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OWL: An Integrated Web-based Learning Environment

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Abstract: OWL (Online Web-based Learning) is an electronic learning environment developed for General Chemistry and currently being adopted by other disciplines. Basic OWL provides a powerful, web-based electronic homework model used by thousands of students each semester. OWL's open architecture allows for extensions that expand its scope from the delivery of straightforward electronic quizzing to the offering of a richer interactive learning environment. Such extensions include guided discovery exercises and intelligent tutors, numerous examples of which are currently being created and tested in large enrollment General Chemistry courses. In this paper we describe OWL and its use on campus. We also report on a number of OWL evaluation studies underway, including some preliminary findings from formative evaluations of OWL's use in classes and of some of Owl's extensions, and the first large-scale evaluation of a Stoichiometry Tutor that is integrated into OWL and that shows significant increases in student performance.

Developing a New Model for Homework in Large-enrollment Classes

Electronic homework has been used in the General Chemistry Program at the University of Massachusetts for 12 years. The first version was implemented using the Plato system, a commercial courseware creation package used by many universities in a variety of disciplines. The two primary General Chemistry service classes enroll between 1200 and 1400 students each semester from 35 different majors. As with any large service course, methods to encourage students to keep up with current assignments are important factors in the success of these courses. Before the introduction of electronic homework eleven years ago, General Chemistry students attended weekly recitation sections lead by faculty members, and took a quiz at the end of each section. Quizzes were graded by instructors and results were distributed one week later. While this system created the desired motivation for students to stay current with the curriculum, it was extremely labor intensive – 72 faculty contact hours each week, plus an even greater amount of TA time spent on grading. A serious pedagogical drawback was the lack of immediate feedback to the students about their work; getting a quiz back a week later provided little opportunity for students to learn from their mistakes.

The Chemistry Department's adoption of electronic homework was motivated in large part by a looming increase in the number of faculty retirements. As is the case nationally, the University was unwilling to replace these retiring faculty members on a one-for-one basis, which meant that faculty resources were under increasing pressure to cover the large contact-hour commitments required by the recitation sections. Electronic homework was seen as a way to cover these commitments with fewer faculty contact hours while maintaining the motivation factor for students to keep up with their coursework.

Adoption of electronic homework afforded the opportunity to change the quiz/homework model at the same time. Because the computer grades automatically, students could take and retake “quizzes” repeatedly until they demonstrated mastery of each topic. Random selection from a large pool of questions for each quiz meant students would seldom see a question repeated, so that instructors could build in an immediate feedback cycle – after a student submitted an answer, the correct answer and a body of informative feedback was displayed that allowed the student to learn from his or her mistake immediately and apply that knowledge to the next question(s) seen. A large part of the success of this model came from the creation of a Chemistry Resource Center, a large room filled with computers that students use for their electronic homework assignments. This room was (and still is) staffed with TAs and faculty who can give help and feedback to students while they are doing their electronic homework. Instructors, TAs and students all felt that this was a better use of their time than recitation sections.

The Chemistry Department was keenly interested in the results of this new model. Several of the authors carefully compared student performance in the years previous to the model’s adoption and in the years immediately after. While there was no improvement in grades, the real gains were seen in students’ affective responses – surveys showed that students overwhelmingly preferred the new approach. There were of course big gains in the cost efficiency of delivering the course. Given that the new model saved resources, was preferred by students, and did not negatively impact student performance, it was wholeheartedly embraced.

Online Web-based Learning for General Chemistry

The Chemistry Department began a collaboration in 1996 with the University’s Center for Computer-Based Instructional Technology (CCBIT) to replace the by-then antiquated Plato system with a Web-based version, OWL. By adopting Web technology, OWL provides a platform-independent delivery system that is available all day from any web-linked computer a student or instructor can work. It also allows developers to incorporate large off-the-shelf software components for web service, databases and middleware. The OWL system was used by the full Chemistry courses for the first time in the spring of 1997, and has been used successfully ever since. In a typical semester over 50,000 Chemistry quizzes are taken, with more than 5000 in one day during peak usage periods. 60-70% of these quizzes are taken outside the Chemistry Resource Center (i.e. in students’ rooms or other labs on campus). Student surveys administered each semester show a high degree of satisfaction with OWL, including a recognition that OWL helps students learn the material and keep up with the class.

A host of similar systems have been created in recent years, such WebAssign at North Carolina State University [1], both CyberProf [2] and Mallard [3] at the University of Illinois at Urbana-Champaign, and even commercial versions such as EBSCO’s CyberExam. Most of the commercial web-based courseware development packages (e.g. Web-CT, Web-in-a-Box and TopClass) provide online quizzing capabilities. OWL, though developed independently, shares many important features with these systems. In addition, OWL has advanced features such as parameterized questions, user-defined multimedia and Java tags, and sophisticated course management tools. It is also missing some useful features found in one or more of the other systems (e.g. essay submission, audio support) that will be added soon. One feature of OWL that sets it apart from others is that, by design, its architecture is open for the addition of new learning modalities such as guided discovery modules and intelligent tutors, and for the incorporation of curriculum content materials whose use by students can be tracked by the system. These extensions to OWL are described below.

OWL is now used in five Physics & Astronomy classes with almost 1000 students each semester. Like Chemistry, Physics has been able to eliminate discussion sections and TA time spent on grading. In one class, TA requirements were halved while the amount of graded homework for each student increased nine times over the previous, non-OWL semester. In this particular class, the instructor was able to measure a significant increase in student performance over the previous semester (a 6-8 point increase in mean scores for each of three midterms and one final exam), some of which can be attributed to the increased time spent on homework

[1] See http://wwwassign.physics.ncsu.edu/.
[2] See http://ntx2.cso.uiuc.edu/wss/services/cyberprof/.
[3] See http://www.ews.uiuc.edu/Mallard/Overview/.

assignments – students reported a doubling of the time spent weekly on homework assignments from one semester to the next [4].

In the coming year (1999) OWL will be used in a wide variety of departments, including Geosciences, Engineering, Microbiology, Education, Spanish & Portuguese, Art History, Mathematics, Biochemistry and Entomology. These departments have been selected by the University to participate in disseminating OWL throughout the campus. In future years OWL will be provided as a service to users from all departments, with support from the University's academic computing facility. OWL is also being tested on other campuses. The Chemistry Department is supporting classes at UMass/Dartmouth and at Tuskegee Institute.

Basic OWL runs in Windows NT and uses straightforward Common Gateway Interface programming written in C++. It uses the Netscape's Enterprise Webserver and Microsoft's SQL Server database program. Students and content authors (instructors, teaching assistants) can access OWL using the latest versions of Netscape Navigator and Internet Explorer.

Using OWL's Open Architecture to Integrate Interactive Learning Activities

The basic OWL system has been created with funding from the University. External funding has been obtained to extend OWL from an online quizzing system to an interactive learning environment through the incorporation of such resources as guided discovery exercises and intelligent tutoring – all web-based. OWL's open architecture allows the incorporation of these new resources by simply treating them as additional quizzes or homework assignments, all delivered over the Web. Students are assigned to work with a guided discovery exercise or intelligent tutor that is embedded in OWL, using it to engage in a learning activity much like an online laboratory. Once the student finishes the exercise, control is returned to OWL and the exercise results are stored with the student's permanent record in OWL's database. This allows instructors to assign active learning tasks in addition to quizzes and track students' progress in completing them.

Discovery Exercises

Guided discovery exercises allow students to interact with a multimedia simulation or visualization activity, using leading questions to guide them to the "discovery" of basic laws and concepts such as gas laws or electromagnetic radiation. This technique has been used successfully in the classroom for many years by one of the authors, Vining. He has created a library of 40 or more such exercises, collectively called *Chemland* [5], that are being recoded in Java to run under OWL's control. 33 of these have been ported to Java, and they are now being fully integrated into OWL [6].

An example of a guided discovery exercise embedded in OWL is shown in (Fig. 1). This Java applet (lower right window), designed to guide the student through an exploration of the physical laws governing the electromagnetic spectrum, allows the student to run the mouse over a bar representing the visible light spectrum (shaded bar at top of small window). As the mouse moves over points in the spectrum, the corresponding values for wavelength, frequency and photon energy are displayed. A click of the mouse at any point shows the waveform for that point in the graph (lower left). The student's task is to answer a series of OWL questions (see top window) that start with the basic mechanics of moving the mouse and noting the resulting parameter value changes (as we see in the three questions shown), but will lead through a careful progression that first familiarizes the student with individual parameters (e.g. changes in wavelength up and down the spectrum), then examines the relationships between parameters (e.g. how does frequency change as a function of wavelength?), and finally requires that the student generalize these observations in order to answer questions about the basic laws governing the behavior of electromagnetic radiation. All question responses are stored in the OWL database so that instructors can track students' progress.

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[4] Personal communication with the instructor, Prof. Jose Mestre.
[5] For the full set of Chemland exercises see http://soulcatcher.chem.umass.edu/web/projects.html.
[6] For Java recodings of Chemland exercises for use in OWL see http://owl.cs.umass.edu/chemland/chemland.html. 25 of the exercises have been licensed to a major Chemistry textbook publisher, to be used in a website accessible to users of their textbook.

For each of the 33 Chemland exercises integrated into OWL a set of guiding OWL questions must be authored that effectively simulate the guidance provided when a skilled instructor uses that Chemland exercise in the classroom. We have currently completed question sets for 21 exercises, and have just begun testing them with small groups of students (results are not yet available). Full scale testing of these exercises will begin in the Spring 1999 semester as they are integrated into the normal cycle of general chemistry homework assignments.

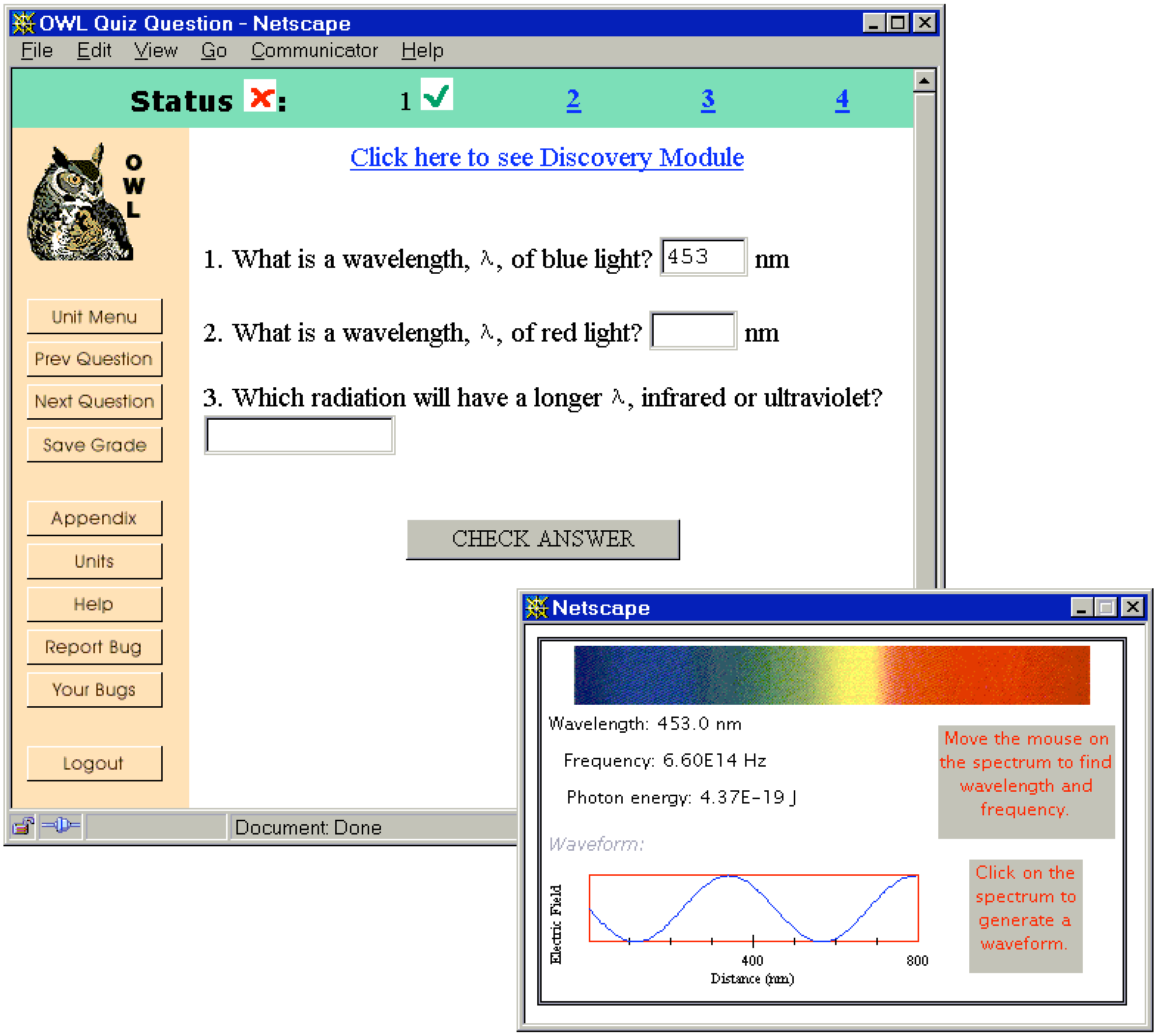

Figure 1: Electromagnetic Spectrum Discovery Exercise from Chemland integrated into OWL

Intelligent Tutors

Intelligent tutors customize their instructional strategies to the needs of the individual student. They vary the pace of instruction, presenting problems in such a way as to challenge the student at the appropriate level. Students are required by the tutor to interact with the instructional material to demonstrate facility with it. OWL is being extended to incorporate intelligent tutors including two already developed. A Stoichiometry Tutor has just undergone large scale evaluation during the fall semester. Results, which were very positive, are reported below. A Lewis Structures Tutor has also been developed and undergone initial formative evaluation. Results suggest it can be effective but has several small, correctable flaws that will make it more so. Large scale testing of this tutor will occur in the spring. Tutor development for OWL is supported by external funding (see Acknowledgments): 15-20 tutors will be created and incorporated into OWL in the next two years.

Stoichiometry Tutor

Stoichiometry is one of the basic curriculum units in first semester general chemistry, though approaches to teaching it vary. Several years ago it was decided that the General Chemistry Program would move teaching of Stoichiometry from lectures to labs. The labs were reorganized to cover the various topics in Stoichiometry over the semester. However, after several semesters trying this approach, the consensus was that students needed additional help – they weren't learning Stoichiometry as well as they had before. Rather than move it back to the lecture (and bumping some other important topic), an intelligent tutor already under development for OWL was made a requirement for all beginning general chemistry students (859 in Fall 1998).

The tutor presents each student with problems in Stoichiometry that start with basics and gradually increase in difficulty, varying this increase according to the perceived ability of each student. 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"). Stoichiometry by its nature lends itself to this kind of approach, and the tutor leverages this problem structure to great effect. Students who use the tutor log into OWL and select the tutor as their current assignment. The tutor tracks the student very carefully and forms an assessment that it passes back for storage in OWL's database. Work with the tutor was broken into three separate assignments spread over six weeks, so students spent considerable time working with it. Each student had to solve a minimum of 29 problems over this time.

Roughly 30 students used the tutor in the summer school of 1998. In preparation for assessment of the tutor a series of three Stoichiometry questions were added to the final exam in many sections in the Fall of 1997. These questions were repeated on exams in the summer and fall finals in 1998. This provides a baseline of performance we can use to assess whether students working with the tutor know more about Stoichiometry as a result. The 30 students who used the tutor last summer showed impressive improvement: they scored 5-10% better than students in the previous fall, but the sample size too small for these results to generalize.

During the past fall the 859 students using the tutor provided a large experimental population. 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 the students from the previous fall (who didn't use the tutor). Results are summarized in (Tab. 1).

Final Exam Questions	**FALL 97**			**FALL 98**			**%Gain**	**Asymp. Signific.**
	N	**#Correct**	**%Correct**	**N**	**#Correct**	**%Correct**		
Question 1	622	464	74.6%	438	353	80.6%	6.0%	.022
Question 2	777	413	53.2%	438	269	61.4%	8.2%	.005
Question 3	776	569	73.3%	438	369	84.2%	10.9%	.000

Table 1: Data from large-scale evaluation of the OWL Stoichiometry Tutor shows that students who used the tutor in the Fall of 1998 performed significantly better on a series of three Final Exam questions than did students in the Fall of 1997 who didn't use the tutor.

Each table row records the results on one of the three exam questions, first for the Fall of 1997 and then Fall 1998. **N** shows the sample sizes, the number of students who responded to each of the three questions on the respective exams. **#Correct** is the number of correct answers and **%Correct** the ratio of the first two. **%Gain** shows the increase in **%Correct** from the non-tutor group to the tutor group, which range from 6% to almost 11%. While these gains are consistent with those from the small summer sample group, the final column (**Asymptotic Significance**), taken from a 2-Way Chi-Square test on the data from each of the exam questions, shows these results to be highly significant.

We also conducted surveys to assess the affective responses of students who used the tutor. Students were asked to respond to 11 questions by selecting one of five options ranging from "Strongly Agree" to "Strongly Disagree". 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.

Lewis Structures Tutor

A second tutor has been developed to teach Lewis Structures, a systematic method for drawing molecules in two dimensions that 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. As with the Stoichiometry Tutor, students log into OWL and choose the Lewis Structures assignment, from which point OWL passes the student ID and assignment information to the Tutor. To complete the assignment, the student must draw one or two Lewis Structures at each of seven difficulty levels. OWL stores the student's assignment progress (whether partially or fully completed) whenever a session is closed. The Lewis Structure Tutor runs as Java program and uses Java server-side technology to manage each student's session. The Lewis Structures Tutor has been evaluated formatively with one section of 164 students. The students scores on two midterm exam questions were compared to scores on the same questions from two sections who did not use the tutor. The results were ambiguous – better on one question and worse on the other – leading the authors to suspect that several hinting techniques used in the tutor actually allowed students to find shortcuts to solving the problems rather than work them out to completion. These shortcuts will be eliminated for full scale testing in the Spring of 1999.

Support for Building Tutors Within OWL

Up to this point tutors we have developed for integration into OWL have been treated as external modules that are programs in their own right and communicate with OWL via message passing. However, we are considering the benefits of building simple tutoring capabilities directly into OWL. While the current external-module approach is good for tutor developers who need a clean interface to OWL's inner workings, it prevents faculty instructors (who are not intelligent tutor programmers) from using their questions in a tutoring context. This is creating a situation where information is being duplicated, as in Stoichiometry, where the Tutor uses its own database of information that is distinct from OWL's question set. Such a tutoring facility, if built into OWL, will not have the sophistication of standalone tutors, but will provide an avenue for instructors to make good dual-use of the knowledge they put into OWL. Both tutoring models will be supported in the long run.

Adding Curriculum Content to OWL

OWL will soon provide the capability to present new curriculum content. The first user of this facility will be the University's Office of Environmental Health and Safety (EH&S), which has tremendous training and certification responsibilities for the campus. For example, over 3000 faculty, staff and student employees must be certified or re-certified annually for Hazardous Materials management. Once this capability is built in, OWL will be able to track the student's or trainee's use of such materials, much as it tracks the results of homework activities now. In order to do this, OWL will be interfaced with the University's employee database, allowing it to track EH&S training requirements and progress for each department on campus.

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