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Effects of Web-Based Multimedia Homework with Immediate Rich Feedback on Student Learning in General Chemistry

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Introduction

Large enrollment courses face great challenges in meeting the needs of a diverse student population. Students enter the class with very different levels of preparation and experience in mathematics and chemistry. One area that can easily be improved is to provide students with the opportunity to determine what material they understand and identify areas where more study or explanation is needed. We addressed this issue by designing and implementing World Wide Web-based homework assignments that include the use of multimedia and immediate feedback. We describe our quantitative and qualitative evaluation of the use of these assignments for one lecture section of general chemistry at a large midwestern university during the fall semester.

Three considerations guided our design of the general chemistry homework assignments. First, we wanted to help students identify their own misconceptions, incomplete understanding of material, and areas where they needed additional help *(1–15)*. Second, we wanted to provide students with immediate feedback to promote student learning and retention *(16–24)*. Finally, we wanted to provide computer animations and multimedia presentations to more easily illustrate certain difficult concepts in general chemistry *(25–30)*.

Misconceptions

Misconceptions are most commonly defined as ideas, views, or mental structures students have that differ from the accepted scientific ones. Numerous studies have shown that misconceptions concerning many aspects of chemical phenomena are prevalent among students. A sampling of these studies include the investigation of misconceptions about phase changes *(31, 32)*, equilibrium *(6, 9, 33)*, the nature of heat and temperature *(34, 35)*, density, covalent bonding and structure *(11)*, and the nature of chemical changes (*3, 8)*. Perhaps the most pervasive misconception, one that seems to underlie all the others, is a misunderstanding of the nature of matter. Students seem to view matter as continuous rather than particulate *(5–10)*, or to view atoms and molecules as tiny pieces of the material they make up *(36)*. Other studies have shown that misconceptions persist, albeit at continuously declining rates, in junior high school, high school, the undergraduate and graduate levels, and even among the ranks of some chemistry professors *(1, 2, 37)*. Many of these misconceptions can be traced to the language and representations used in chemistry as well as the reasoning ability of students *(4, 5, 7, 13–15)*. One of the challenges in addressing and dispelling these misconceptions is making the student aware of the fact that the problem exists *(3, 31, 38)*. The most effective tactic for dispelling misconceptions seems to be for the student to encounter situations that the misconceptions do not explain *(39, 40)* and then construct new conceptions to replace the inadequate ones. Several studies have involved the development of multiple-choice diagnostic tests to assist teachers in identifying the misconceptions of their students *(1, 4, 11, 12)*. For this type of question to assist students in their learning, some form of feedback must be provided to alert students to errors in their understanding *(24)*.

Feedback

Within the behaviorist paradigm, feedback was seen as a form of reinforcement *(21)*. Kulhavy criticized this idea, substituting an information-processing view about reinforcement *(41)*. Under this view, feedback is a tool to help the learner identify errors in learning and substitute correct information. Kulhavy described several criteria under which feedback is most effective. One factor he identified is that feedback is most effective when the student is certain about the answer but gets it wrong. In this situation the learner is more likely to carefully examine the feedback and the processes that led to his or her wrong answer and reconcile the two in a way that is more likely to be correct and retained. He thought that delayed feedback was more effective than immediate feedback, because perseverance of an incorrect answer is more likely to interfere with immediate feedback than with feedback that has been delayed long enough for the incorrect answer to decay in strength and vividness. He called this effect the perseveration–interference hypothesis. In addition, Kulhavy identified feedback as ineffective if it is available before the learner has had to construct a response (pre-search availability) or when the learner does not understand enough about the subject to construct a meaningful answer.

Kulik and Kulik challenged the effectiveness of delayed feedback *(42)* in a meta-analysis of 53 research studies comparing immediate and delayed feedback. The studies they reviewed consisted of three sorts of learning situations: school-like quiz instruments, acquisition of test content, and memo-

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rization of lists. Their review found that the first learning situation was most assisted by immediate feedback, the second by delayed feedback, and in different studies immediate or delayed feedback most assisted the third. Kulik and Kulik went on to theorize that immediate feedback was actually most effective in all three situations, and that the artificial environment of the acquisition of test content and memorization of lists experiments influenced which feedback appeared most effective since they resembled other experiments comparing massed versus distributed learning.

Since then, other recent research *(22, 23, 43, 44)* has returned to Kulhavy's *(41)* original view of the effectiveness of delayed feedback. In all cases described in the literature, feedback does increase student retention and performance on post-tests, but the relative advantages of immediate versus delayed feedback are under dispute. As outlined below, however, the feedback in our online homework program falls somewhere between the extremes of immediate and delayed feedback. The feedback received in this study came anywhere from minutes to days after students answered the questions because students are able to print out the questions and work on them in their own time before submitting them for grading. However, the feedback was immediate upon submission of the final answers. Moreover, another significant difference between many of the research studies on feedback and our design is that the pre-test and post-test question items in the published research are often identical. The more common and more pedagogically sound design is for the two to be similar but different enough to demonstrate that more meaningful learning than (potentially) rote memorization of the correct response has taken place.

The drawback to providing diagnostic or remedial feedback with text-based homework is the time involved in grading the assignments. Computers are ideally suited to quickly grading and providing feedback on large numbers of objective assignments. Feedback administered through the use of computers has been shown in two meta-analyses to have a modest effect on student learning *(20, 45)* with effect sizes between 0.35 and 0.80.[1] Other variables that affect the magnitude of the effect of computer-based feedback include delaying the post-test, the type of computer-based instruction, format of the material studied, the availability of supplemental materials *(45)*, and the format of the feedback (confirmation, correct-answer) *(20)*. Schimmel also pointed out that variation in previous studies' results could potentially be explained by variations in the vividness and complexity of what students were being asked to recall *(20)*.

Computer-Based Instruction

Several studies have shown a modest effect on student learning when instruction is delivered in computer format. In a meta-analysis of 55 studies, Kulik and Kulik *(46)* concluded that computer-based instruction enhanced student learning with an effect size of 0.30, took less time than traditional instruction, and positively affected student attitudes toward the subject and computers. The effect sizes were generally larger for small treatment durations, for two-teacher experiments, and for studies published in peer-reviewed journals rather than in dissertations. All forms of computer-based instruction were effective at the college level, while computer-enhanced learning was somewhat less effective at the precollege level. A few studies in educational psychology and music had especially pronounced effect sizes, and Kulik and Kulik suggest these studies as areas for future research to determine why they were so effective. The results of analyses of computer-assisted instruction in the sciences *(47, 48)* support these results.

In the field of chemistry, studies have reported using computers to assist students in a variety of ways. Williamson and Abraham *(26)* showed that computer-based animations of molecular-level events shown in a lecture environment significantly improved student performance on a logical thinking test (0.50 effect size). There was no effect on attitude or course achievement and no additional effect when the animations were also shown in recitations. They concluded that viewing the animations aided students in constructing dynamic rather than static mental models of the particulate nature of matter.

Meta-analyses have shown that hypermedia's effects on instruction have been modest *(25, 49)*. Emerson and Mosteller *(25)* concluded that hypermedia functions best as a supplement to, rather than a replacement for, good teaching. They suggested that hypermedia is most effective when the learner is an active participant, the user makes choices and receives feedback, the program involves multiple senses of the learner, and group collaboration among learners is facilitated.

The emphasis on computer-based instruction in science has focused on the need for high quality materials that are integrated into the curriculum and that can be continually improved *(50, 51)*. Effort also needs to be made to address learning theory and the needs of the students *(52)*. An area of computer-based instruction that has not been extensively developed, but may hold the most potential, is the ability to use multiple representations of chemical phenomena (*28–30, 53)*. Particularly since this is an area where significant misconceptions are held by students, the ability to show a student a video of a macroscopic phenomenon and have them relate it to a particulate-level description or animation should enhance the ability of students to build mental models of the particulate nature of matter. Successful computer-based homework programs have been reported *(54–56)*, but there has been little research on the impact of these programs on how students learn. Most of the existing research has focused on more of a drill and practice model with no feedback given, rather than providing feedback that can assist in diagnosing misconceptions.

Purpose of This Study

We evaluated the computer-based online homework assignments we designed for a general chemistry class to determine whether providing chemistry homework assignments via the World Wide Web increases student performance in General Chemistry as measured by quantitative class scores (exams, quizzes, homework, laboratories, total points). In addition we wanted to discover whether there is any subset of students who are affected more or less favorably by making the homework assignments available on the Web.

Methods

Overview

The homework assignments were designed as diagnostic tests with the considerations outlined above in mind. They were implemented using the commercial server-based software package WebCT *(57)*, which provided the desired functionality with little programming skill required by the instructor.

Distracters to multiple-choice questions were constructed to correspond to common student misconceptions as well as mistakes students typically make. These mistakes and misconceptions were identified based on the authors' experience with answers to free-response questions used on quizzes and exams in previous semesters and on items in the literature (see references in misconceptions section, above). Therefore, when the student answered a question using one of these misconceptions, the feedback to that question pointed out the inconsistency or error and encouraged the construction of a more scientifically acceptable conception. The feedback was not available until after the student had responded to the question, thus preventing pre-search availability.

Supplemental material was available in the sense that the feedback directed the student to appropriate material for further study (e.g., sections in the textbook, corresponding problems in the textbook, CD-ROM-based tutorials available in campus computer laboratories, or Web-based tutorials designed on this campus). We included graphical representations of matter in many questions as well as dynamic browser plug-ins and videos in a few questions to probe students' reactions to the media. We report here the impact of these homework assignments on students, with outcomes ranging from course, laboratory, and exam grades to qualitative interview responses.

Treatment

The homework assignments were accessible to students through WebCT, a server-based Web course software program that has quizzing, grade management, chat, bulletin board, and group work capabilities. The homework assignments were programmed as part of the quizzing function, using primarily multiple-choice and matching questions. The questions on the homework assignments were randomly drawn from a specified set of questions testing the same concept. This allowed the delivery of a personalized set of questions to each student. The questions were designed to exploit a variety of learning styles and forms of media. For example, graphics and interactive plug-ins were often used to accommodate learning styles other than those that rely solely on reading and calculations. Examples of various sorts of homework problems are given in Appendix 1 of the Supplemental Material.[W]

Students had two chances to complete each homework assignment, and their higher score on each assignment was recorded and used to determine grades. Students received a different set of questions for their second attempt rather than being given a second chance at the questions they received for their first homework attempt. The students were encouraged to attempt each assignment early in the week (weekend or Monday) in order to see the type of problems and knowledge tested in that assignment. They could then focus on relevant instruction during the week and ask questions about difficult concepts of the instructor, teaching assistant, tutors, or fellow students. To improve their scores and verify that they had learned the required material during the week students could undertake the second-chance homework assignment, completing it before the Thursday afternoon deadline. This opportunity to improve their scores also provided incentive to read and follow up on the feedback.

Design of the Study

The subjects were students in a first-semester general chemistry class taught during the fall semester at a large midwestern university. Most of the students were first-year college students with a range of standardized test scores and mathematics and science backgrounds. Most of the students were Caucasian and about half were women.

The subjects were assigned to treatments based on section numbers rather than any characteristics of the subjects themselves. The course had several discussion-recitation and lab sections numbered sequentially, with two sections (an odd and an even number) assigned to each of the teaching assistants (one teaching assistant was assigned four sections instead of just two). The odd sections were arbitrarily assigned the WebCT online homework, while the even sections were assigned homework from the textbook that was completed using paper and pencil. Homework assignments typically included 8–10 questions. All students in the class received this treatment, but data are only reported for those students who consented to participate in the study (n = 200). WebCT graded the online homework assignments for accuracy of response, while the teaching assistants graded the paper-based homework assignments for completion. Students were assigned 0–3 points on a spot-check based on the relative completion of the homework assignment without regard to its correctness. This difference in scoring was addressed in the statistical analysis of the results.

The quantitative data included the following: all class scores, including homework, laboratories, and exams; standardized test scores (ACT and Math Placement scores); a version of the Group Assessment of Logical Thinking (GALT) test *(58, 59)* administered online in WebCT; and pre- and post-attitude test scores also administered online in WebCT (the text of the pre-and post-attitude surveys is shown in Appendix 2 of the Supplemental Material[W]). The content of the GALT test was nearly identical to the paper and pencil version in the literature, but was formatted to be delivered using the quiz tool in WebCT. Both GALT scores and ACT Math scores were included because they have been demonstrated to correlate with performance in general chemistry courses *(60)*. The independent variable was the presence or absence of online homework. Covariates were the standardized test scores and the GALT test score. The dependent variables were the final course grade, the aggregate scores on course components, and the attitude scores.

Data from semi-structured interviews were also collected. The median score on the GALT was 10 out of 12 possible, so the students were divided into four cohorts based on GALT (high = 10 or greater, low = 9 or less) and their homework treatment. Six students were randomly selected from each cohort and invited to participate in the interview. If an invitation was refused, another student was randomly selected from the same cohort. Students were offered a small incentive to participate ($5 certificate for pizza from a local restaurant). The experimental protocol was modified to only include 14 interviews rather than 24 due to the difficulty in identifying students willing to be interviewed. The students interviewed included representatives from each of the four cohorts: 4 from the high-GALT online cohort, 4 from the low-GALT online cohort, 3 from the high-GALT text-based cohort, and 3 from the low-GALT, text-based cohort. We interviewed 12 female and 2 male students (female students seemed more willing to participate in the interviews); all were traditional college students (traditional meaning under the age of 22, single, attending college immediately following high school).

The interview protocol is shown in Appendix 3 of the Supplemental Material.[W] The interviews were transcribed verbatim and analyzed by the investigators independently. Each investigator generated a list of responses for each student using a common coding scheme. The lists were then compared and a few minor discrepancies resolved. The responses to each question were separated into groups based on the student's membership in a cohort and the responses were analyzed for patterns within and across the cohorts.

Results

Quantitative Analysis

In general, for the quantitative analyses, the level of significance was set at $\alpha = 0.05$.

The available dependent variables for each subject were the total points accumulated, the total exam scores, the total quiz scores, the total lab scores, and the total homework scores. When these point totals were compared by multivariate analysis of variance (MANOVA), a significant difference was detected between the odd- and even-numbered sections ($\alpha < 0.001$). The homework was graded differently for the two groups, however. Students in the even-numbered sections were awarded 3 points per homework assignment completed, irrespective of the accuracy of their work, while the homework in the odd-numbered sections was graded for accuracy. For statistical comparisons, we subtracted the total homework points from the total points for both groups and compared total points, exams, quizzes, and labs by MANOVA. This time, no significant differences persisted ($\alpha = 0.887$).

To examine whether the online homework added to or interacted with any covariates, we compared matrices of scatterplots and fitted the data using multiple regression. The covariates considered were ACT Math scores, Math Placement scores, GALT scores, and TA assignment. For total points, exams, and quizzes, ACT Math scores, Math Placement scores, and GALT scores, but not TA assignment, seemed to correlate with the dependent variables. Since ACT Math and Math Placement scores appeared correlated with each other and probably measured the same factor, a student's score on the ACT Math test was used instead of the Math Placement scores because of the wider range of values. A subject's teaching assistant did not seem to have an effect (one-way ANOVA, the largest difference was seen with quizzes, $F_{4,\,195} = 0.901$, $p = 0.464$). The nested models fitted to the data and the partial *F*-test results are summarized in Table 1 of the Supplemental Material.[W] In no case was there evidence to conclude that the assignment to an online section affected the dependent variable, after correcting for the effects of ACT and GALT. In all three cases, the ACT Math and GALT scores were sufficient to explain 25–30% of the variation in the dependent variables.

When we analyzed the pre- and post-attitude test responses, the class as a whole showed significant differences on questions 8, 10, 12, and 13 (see Appendix 2 of the Supplemental Material[W] for the content of the questions). When the student responses were further subdivided by GALT or by treatment, however, no significant differences across these groups persisted. There were differences between student responses when they were divided by teaching assistant, most likely reflecting a strong confounding effect of history between the TA and the student, or between students in each section.

Subjects were assigned to treatments by sections, rather than individually, so it is impossible to completely rule out the possibility of other confounding variables in the results. However, before enrolling in sections students had no knowledge of the experimental conditions, and there was no evidence of widespread adding and dropping after the experiment was announced. A high proportion of consent forms were returned by both control and treatment groups after the experiment was described to the students, indicating that the subjects did not find the experimental method objectionable. Thus it seems reasonable to conclude that any observed results were caused by the experimental treatment. Subjects were not selected from any larger population, so inferences to such a larger population must be made with caution.

Qualitative Analysis

The responses to most of the questions were similar across all four cohorts (see Appendix 3 of the Supplemental Material[W] for the questions). Virtually all students were taking general chemistry as a prerequisite for their majors (question 1 in Appendix 3), whether this prerequisite was explicit or perceived. The majority of the students were planning to major in a health-related field, either pre-medicine or pre-pharmacy.

Interestingly, the reported study habits of students in all four cohorts were quite similar (question 9 in Appendix 3). Students generally read ahead on Sunday night to familiarize themselves with topics scheduled to be discussed in lecture. They spaced their homework assignments over the week; the students in online sections generally attempted their homework for the first time early in the week in order to receive feedback and instruction in problem areas before their final attempt, as they were urged to do. A subtle difference existed between the high-GALT students and the low-GALT students: the former seemed to have less rigid study schedules while the latter were able to more precisely describe their study schedules to the interviewer.

All 14 students indicated that they appreciated and enjoyed multimedia videos and animations while they were learning chemistry concepts (question 14 in Appendix 3). However, this did not always translate into a greater satisfaction with the online materials. The greatest difference between the online and paper-and-pencil sections was in the responses to questions 8 and 12, which asked about the role of computers in the learning process and how their experience would have been different if they had been in the other group. The high-GALT students tended to find working on the computer more distracting and preferred to work through problems on pencil and paper, although they did not think the format of the homework would affect their performance. Generally, their responses to question 12 indicated that they preferred the paper-and-pencil assignments to the online assignments. The low-GALT students, on the other hand, liked receiving the immediate feedback and tended to prefer the online homework assignments. A majority of these students indicated that they believed their performance would improve if they had been in an online section or decline if they had been assigned to a paper-and-pencil section. They also reported a greater satisfaction with the online materials in general.

Discussion

Effects of the Homework on the Students

As outlined in the Results section, there was no measurable quantitative effect on the students' outcomes. Since the primary difference was in the presentation of the homework rather than in the content, it is not surprising that there was no significant difference in student performance, although the literature had suggested that the inclusion of feedback might have had a positive effect. Many confounding factors may have obscured this result, however. One of these is a great deal of anecdotal evidence that the cohorts were not isolated as to the experimental treatment. Several students assigned to text-based homework sections reported accessing their friends' online homework in order to obtain the feedback on the material.

It is interesting that the high-GALT students expressed less enthusiasm for the online homework while the low-GALT students were more positive. Two explanations that are not mutually exclusive for these results are possible. First, with most school activities still based on paper-and-pencil homework problems, the high-GALT students may have been less comfortable with the novelty of the online homework, preferring a strategy with which they were familiar. Second, it is possible that the low-GALT students, in general, tended more toward less abstract and mathematical learning styles, preferring visual, spatial, and hands-on learning situations *(61)*.

While still limited by the technology available, in many instances, the online homework included graphical, animated, and dynamic media as part of the questions, possibly stimulating low-GALT students who prefer other learning styles. For example, several questions used the browser plug-in Chime *(62)*, which allows the dynamic three-dimensional display of molecular structures that would otherwise have to be shown in a static image or paper-and-pencil symbolic diagram. The use of images also made it possible to construct more conceptual questions. (See questions 2 and 3 in Appendix 1 of the Supplemental Material.[W])

Implications

Computer-based instruction has promised to facilitate more effective and personalized instruction to large numbers of students while reducing the time spent by the instructor assessing student work. Our results indicate that the second part of this promise is closer to reality. The quantitative and qualitative results indicate that the online homework cannot be considered more effective to the student: objective scores were unchanged and student opinion was split over whether the online homework was more or less effective than traditional homework. After an initial investment of expertise and time, however, the time saved was substantial. Over 200 students took the course, and in the odd sections, neither the teaching assistants nor the instructor had to grade a single homework assignment. There were technical problems with the server and the homework assignments that needed continual attention during the term, but a single technical assistant to the course could easily resolve these. The potential for personalized, detailed, rich feedback to the students at low cost to the instructor in terms of time spent grading is an advantage that should not be overlooked.

Another consideration is that the work described here represents only a first attempt by the authors to integrate class assignments and computer technology. Efforts are ongoing at the university involved in the study to incorporate computer technology into other class activities (e.g., quizzes, exams, and pre-laboratory assignments) in effective ways. Second, many of the homework assignments used in this study were primarily textual, similar to problems in traditional textbooks, with only the feedback added. Additional study is needed to assess whether more dynamic and interactive assignments, with a greater number of graphics and animations, will be more effective in promoting student learning. Interactive tutorials are also being developed that should have a greater impact on student learning than homework problems alone. It is especially promising to note that students with low-GALT scores, who typically struggle in chemistry courses, found their experience more satisfying with the inclusion of online homework.

In conclusion, we believe that computer-assisted instruction is still developing. There are still many variables to be evaluated in determining the most effective way to harness the capabilities of the computer to improve instruction. Doubtless, many variations of computer-based instruction will eventually be devised, suited to each instructor's style. Additional research is needed to determine the parameters of effective computer-aided instruction programs in the classroom of the future.

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Note

1. The effect size is defined as the difference in the means between an experimental and control data set divided by the standard deviation of the control set *(63)*. It provides a way to compare quantitative results from different reports in the literature.

[W]Supplemental Material

Sample online homework questions, pre- and post-exposure attitude surveys, the interview protocol, and a tabular synopsis of the statistical analyses are available in this issue of *JCE Online*.

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