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Improving Instruction and Reducing Costs With a Web-based Learning Environment

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Abstract: An electronic learning environment manages homework assignments for more than 3,000 students in large enrollment courses at the University of Massachusetts at Amherst. Originally developed to fulfill a critical need in the Chemistry Department, the system has been so successful that it has been expanded to other departments and supports new, interactive forms of learning over the World Wide Web. Careful and thorough evaluation has been an integral part of the system's development, which has now been adopted by ten departments and seven other institutions. We report here on the costs and benefits of using the basic system and on significant increases in student performance.

1. Enhanced Undergraduate Teaching

Costs in higher education place tremendous pressure on institutions. Faculty lines are difficult to acquire and budgets for TA resources are often reduced. These pressures are acute in teaching "service" courses such as general chemistry and physics required for majors in many other departments. For example, the two-course general chemistry sequence offered by our Chemistry Department serves 1400 students from 35 departments. The challenge was to develop an effective system that supported increased student study time and reduced the need for more instructor resources.

The Chemistry Department embraced this challenge almost 15 years ago when it switched from a recitation-based model to the exclusive use of electronic homework as a means of encouraging students to work with the material on a regular basis outside of class. Working closely with the Computer Science department, the Chemistry Department replaced its original system with OWL (Online Web-based Learning) a modern web-based homework system complete with enhanced authoring tools (Hart et al., 1999a). Current goals are to:

1) Expand the use of OWL in other large service courses. This effort started with the Physics Department in the Fall of 1997 and has since expanded to over ten departments, such as Geosciences, Biochemistry, Nutrition, Education, Foreign Languages and Mathematics. We will use Physics as a case study in this paper because we have carefully documented both the costs/benefits to the department in adopting OWL, and because we have seen impressive learning outcomes associated with OWL use over four semesters.

2) Turn OWL into a true online learning environment. By leveraging the university's investment in the creation of OWL, we have acquired significant grant funding to expand OWL's capabilities, creating and deploying online learning activities that are more sophisticated than anything available to date. We have carefully evaluated the impact of these new activities in the large-enrollment general chemistry courses (1400 students/semester) and are beginning to see impressive results, reported below. The simulation and intelligent tutoring systems record and respond to large numbers of students with very low overhead for course instructors.

Of significance is the size of the testbed: 1400 regular users in Chemistry, 1000 in Physics and 600 in Geosciences. Such sample sizes give us greater confidence that we can identify real impacts on learning resulting from OWL use.

The "traditional" system of recitation sections and weekly quizzes was extremely labor intensive -- 72 faculty contact hours each week was spent in Chemistry, plus an even greater amount of TA time spent on grading. Eliminating recitation sections saved significant faculty resources (critically, at a time when large numbers of faculty were retiring) and produced a pedagogically superior model.

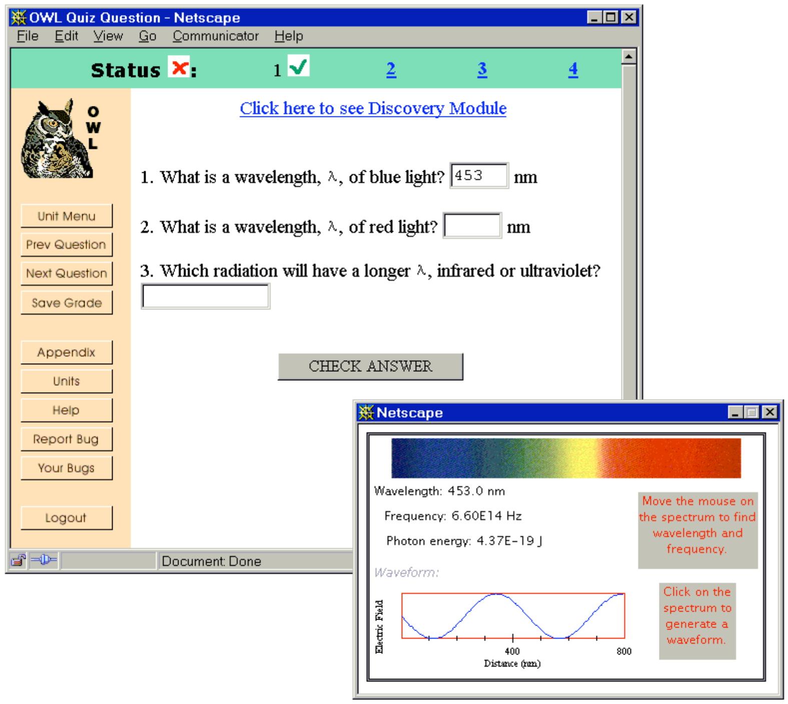

Figure 1: Discovery Exercise Modules in OWL

OWL provides a platform-independent delivery system available anytime from anywhere. In a typical semester over 50,000 quizzes are taken, with more than 5000 in one day during peak usage periods. 75% or more of these quizzes are taken outside the Chemistry Department's Resource Center (i.e. in students' rooms or other labs on campus).

2. Evaluation Studies

Third-party evaluation of student performance was incorporated from the outset. Qualitative feedback in chemistry from a survey of 330 students (Figure 2) shows that students believe OWL helps them learn the material covered in class and in particular, that the direct feedback is very helpful. These results come from a sixteen-question survey administered as part of the course evaluation or in conjunction with the final exam. Typical questions include "OWL helped me to learn the material covered in class" and "OWL feedback helps me learn from my mistakes."

Wider campus distribution is a primary goal of OWL and new departments want to see evidence that OWL saves resources and is an effective pedagogical tool. We have worked with experts in cost modeling and educational psychology[1], and are preparing a cost/benefit analysis of OWL use in four departments over two years. We studied cost savings and student performance gains in the Physics Department.[2] Student exam scores improved while using OWL (see Figure 3). The professor taught Physics I without the use of OWL in 1997 and then with OWL in subsequent years. He taught all of the students himself, using the same curriculum and covering the same material in as close a fashion as he could across semesters, given the questions and topics brought up by the students.

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[1] Professor Michael Royer of the University's Psychology Department.

[2] Collaborators in the Physics Department include the Associate Department Head Professor Arthur Swift and the co-director of the Scientific Reasoning Research Institute (SRRI) Professor Jose Mestre. SRRI studies Physics education from K-16.

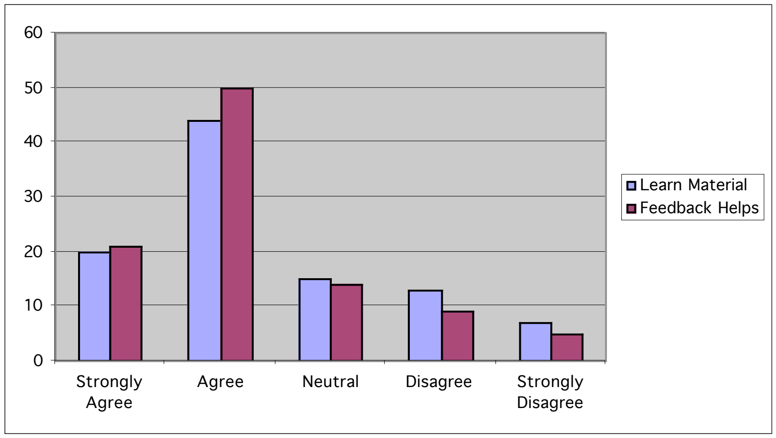

Figure 2: OWL Survey with 330 students

Institutional data tells us the control group is comparable to the treatment group, even though they are one and two years apart. The improvement can not be attributed to different Scholastic Aptitude Test scores nor to weaker students dropping the course. These factors were measured in all three years and no significant differences were found. The average score increased in most semesters in which OWL was used. All of the differences are significant except forExam 1 in the second OWL semester and Exam 3 in the first OWL semester.

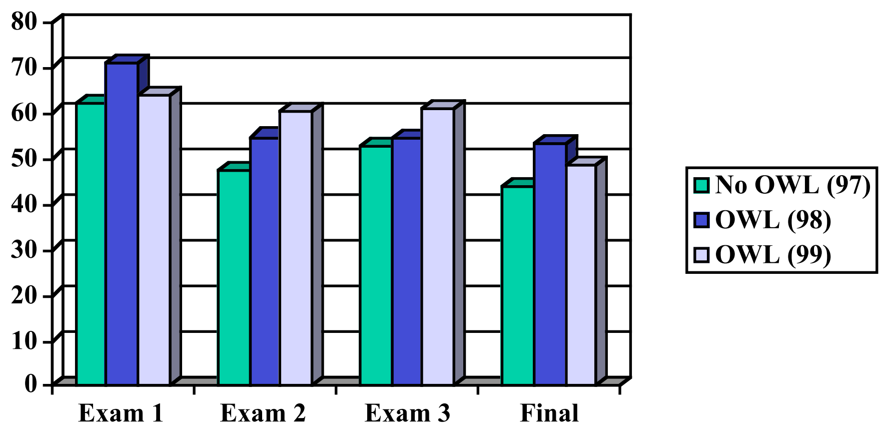

Figure 3: Exam Score Averages in Physics I
(one semester without using OWL and two with OWL)

Overall, the semesters with OWL had a substantial advantage in test scores when compared to those without. Since the only major difference between the content of the semesters was the presence of OWL, this finding is very promising. The benefit conveyed by the use of OWL seems to be consistent over time.

In general, the standard deviation from the mean test score decreased on each test (see Figure 4). It was different across the semesters, with the OWL semester generally having the same or lower variance in test scores. This indicates that OWL is helping to raise the test scores of those who otherwise would have done worse, thereby tightening the distribution.

The weakest students seem to benefit most from OWL use (see Figure 5). When the students in the physics classes were divided into quartiles based upon their exam performance (Quartile 1 contains the weakest students and Quartile 4 the strongest), a clear pattern emerged in which the OWL advantage (the amount by which the average test score in the OWL semester was greater than that of the non-OWL semester) was greatest for the weakest students (first and second quartiles) and least for the strongest students (fourth quartile). This pattern was consistent for both semesters during which OWL was used.

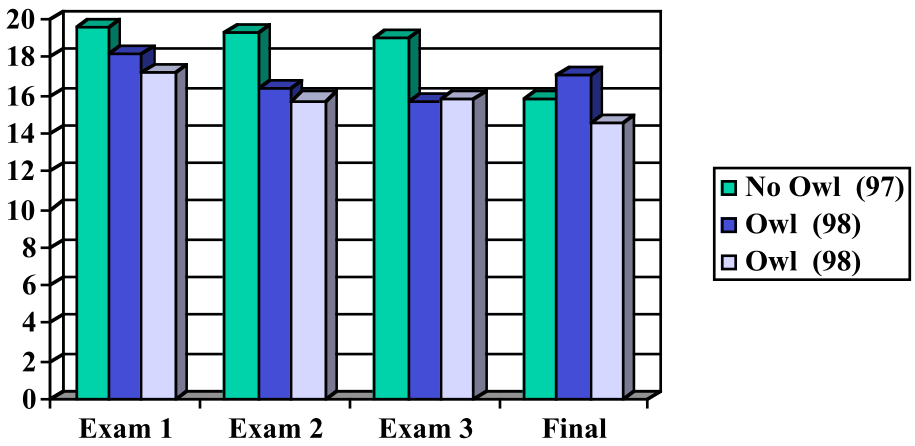

Figure 4: Standard Deviations of Exam Scores in Physics I

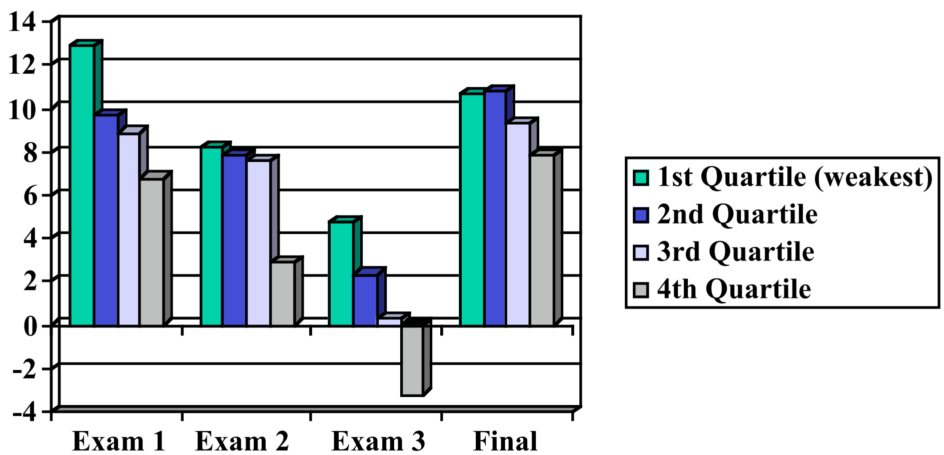

Figure 5: Advantage on Exam Scores Due to OWL is Greatest for Low Ability Students

3. Effective Implementation of the Homework System

OWL contains large databases of questions authored by faculty from many departments. In addition to the electronic questions and feedback, Chemistry faculty have developed Guided Discovery Exercises. Basic OWL provides electronic homework for students, posts assignments, grades them automatically, and stores the results. Students can repeat assignments until they master them by passing a required threshold. Feedback provided by the question author instructs the student when wrong answers are given. This feedback cycle is one of the primary benefits of OWL. Course management and authoring tools allow the instructor to manage the course and track student progress. There are currently over 3500 students in ten departments using OWL each semester.

OWL has been extended from an online quizzing system to an interactive learning environment through incorporation of resources such as Guided Discovery Exercises and intelligent tutoring – all web-based. OWL's open architecture allows the incorporation of these new resources by treating them as additional quizzes or homework assignments. Guided Discovery Exercises allow students to interact with a multimedia simulation or

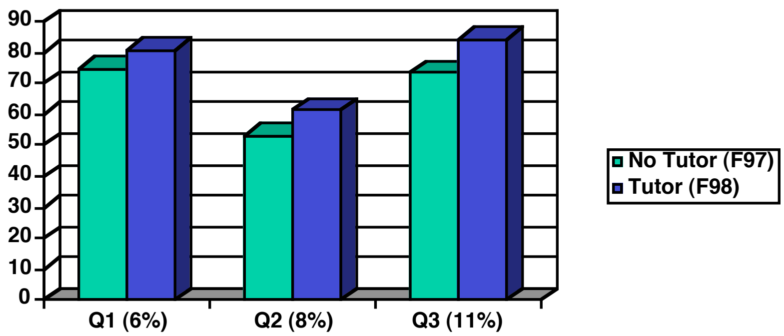

Figure 6: Stoichiometry Tutor -- Percent Correct Responses for 776 and 438 students, respectively

visualization activity, using leading questions to guide them to the "discovery" of basic laws and concepts such as gas laws or electromagnetic radiation. These exercises allow students to interact with a multimedia simulation or visualization activity such as that shown (in Figure 1) using leading questions to guide students to the "discovery" of basic laws and concepts such as gas laws or electromagnetic radiation. Prof. William Vining of the Chemistry Department has created the library of 65 such exercises, collectively called Chemland (see http://soulcatcher.chem.umass.edu/web/projects.html), though these exercises only run standalone on a PC. Forty of these exercises have been ported to Java to run on the Web under OWL's control. These are integrated into OWL (see http://owl.chem.umass.edu/Chemland/chemland.html). For each of the ported Chemland exercises a set of guiding OWL questions effectively simulates the guidance provided when a skilled instructor uses that Chemland exercise in the classroom.

Intelligent tutors tailor their instructional strategies to the needs of the individual student, varying the pace of instruction and presenting problems in such a way as to challenge the student at the appropriate level. Students are required to interact with the instructional material to demonstrate facility with it. OWL is being extended to incorporate more than a dozen intelligent tutors. A Stoichiometry Tutor presents each student with problems that start with basics and gradually increase in difficulty, varying this increase according to the perceived ability of each student (Eliot, 1999). If the student can solve the given problem, the tutor generates another, slightly more difficult one. If the student makes a mistake, the tutor gives hints by breaking down the problem into its constituent subproblems. If mistakes are still made, the tutor provides additional, more fundamental hints in a recursive manner, until it bottoms out in the most basic chemistry (e.g. "the atomic weight of Oxygen is 16").

The Stoichiometry Tutor underwent large-scale evaluation during the Fall 1998 semester. Results, which were very positive, are reported in (Hart et al., 1999) (see Figure 6). Tested with 859 students, the tutor produced impressive improvements with students scoring 6-11% better than those not using the tutor. Pretests of these students using the same three exam questions showed that their knowledge of Stoichiometry was minimal (in the best case, only 14% of students could answer a question correctly). The same 3 questions were included in the finals for three of the five course sections, giving us an experimental group of 438 whose scores could be compared to a control group of students from the previous fall who did not use the tutor.

Qualitative evaluation measured students' reactions. Of 578 respondents, 58% agreed or strongly agreed that the tutor was a good use of their time, 72% that it improved their understanding of Stoichiometry, and 71% that the tutor helped them learn from their mistakes. On the flip side, only 10% felt the tutor was hard to learn how to use, though 38% said they had experienced some frustration when the tutor had problems (several performance problems with the tutor only surfaced when it had 859 regular users!). Only 22% felt more help should have been provided in how to use the tutor.

A Lewis Structures Tutor has been developed and evaluated with over 600 students (see Figure 7). Lewis Structures is a systematic method for drawing molecules in two dimensions and is used to infer molecular geometries. This tutor is very interactive, allowing students to drag icons representing atoms, bonds and electron pairs into proper alignment and get coaching when they encounter difficulties. The Lewis Structures Tutor runs as a Java program and uses Java server-side technology to manage each student's session. The chart above shows that the 350 students in the sections who were assigned to use the tutor responded correctly to the exam questions about Lewis Structures significantly more often than the 295 students in the sections who didn't use the tutor.

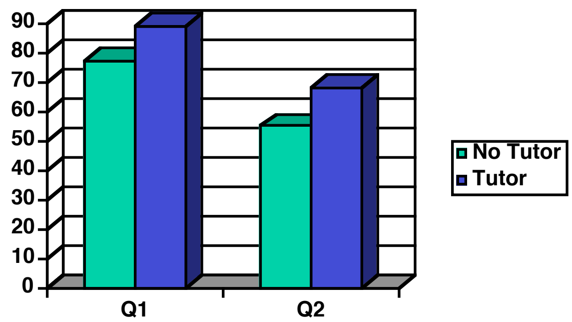

Figure 7: Lewis Structures Tutor --Percent correct responses for 600 Students

4. Cost Savings

Physics began using OWL with two courses and quickly moved to seven. If we consider its use in Physics up through five courses (900 students), we can analyze the cost savings realized by the department (and by extension the University) for this use. The costs for OWL courses, including set up and maintenance, authoring new courses, cost of a TA, and administration, totals around $25,000/semester. The savings come from the number of recitation sections dropped, which total 74 over these three semesters. This results in savings of instructor time roughly equivalent to a full instructor each semester (Physics' average faculty salary is $83,000/year and fringe benefits put this number over $100,000/year) and in savings of TA time for grading of $20,000/semester. There is also a savings in space as classrooms used for recitation sections are returned to the University pool for reallocation (the computer lab.

5. References

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Acknowledgments

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