systems, is especially useful in that students cannot cheat by copying each other's final answers or by copying answer keys supplied by the program after homework submission. For this reason, and consistent with common usage of Web-based homework, the

students were allowed to revise and resubmit their homework. Points were given only for correct answers—no points were given for simply completing an assignment. In the end, the grade recorded was only their highest score attained over all attempts for each problem set. In keeping with typical practice, unlimited attempts were allowed (a choice of the instructor, which can be altered in most Web-based homework systems). An example of a Web-based question and the automatically generated feedback is shown in Figure 2. As with the paper group, each homework point corresponded to 0.1% of the final course grade.

Data and Analysis

To determine whether learning outcomes are as good for Web-based homework as for paper-based homework we consider the homework scores, pretest scores, and posttest scores. Here the use of a pretest is essential. Without it, especially for a small sample size, differences in incoming student ability would not be accounted for. For example, one section might score significantly higher on an exam simply because they are a more successful group of students. By collecting pretest scores, one can “level the playing field” and account for incoming ability by calculating a normalized gain [25]. Normalized gain, $\langle g \rangle$, is defined as:

$$\langle g \rangle = \frac{\text{posttest} - \text{pretest}}{\text{max} - \text{pretest}} \times 100\%$$

where max is the maximum score possible on the pre/posttest. $\langle g \rangle$ measures the percentage improvement of the posttest score relative to the pretest score compared with the maximum amount of improvement that could have achieved. This, in turn, is assumed to be the improvement due to the learning that took place between the pre- and posttests.

The distributions of normalized gain are given in Figure 3. The mean scores in these groups are 86.3% (Web) and 80.4% (paper). The Mann–Whitney test is used because the distribution is not normal ($\text{skew}_{\text{Web}} = -1.05$, $\text{skew}_{\text{paper}} = -1.95$) [26]. The difference in the distributions is not significant with $p = 0.568$. The interpretation here is that the learning outcomes for the Web-based homework group and the paper group are statistically equivalent.

Correlations. Because homework has been shown to be helpful for student learning, one expects that homework scores should correlate with the normalized gains. Further, if one method of homework delivery was more effective for learning than the other, then one would expect that the correlations between homework scores and normalized gains are stronger for the more effective delivery method.

Table 1 lists the correlation analysis results for homework scores and normalized gains. As with the analysis of distributions, we are mindful of the lack of normality in the data and use Spearman's Rank Order Correlation [26]. Although there is significant scatter in the data (plots shown in supplementary material), for both groups of students the correlations are positive ($\rho = 0.410$ for the Web group and $\rho = 0.478$ for the paper group). Both correlations are statistically significant with $p = 0.005$ for the Web group and $p = 0.001$ for the paper group. When the correlations are compared to each other, however, one is not significantly stronger than the other with a z_{obs} ratio of only $z_{\text{obs}} = 1.03$ ($|z_{\text{obs}}|$ must be greater than the critical value of 1.96 to be significant at the $\alpha = 0.05$ level)

Table 1. Correlation of homework scores with normalized gain.

	Web-based homework	Paper-based homework
Correlation of homework scores with normalized gain (significance)	$\rho=0.410$ ($p=0.005$)	$\rho=0.478$ ($p=0.001$)

[26, 27]. This statistical equivalence is consistent with the hypothesis that Web-based homework is equally effective as graded, paper-based homework.

Timesaving for Instructor. One attraction of Web-based homework is the potential timesaving for the instructor. For paper-based homework, the author spent approximately 45 minutes grading and recording each assignment (five total hours for eight assignments). This figure would vary, of course, with the depth of comments given on each paper. As described in the Methodology section, the author gave very brief comments on only 20% of the problems and checked the rest of the student work for completion only. For the Web-based homework, because this was the first time it was used, the author actually spent more time implementing the use of the Web assignments. It took approximately 60 minutes for each assignment to be coded into the HTML format and integrated into the WebCT software. In subsequent (post-study) uses, however, the author spends approximately 10 minutes three times per term to download student homework grades (30 minutes total for the term). Further, it should be noted that because the study was conducted most, if not all, major textbook publishers have developed sophisticated homework systems, which promise to eliminate much of the work of setting up the assignments [28]. In summary, excluding time for initial setup, the potential timesaving of using Web-based homework is significant: for eight assignments per term the author anticipates approximately 90% less time spent grading/recording homework (30 minutes versus 5 hours per term). This timesaving would be expected to grow with increasing class size.

Use of Web-based homework also eliminates the need to return paper homework during class time. With a class size of $N_{\text{paper}} = 44$ students this took approximately five minutes each assignment. Although five minutes is only 10% of a 50-minute period, class time is a very precious resource and even a small amount of timesaving is important.

Qualitative Data: Small Group Instructional Diagnosis.

As stated in the Methodology section, Small Group Instructional Diagnosis data were collected from both groups of students. In the Web group the students were asked to respond to the question, "How is your use of *Web CT homework* impacting your learning in this class?" In the paper group the students were asked, "How is the use of *homework* impacting your learning in this class?" In the Web-based groups a total of 40 comments were reported out of the focus groups and the SGID facilitator led the class to a verbal consensus on which comments were universally held as most important. This process eliminated most "silly" or vague comments and 17 comments remained. In the paper groups 18 comments were reported out and 8 were universally held as most important. These comments for each group are reported verbatim in the supporting materials.

Several themes emerge from the students' responses. A theme that is common to both the Web and the paper group is

that the homework prepares them for quizzes and tests (mentioned 2 times in the Web group and 5 times in the paper group). Another theme is the importance of receiving feedback after completing the homework. In this case the Web group mentioned that feedback was a good thing 4 times. The paper group mentioned that getting feedback through online posting of answer keys was good, but mentioned that more immediate feedback through the answers to odd numbered problems or through handing out paper copies of answer keys would be better. The Web group mentioned other advantages particular to Web-based homework including convenience (3 times), usefulness of automated hints (3 times), and the ability to redo homework (8 times).

Limitations

This study was intended to compare typical use of paper-based homework and *typical* use of Web-based homework. Its results might not be generalizable to other situations. For example, for our paper-based group, we had a two-day turnaround for getting graded work back to students. Other research has shown that more immediate feedback (for example, through peer grading) could be more effective for student learning [29], although ways in which peers can grade each other is bound by the restraints of the Family Educational Rights and Privacy Act (FERPA) [30]. Conversely, many instructors who do grade homework might take longer than two days to return the graded work and this might be less effective for student learning. These differences could contribute to a more or less favorable comparison with the Web-based alternative. Additionally, the Web-based group had every problem graded by the computer and was allowed to revise their work. This was not the case with the paper-based group as it is, in our opinion, very uncommon for an instructor to grade every problem or to allow students to revise their work. Even so, there may be situations such as small classes where instructors may be able to give more detailed and individualized feedback on each problem in paper homework than was given in this experiment's Web-based homework. If these things (giving immediate feedback, grading all problems, giving individualized feedback, allowing revision of work) were done for a class using paper-based homework it is entirely possible that the homework would have been more effective for student learning and may have had an advantage over Web-based homework. As it stands, immediate feedback, grading every problem, and allowing revised work are easily incorporated into Web-based homework and are therefore included in our study of *typical* use.

Discussion

It is heartening that homework scores correlate significantly with normalized gains irrespective of the method of delivery (Table 1). This means that success in homework is a good predictor of success in other aspects of general chemistry. Strictly speaking one cannot conclude from our evidence that time spent working on homework causes success in the course, still these correlations are consistent with the large body of previous research that show that assigning and grading homework is a useful practice [3].

Because the correlations are not significantly different from each other depending on the method of homework delivery (Table 1) this study does not provide clear evidence that one

method is superior to another for homework effectiveness. As there is no consensus on this issue with previous research, our results simply add evidence to physics education research studies that show Web-based homework to be simply as effective as paper-based homework [16–18]. Given this to be also true for the case of general chemistry, our results are a “green light” to those who would implement Web-based homework to realize the gains in timesaving for the instructor and for classroom time.

The Small Group Instructional Diagnosis indicates that students are favorably disposed to both types of homework but that Web-based homework has some advantages over paper homework. Here the students’ views are consistent with findings of previous research [5–10]. Both groups mentioned getting feedback on their homework as important. For the Web group they specifically mentioned appreciating “instant feedback” and how they “instantly know if you’re right or wrong.” In the same vein, the paper group would appreciate more timely feedback. They like that the answer keys were posted online but would suggest more immediate methods such as assigning odd-numbered problems (with answers in the back of the book) or hard copies of the keys passed out when the homework is returned.

The most frequently mentioned advantage that Web homework has over paper homework (as it was administered in this experiment) is the ability for the students to resubmit the homework as many times as they desired. The students mention that they “can try again to get it right.” They believe that it “helps you understand the material because you get to redo the homework as many times as you want” and “you can keep trying to get a better grade.” And so, even if this does not translate into higher performance on posttests, the students perceive that the ability to redo the homework is helping them learn. This affective advantage might be significant enough for one to favor Web-based homework over paper homework. And while it is true that it is possible for instructors to allow students to resubmit paper homework as well, it is undoubtedly more convenient to do this with Web-based homework.

Future Work

Beyond the question of homework effectiveness in general, it would be helpful to know how to best implement Web-based or paper-based homework to increase their effectiveness. In pursuit of this question research is needed on the cognitive function that homework serves. On the one hand, studies suggest that when some students “game” Web-based homework they pick up unproductive “novice-like” habits [19]. For example, some students will recklessly work out first draft answers in order to get the feedback from the computer for a second try. Possible remedies to this problem could be loss of points for excess submissions, limiting the number of submissions allowed, or basing the students’ scores on an average of all submissions. Working out a set of best practices to reduce this “gaming” of Web-based homework will likely be a very significant area for future research. Given evidence that suggests that the timing of feedback is key to learning, computer-based homework could be an important tool in advancing student understanding when the students’ minds are most open to learning [31]. As textbook publishers offer more and more sophisticated Web-based homework systems [28], the chemistry education community needs to investigate what the best practices are in using this increasingly available tool.

Although Web-based learning shows promise, it seems that there are likely right and wrong ways to implement it. Figuring out the right way will require additional careful study.

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