

InterChemNet: An Integrated Instrumentation and Web-based Course Management System for the General Chemistry Laboratory

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The InterChemNet (ICN) system was designed to overcome some very real barriers to providing an active learning environment in large general chemistry classes by targeting the lab portion of the course. At the University of Maine, chemistry labs had been taught with about 550 students doing the same thing in a given week. All students would be asked to read the same handout, work out the same pre-lab exercises, perform the same manipulations, and hand in lab reports that were essentially identical. While this approach is efficient as far as preparation and grading is concerned, it hardly inspires a sense of curiosity in students (1,2). It definitely does not convey much to students about how scientists do science. At the other extreme, by contrast, highly individualized and interactive lab sessions have been proven to be highly effective in helping students construct their own learning but at a high cost in resources and teacher time (3,4). In this context, ICN began at the University of Maine in 1993 to change the environment for hands-on and active learning in the laboratory program and to provide tools to manage an individualized learning experience.

The ICN program is a Web-based platform to support instrumentation, curriculum delivery, and evaluate the effectiveness of laboratory curricula. At the heart of the system is a relational database to organize multiple courses and sections simultaneously. Data can be collected and subsequently viewed through a Web-browser using interface modules designed specifically for students, instructors and course developers. Instructors set up a course by entering curriculum materials such as lab handouts, individualized assignments, and online questions. Automatic data retrieval allows instructors to review student responses to evaluation questions immediately in order to monitor student progress. Students use the system to collect and analyze spectroscopic data, track their progress in the lab, choose experiments each week, and access curriculum materials and safety information.

In the next section we briefly describe the components of InterChemNet and show how these features promote active learning. We focus on a) the economical introduction of spectroscopic instrumentation, b) the use of the Web to facilitate and enhance course management practices, c) the

use of technology to offer an array of student-centered activities, and d) assessment of student learning and evaluation of course materials using integrated on-line tools. We then present some preliminary evaluation data from the ICN system. Finally, we discuss the implications of our work and outline some of the ways ICN can be used in other institutions, disciplines, and educational settings.

Overview of InterChemNet

The ICN project's initial goal was to provide access to modern instrumentation to large numbers of general chemistry students. The ICN program overcame an ease-of-use barrier by creating a student-friendly instrument interface suitable for an educational setting and overcame an economic barrier by creating a Web-based computer infrastructure to minimize the number of instruments needed.¹ Once this infrastructure was in place, we realized that the same technology could be used to address other important problems in the general chemistry lab program, including course management and curriculum development and evaluation.

Introduction of Modern Instrumentation

ICN began with the belief that students in introductory science courses should have hands-on experience with modern chemical instrumentation (3,5-13). This kind of laboratory experience is valuable because it illustrates the principles of the science while exposing students to modern practice, using instruments comparable to those found in a research or medical analytical laboratory. The ICN program networks instruments like full-scan UV-visible and FTIR spectrometers. Students use valuable instrument time only to scan samples, taking only about 1 minute per spectrum to acquire and store needed data. The shifting of data analysis from scarce instrument consoles to ubiquitous PCs results in a dramatic increase in the efficiency of instrument use;² this allows us to serve the needs of 550 students each week (~90 students per lab period) with 4 UV-visible instruments³ and 4 FTIR machines.⁴ We estimate that each technique costs between about \$2 and \$10 per student credit hour to implement and maintain.⁵ The system is easily scalable so that larger or smaller programs can purchase and use more or fewer instruments. Existing instruments can be integrated into the system with the addition of a short control program module. We note that the ICN approach is slightly different from some other networked instrument systems^{6,7} because it

relies on research grade instruments with a simplified interface (14).

Since every student's full spectrum scans (whether UV-vis or IR) are unique and are safely stored for later use, data analysis can be performed on any computer that can connect to the server via the Internet to retrieve the stored spectral data. Students use an account name and password to access the spectral data through the Web browser, and a uniform interface makes it easy for students to display, analyze and print their data. It is important to stress that ICN uses a number of real instruments in much the same way that researchers now use multiple techniques to analyze their samples. Figure 1 shows the Web-based data analysis screen for a UV-visible experiment. The spectral analysis interface mimics many of the features of commercially available programs. However, the interface that we have constructed is much simpler than that provided by the instrument makers. It is our experience that the simplification of the data screens helps focus the students' attention on the data that the technique provides rather than on figuring out the "system". Thus the interface for FT-IR data is quite similar to that for UV-vis experiments. Perhaps most important from a pedagogical point of view is the ability for several students to display their own spectra simultaneously on one screen. This feature allows students to collaborate on group projects.

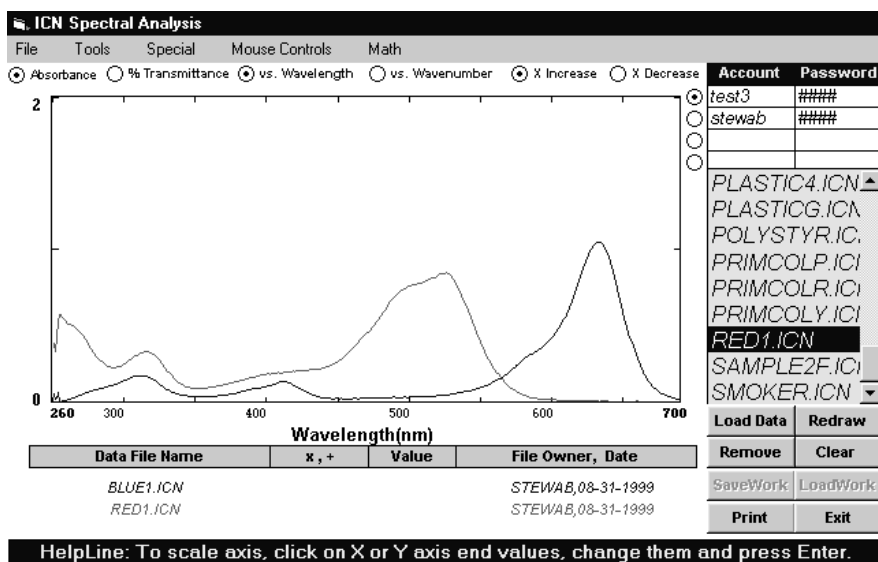


Figure 1 Students use an account name and password to access their spectral data through the Web browser. A uniform interface makes it easy for students to display, analyze and print their data.

By 1998, over two thousand students had used UV-vis and FTIR spectrometers with InterChemNet (15), and the hardware and software infrastructures for managing very large streams of student-generated data efficiently and economically were in place. From a course management perspective, the generation and handling of large amounts of individual data showed us that we could provide a more individualized experience even for large courses. The application of these ideas to other aspects of course management and delivery are the subject of the next sections.

Lab Management

The program has powerful functionality that allows a user to set up a course as well as monitor multiple sections within a course. These features are accessed through an “Administrator Progress Page” and can be used to build a course by selecting the sequence and availability of experiments. A key innovation, to be described in detail below in conjunction with the student module, is the ability to offer multiple experiments during a given lab period. Lab handouts, assignments, and quizzes can be entered and edited in a series of linked pages. The administrator establishes the number of sections and the lab instructor associated with each section. The lab manager or instructor can also control the times at which various curricular resources are made available online to students. For example, a given lab can be restricted to weeks 4 and 5 of the course. Since multiple labs also can increase the number of different chemicals and supplies needed in a given week, the lab manager also has a tool to track inventories and plan quantities of chemicals needed based on the student selections from the available choices. Since the system was designed for large courses with multiple sections taught by different teaching assistants or lab instructors, administrators can also view and modify any information within a particular section, including student progress, assignments, grades, and evaluation question results.⁸

A password-protected “Instructor page” allows lab instructors to monitor the progress of students in his or her lab section(s). Instructors can view the individual progress page of any student in their sections by accessing the student progress page directly, thus viewing the assignments and status of each student. Instructors also have access to the results of evaluation data and can assign or edit grades and comments on each experiment. The grades are posted instantaneously on the student’s progress page. Thus, the ICN system provides an effective means for communication between instructors and students.

Student Centered Activities: Individualized Pathways

In contrast to the “lockstep approach” that was in use previously at the University of Maine, the ICN system allows students to dynamically create their own *individualized pathways* through the course. The term *individualized pathways* is our metaphor for a range of strategies that can be implemented to individualize every student’s experience. These strategies can include presenting different procedures and treatments of the handout to different groups of students, providing students a choice of laboratory experiments, and generating different assignments within a given lab procedure. The latter two strategies are obvious to a student (e.g. choice of two different experiments in a given week) and have the effect of enabling students to have some control over their lab experience. The first strategy mentioned above is among those aimed at curriculum development and assessment (e.g. differences in experimental procedures). Thus, individualized pathways are meant, in the short term to generate enthusiasm for lab while, in the long term, to provide a means to improve the curriculum.

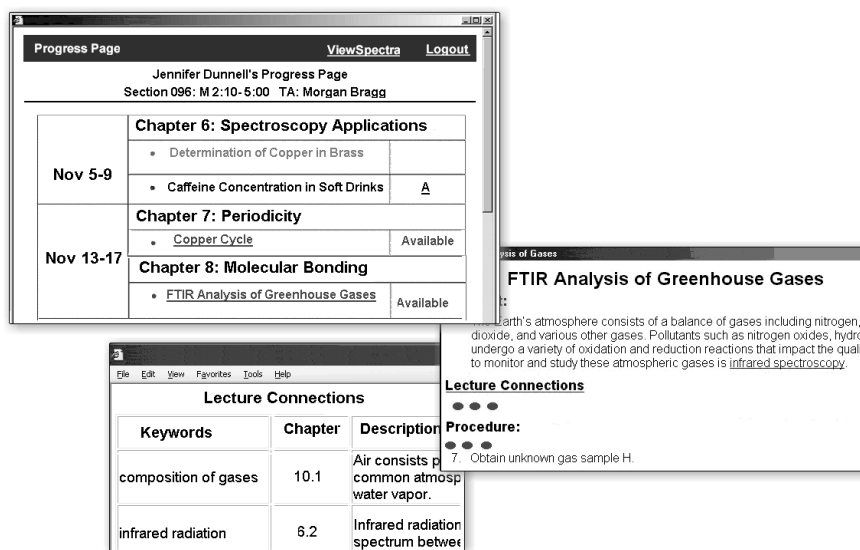


Figure 2 Student progress page with several lab choices for a particular week. Grade information can be displayed at the instructor’s option. Active links help direct student flow through the program.

At the beginning of the semester, each student creates an account name and password to access her own individualized *progress page*. Figure 2 shows a student progress page with several choices for a particular week. Within a given time period, different labs will typically relate to the same concepts and technical skills but will be contextualized in different ways for different

potential audiences (*e.g.*, nursing students, engineers, environmental science students). Going one step further, ICN allows the creation of variable sets within a given lab procedure. For example, a lab involving the titration of a weak acid can be created with three or four different weak acid compounds each of which may be prepared at different initial concentrations. Thus within a lab section of twenty students, even if, say, eight students have chosen the same lab, their individual assignments will be different and will generate different and unique data sets. This allows the ICN approach to promote student interaction and collaboration while providing a check on outright copying. Students can then access their individualized handout on the Web along with links to Material Safety Data Sheets, video clips of procedures, pictures of lab equipment, references to sections in the lecture text, and background information pertinent to each experiment.

Integrated Assessment and Evaluation Tools

The InterChemNet system has an integrated evaluation module that tracks student learning and attitudes as they use the system. The questions are created along with the curriculum materials and are designed to be part of the sequence of materials viewed by the students as they progress through the course. For example, the instructor can insert a series of online questions that must be answered before the student can gain access to the following week's lab assignment. One built-in option allows for a sequence of pre- and post-testing for each experiment. In the "Administrator" and "Instructor" pages, the evaluation module delivers preformatted graphical summaries of the students' responses to the evaluation questions. Thus evaluation results from different courses and/or multiple sections of the same course can be compared quickly and easily.

Three types of questions are currently being used in the ICN system: multiple choice, number input, and text response. Questions have been categorized as either science-content or attitude questions. Students answer content questions before they receive the lab assignment but receive no answers or feedback for these questions. After the assignment, they again answer the same questions and receive feedback and the correct answer if appropriate. The evaluation questions are not graded but must be completed in order to receive the next assignment and progress through the course. The answers to the multiple choice questions are collected in the database and can be treated in a statistical manner as described below to provide a quick snapshot of student performance and satisfaction. The number input and text response questions allow for the collection of open-ended responses and are thus less amenable to automated data treatment. These responses

are more helpful for understanding how students are thinking. We note, however, that careful reading and coding of these responses permits a statistical treatment of this data as well.

Once students have completed an experiment and answered the accompanying evaluation questions, the ICN database contains a rather rich store of data about student performance. In principle this data could be mined for correlations between student performance and a whole host of factors such as major, gender, instructor—we come back to this point in the discussion section.

In practice, many instructors and course administrators need a very rapid assessment of student performance in order to get an ongoing sense of what is working and where problems have arisen. The evaluation module provides this *rapid screening* of data in two ways. First, it provides an automatic analysis of pre- and post- testing results for each experiment and includes a graphical display of those results. Second, the evaluation module can display the text of open-ended response questions to the instructor for a rapid scan of student answers to these questions. This has been used to identify points that need to be clarified in the next class or changes that might result in better learning.

Results

The ICN system was student tested in Fall 2001, when 500 students taking CHY 123 (Introduction to Chemistry Laboratory) used ICN to perform 5,000 individually assigned experiments and take approximately 10,000 spectra using 4 UV-visible and 4 FT-IR spectrometers. Students accessed the Web-based program more than 25,000 times during the semester. Online evaluation questions and a paper version of the university-wide course exit evaluation questionnaire were used to monitor student attitudes toward using ICN. When asked on line whether ICN was an aid in managing the course material and doing chemistry, 95% of the students gave ICN an overall positive rating in response (see Figure 3). This attitudinal “snapshot” is confirmed by results from the paper version of the university questionnaire (administered at the end of each semester), showing a continued gradual improvement in student attitudes towards the course from previous years, particularly in the areas of how well the labs were integrated with the course material and the overall rating of the course. In Fall 2001, 77% of the students gave a positive or neutral rating to how well the experiments were integrated with the lecture material and 89% offered an overall positive or neutral rating of the laboratory. These results compared to 68%, and 78%, respectively, for the same course the previous year. In addition, 60 students made comments that expressed an

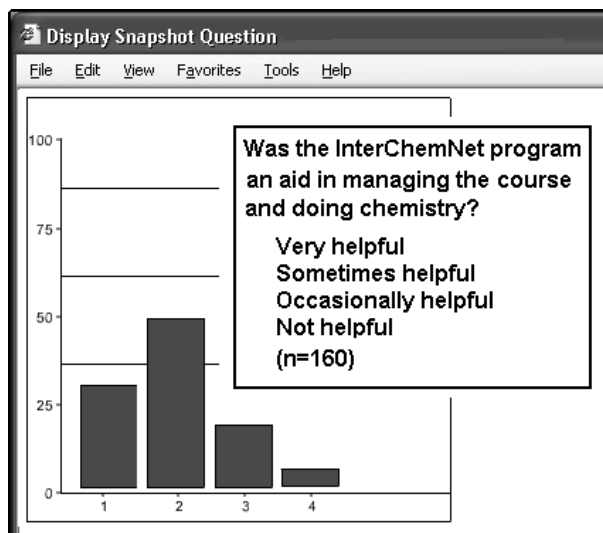


Figure 3 Online display of results for a student attitude ("Snapshot") question.

overall approval of the new laboratory program, particularly with the ability to choose experiments each week. Some of these comments were as follows:

"The way the lab is run is awesome. Working at your own pace allows you to learn and absorb more info."

"I found it helpful that students were able to choose which labs they were going to do. It allowed us to integrate the labs with the lectures."

These results suggest that students have had an overall favorable rating of the course throughout the process of implementing the new Web-based management system.

In addition to monitoring student attitudes about specific experiments and the course, the ICN program can also be used to evaluate specific learning outcomes associated with each experiment. Figure 4 shows summary data for four experiments offered at the University of Maine in the fall of 2001. As we shall discuss further in the next section, data tables like that in Figure 4 are generated automatically by the ICN program. The questions shown here (*e.g.*, multiple choice) lend themselves to quantitative measures of student learning. We have implemented a "gain" index (16,17) given by,

$$gain = (\%CorrectPost - \%CorrectPre) / (100 - \%CorrectPre),$$

to provide a rapid comparison of the effectiveness of multiple experiments in a course. Two of experiments displayed in Fig. 4 were offered during the fourth week of lab and were intended as alternative treatments of the same set of techniques and concepts. The first experiment, a traditional analysis titled simply “Acid-Base Titration”, was selected by 208 students; the second experiment entitled, “Analysis of Vitamin C in Fruit Juices”, was chosen by 337 students. Each student who selected one of these two experiments was randomly assigned a “pre” question and a different “post” question. We focus here on the query, “The endpoint of a titration is reached when:” which was presented to 106 students in the first lab (60 “pre” and 46 “post”) and 167 students doing the second lab (85 “pre” and 82 “post”). The group of students who completed “Acid-Base Titration” demonstrated a gain for this question of 0.54 while those who did the “Analysis of Vitamin C in Fruit Juices” posted a gain of 0.83. Assuming that both groups of students are drawn from the same population, we have calculated that the probability that the difference in these two gains is random is less than 0.01; this result was obtained using a two-tailed *t*-test with pooled variance (18). The difference in gains may be due to the superiority of one set of curricular materials over the other and a result like this leads us to look carefully at both procedures for clues. However, lab choice is one of the very interventions we are trying to assess and this may affect our assumptions about the randomness of the population. We hope to construct, in the future, a more nuanced picture of the learning dynamics in the general chemistry lab by correlating such factors as learning style results (19) and gender differences with lab selection as well as learning results; these results will be reported in a future communication.

Lab Title	Question	Pre	Post	Gain
Acid-Base Titration	The initial and final levels of NaOH in a buret during a titration are shown. What volume of NaOH was delivered?	0.40	0.58	0.30
	The end point of a titration is reached when:	0.72	0.87	0.54
Analysis of Vitamin C in Fruit Juices	The initial and final levels of NaOH in a buret during a titration are shown. What volume of NaOH was delivered?	0.40	0.55	0.25
	The end point of a titration is reached when:	0.64	0.94	0.83
Copper Cycle	When copper metal is dissolved in concentrated nitric acid, a clear blue liquid is formed. When 6 M sodium hydroxide is then added to the solution, a white cloudy precipitate is formed. What is the precipitate?	0.48	0.50	0.04
	Which of the following is a redox reaction?	0.33	0.42	0.13
FTIR Analysis of Greenhouse Gases	Nitrogen gas (N ₂) is used to blank the FTIR spectrometer. Which of the following gases could also be used to blank a spectrometer?	0.39	0.45	0.10
	Infrared spectroscopy records	0.25	0.47	0.29

Figure 4 Administrator view summarizing online evaluation questions for a series of labs.

The table of Figure 4 does not show the alternative answers nor some of the details of the sampling (reported, for completeness, above). For a more detailed look at a specific experiment, the ICN program can generate a display like that of Figure 5 which shows the complete pre- and post-results for the “endpoint” question for the “Vitamin C” lab. This graphical display is useful for visually oriented instructors and provides a more complete picture of the alternative answers and the evolution of the distribution of those answers, pre- and post-. The rather high performance on this question is typical of questions focused on specific experimental techniques.

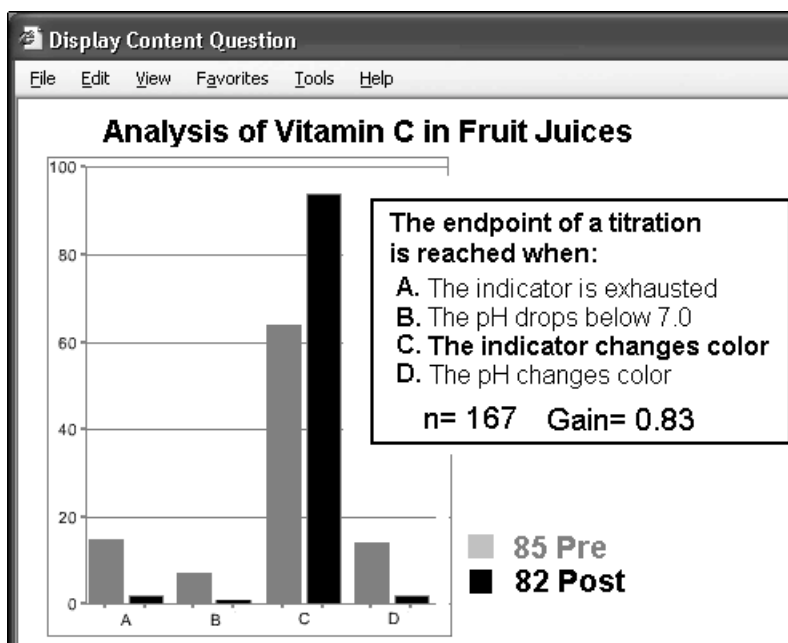


Figure 5 Graphical display of results of the online pre- and post-lab questions exploring student understanding of the endpoint of a titration.

However, not all of the data indicates that students are learning what *we think* the experiment should be teaching. For example, as Figure 4 shows, in an experiment called “Copper Chemistry: The Copper Cycle,” one particular question asks about the nature of the precipitate formed when sodium hydroxide is added to aqueous copper (II) nitrate. Our outcome data shows that 48% of the students responded correctly before the experiment and only 50% responded correctly after conducting the experiment; this suggests that our module is NOT teaching students adequately about *oxidation and reduction* chemistry, an important goal. We welcome this data as a signal that we should focus our attention at a point that we did not recognize as problematic. Since

the ICN evaluation module allows us to gather evaluation data throughout the semester as part of the course delivery mechanism, we hope that it will dramatically lower the activation barrier for conducting and analyzing chemical education research within a course.

Discussion

As originally conceived in 1993, ICN involved networking modern instrumentation and connecting it to a student-friendly server distribution system. As this was being accomplished over the next few years, we became intrigued by the possibility of adding additional features including (a) offering students choice of lab experiments without increasing the time commitment of the lab manager, (b) creating individual lab assignments to promote student collaboration (but not copying), (c) developing a standardized way to create lab experiments, (d) defining and offering a course simultaneously with other courses, and (e) integrating assessment into the delivery of the course. As we look ahead, we believe that these capabilities, implemented in ICN initially for an audience of college students here at the University of Maine, offer a new set of tools to address an array of teaching and learning issues in grades 9-16 education: systematic curriculum development with assessment, integration of curricular components both horizontally and vertically, and outreach to local high schools and colleges.

Engaging Students in Learning Chemistry

In realizing our conception of individualized student pathways, we have implemented a rich set of tools with broad implications for the use of instrumentation, course management and evaluation. Ultimately these factors allow for a more active model of student learning in the course. At the most basic level, the general chemistry course should teach students the modern practice of chemistry as well as its mature principles. By increasing the efficiency of instrument use, we have put research grade instruments in the hands of 550-600 general chemistry students each fall semester. One of the goals of the ICN project was to develop a curriculum that leads students from mastery of basic skills and concepts to more open-ended “discovery” labs. By carefully introducing new tools such as spectrometers early in the semester, more complex, integrative exercises using an array of chemical tools are possible later in the semester. A side benefit is the availability of these research grade instruments for use in upper level courses and by researchers at times when the large courses do not meet.

Central to our conception of individualized pathways is the possibility of student choice of experiments based on factors such as personal interest, disciplinary (major) focus, and level of difficulty. Our expectation, borne out by the student feedback quoted above, was that choice would provide more active engagement with the material through conscious selection of experiments as opposed to the passive completion of mandatory assignments. Student choice is only one aspect of the individualization of the curriculum, however: as noted above, the instructor can choose to create a number of assignments within a given lab. These assignments are made randomly to students who choose the experiment. The interaction with the system is two-way as well. Students use the system to access and analyze their data, especially spectral data and to answer questions about the lab. InterChemNet's Web-based format is conducive to embedding ancillary information: students have access to a wealth of information regarding lab procedures, safety, and calculations. A notable feature is a "Lecture Connections" module that helps students connect principles needed for lab with source material in the lecture course and the textbook. Evaluation data suggests that "Lecture Connections" is a useful mode for integrating lecture materials into the laboratory portion of the course. The lab choices, random assignments, and possible selections of ancillary materials, effectively ensure that every student will navigate a different route or path through lab curriculum.

One striking consequence of making possible individualized student pathways has been a concomitant change in the role of the lab instructor (teaching assistant) from authority and disciplinarian to resource person. The instructor acts as a source of information about techniques and principles rather than acting as the source of "correct procedure" for the whole section. Likewise, the teaching assistant can encourage collaboration between students to learn *techniques* while their differing assignments render moot the problem of copying of *results*. TA training, which is always a critical aspect of running a large lab program, now requires a change of emphasis from mastery of specific content to be conveyed to students to the principles of guiding students through the process of doing science. This aspect remains an active area of development in our program at the University of Maine.

Curriculum Development Cycle and Action Research

InterChemNet's evaluation module is integrated into the program at two important levels. First, instructors are offered the option of entering survey or evaluation questions as they input the curriculum materials (lab handouts, lecture connections, safety information, etc); this allows the

creation of evaluation materials to be an integral part of curriculum development and delivery. Second, questions are presented to students as part of the normal flow of the program and become a routine part of the curriculum delivery. The instructor can control the mode of questioning and the content in such a way as to strike the desired balance between assessment, evaluation, and promotion of critical engagement with the lab data for analysis.

ICN thus provides instructors an easy method to query their students on a host of issues; this in turn creates a very large amount of data that needs to be collated and presented in a systematic fashion. We have built an integrated analysis tool in order to perform rapid and automated statistical treatment and display of the datasets generated by each curricular unit; examples of these results are presented in Figures 4 and 5. The evaluation can be carried out simultaneously at several different “curricular scales”. At the coarsest level, ICN can automate pre- and post- testing of the entire course and display gains in student learning immediately. But the real strength of the system lies in the ability to go to finer levels, evaluating individual lab experiments (*e.g.*, Figure 5) or even the learning of a given concept within a lab. This approach allows the instructor to assess how particular curricular “interventions” have worked.

The integrated assessment tools have allowed us to confirm, in some cases, the efficacy of our curriculum innovations (20). Just as interesting, and probably more important, are the cases where rapid assessment indicates low or non-existent gains – as with the Copper Chemistry lab mentioned above – or where students express dissatisfaction with aspects of the course. The immediate feedback allows for rapid modification of the learning materials and course protocols followed by further evaluation, in some cases, before the end of the course. This curriculum development cycle is similar in many ways to the action research methodology (21), and is consistent with a growing trend in chemical education towards this type of research study (22). The deep integration of assessment with curriculum delivery, made possible by the ICN approach, should dramatically reduce the overhead associated with conducting pedagogical research in a working classroom.

Dissemination and Outreach

The ICN system has been developed and extensively tested at the University of Maine. We should stress that we have taken considerable care to make the system easy for instructors to use to modify experiments or add new ones. It is a system for course development and evaluation not just

curriculum delivery. The system architecture relies on a dynamic relational database structure using industry standard Access database and Cold Fusion server development tools.⁹ Instead of a series of static Web pages, the ICN system offers a Web interface to modify the content of the database. This data is then incorporated into Web pages that are served out to student “clients”.

By using industry standard software tools, the system is portable for users—both students and teachers—and reasonably straightforward to install for administrators. Students can access the client side of the program from any computer cluster or dorm room that is connected to the Internet. Instructors from college or even high school settings can create and modify a course using standard Web browsers. Most science departments, colleges or high schools have an IT department or guru to set up standard Web services.

The services provided by the ICN program can be used at a variety of institutions with different curricular goals. A good contrast with the large general chemistry program at the University of Maine is the adoption of the system at Bangor High School to provide access to spectroscopy experiments (23) to students in tenth and eleventh grades. In this collaboration with M. Benoit, a Chemistry department “loaner” UV-vis spectrometer¹⁰ and the ICN program were used for data acquisition and analysis with modified labs and new curriculum materials (24). The ICN system was also used to acquire data on student learning in the high school classes. The adaptation has proved so successful that Benoit sought and was awarded a Toyota Tapestry grant¹¹ for the school to obtain instruments and is now assisting in the training of other high school teachers.

Potential adopters of ICN may first be interested in managing the use of spectrometers or perhaps in the possibility of creating individualized pathways for their students. The system can also be used simply to do on-line evaluation of an existing curriculum; here, at Maine, for example, we have used the ICN program to perform an evaluation of our ongoing Peer Led Team Learning project (25) associated with the General Chemistry lecture course. In any case, it is easy to start from the existing curriculum and gradually phase in the use of desired features. Some users (particularly at high schools) may wish to adopt--with only minor modifications--some of the 40 or so experiments that have been integrated into the working system here at the University of Maine. The capabilities of ICN offer the opportunity to define local curricular goals, and to deliver and assess a course to meet those goals. An eventual outcome of a successful dissemination project is

the creation of a mechanism (*e.g.*, a database) for sharing curricular innovations, integrated lab experiments, and evaluation strategies with other users of the system. InterChemNet provides a common framework to help manage the complex task of comparing learning outcomes in different learning environments.

Summary

ICN is a Web-based program designed to foster active learning in the lab. The system allows students choices of discovery-based experiments, a host of background information, and quick and easy access to UV-visible and FTIR spectrometers. An evaluation module is integrated into the system to provide immediate feedback for students and evaluation data for instructors. Because assessment is integrated with curriculum delivery, ICN facilitates the introduction of education research into existing courses based on local curricular goals. By making it easy for instructors to analyze learning outcomes for the course, ICN can be used to promote a systematic and evidence-based curriculum development cycle. For more information, please visit the website at www.interchemnet.com.

Acknowledgements

The InterChemNet project has been supported by the US Dept. of Education: FIPSE grant #P116B981469 and FIE grant #R125K010106 and by Beckman Instrument Corp., Midac Corp., Ocean Optics, and Microsoft Corp. Support from the University of Maine College of Liberal Arts and Sciences and the Department of Chemistry is also acknowledged. The authors thank, Michele Benoit, Kate Henchman, Cheng Liu, Mike Scott, Bill Vining, Herman Weller, and an extended group of student programmers for helpful conversations and contributions.

Notes

1. Although some industrial companies in the mid-1990's were developing spectra based management programs for their scientists, we were interested in a program appropriate for an educational setting, i.e. easy for introductory students to use without sacrificing any of the essentials of instrumental use.
2. In stand-alone mode, where a spectroscopic instrument and its console are used to acquire and then analyze data--mimicking the mode of use in research--every student might need about 30 minutes to complete this portion of an assignment. At the University of Maine, with 120 students to be served in a 3 hour period each afternoon, this would require about 20 machines of each type to be available, ignoring, of course, the tendency for students to finish prep work in bunches. Taking this latter effect into account, 40 machines might be needed for a program such as ours. Indeed this paradigm of instrument use is similar to that applied to inexpensive equipment like pH meters and to a lesser extent, single wavelength spectrometers like the SPEC20. For spectrometers costing between \$2,000 and \$10,000, this mode of use is not economically viable.
3. Beckman DU 7500 full spectrum UV-visible scanning spectrometers from Beckman Coulter Corporation are used.
4. Midac M Series FT-IR spectrometers from Midac Corporation are used.
5. At current prices, a suitable FT-IR machine or a high-end UV-visible spectrometer would cost about \$10,000. Counting 5% for maintenance and repairs, such a machine would last for about 7 years for an overall cost of \$13,500. In this same 7-year period this instrument is used by one-fourth or about 1365 of our students. Thus one such instrument costs about \$10 per credit hour. For a less expensive UV-visible spectrometer costing about \$2000, a similar analysis leads to an estimate of \$2 per student credit hour.
6. Systems that integrate instrumentation for the education market include Acculabs Products Group, Casio EA-100, Microlab, PASCO Scientific, MeasureNet Technology, SCI Technology (Labworks), TAL Technologies, Team Labs, Texas Instruments, and Vernier Software & Technology.
7. Systems that focus on analog-to-digital conversion for research and industry with uses in education include DATAQ Instruments, Keithley Instruments, Labtronics Inc., National Instruments. (14)
8. Other course infrastructure software that integrates evaluation with delivery includes Blackboard, WebCT, and WebAssign. (14) ICN has specific features designed for use in laboratory courses.
9. Access is a Microsoft database product. Cold Fusion from Macromedia uses SQL query protocol to insert database information dynamically into Web pages served out to clients.
10. Ocean Optics Chem-2000 UV-visible spectrometers from Ocean Optics, Inc were used.
11. Toyota Tapestry grants are awarded through the National Science Teachers Association <http://www.nsta.org/>

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Figure Captions

Figure 1. Students use an account name and password to access their spectral data through the Web browser. A uniform interface makes it easy for students to display, analyze and print their data.

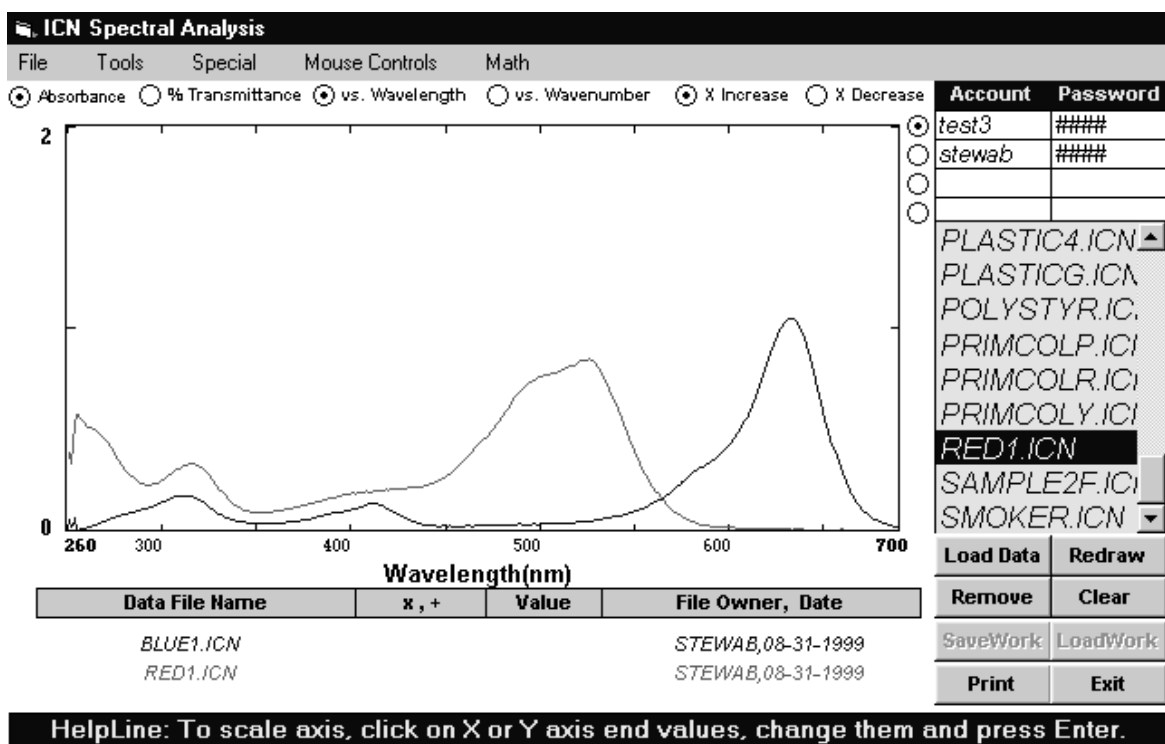
Figure 2. Student progress page with several lab choices for a particular week. Grade information can be displayed at the instructor's option. Active links help direct student flow through the program.

Figure 3. Online display of results for a student attitude ("Snapshot") question.

Figure 4. Administrator view summarizing online evaluation questions for a series of labs.

Figure 5. Graphical display of results of the online pre- and post-lab questions exploring student understanding of the endpoint of a titration.

Stewart *et al* Figure 1



Stewart *et al* Figure 2

Progress Page [ViewSpectra](#) [Logout](#)

Jennifer Dunnell's Progress Page
Section 096: M 2:10-5:00 TA: Morgan Bragg

Nov 5-9	Chapter 6: Spectroscopy Applications	
	<ul style="list-style-type: none"> • Determination of Copper in Brass • Caffeine Concentration in Soft Drinks 	<u>A</u>
Nov 13-17	Chapter 7: Periodicity	
	<ul style="list-style-type: none"> • Copper Cycle 	Available
	Chapter 8: Molecular Bonding	
	<ul style="list-style-type: none"> • FTIR Analysis of Greenhouse Gases 	Available

FTIR Analysis of Greenhouse Gases

Earth's atmosphere consists of a balance of gases including nitrogen, carbon dioxide, and various other gases. Pollutants such as nitrogen oxides, hydrocarbons, and sulfur dioxide undergo a variety of oxidation and reduction reactions that impact the quality of the atmosphere. The primary method to monitor and study these atmospheric gases is [infrared spectroscopy](#).

Lecture Connections

● ● ● ●

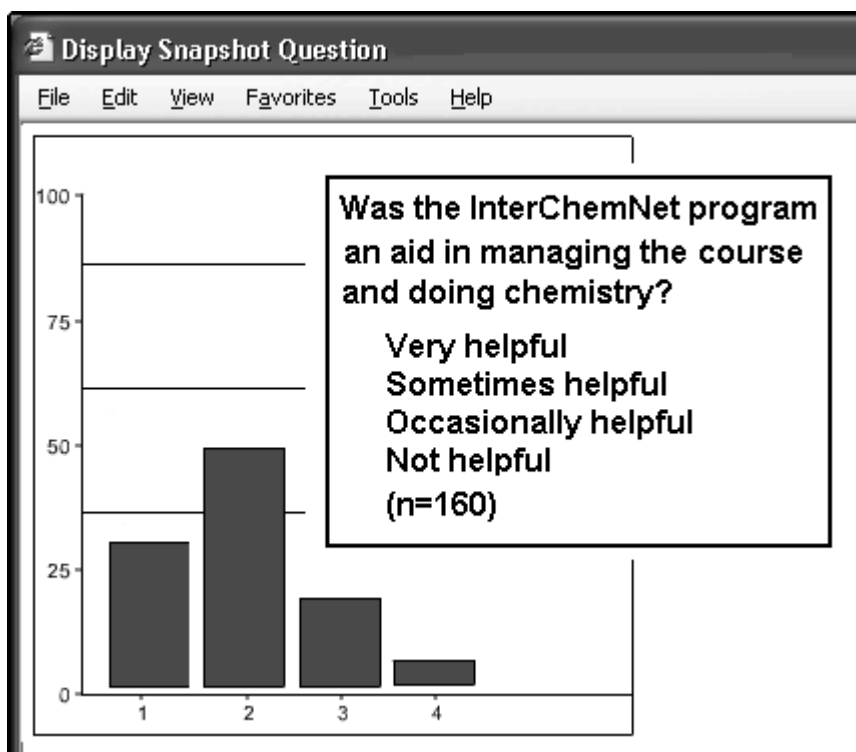
Procedure:

● ● ● ●

7. Obtain unknown gas sample H.

Lecture Connections		
Keywords	Chapter	Description
composition of gases	10.1	Air consists of 78% nitrogen, 21% oxygen, and 1% water vapor.
infrared radiation	6.2	Infrared radiation spectrum between 2.5 and 25 micrometers.

Stewart *et al* Figure 3



Stewart *et al* Figure 4

Lab Title	Question	Pre	Post	Gain
<u>Acid-Base Titration</u>	<u>The initial and final levels of NaOH in a buret during a titration are shown. What volume of NaOH was delivered?</u>	0.40	0.58	0.30
	<u>The end point of a titration is reached when:</u>	0.72	0.87	0.54
<u>Analysis of Vitamin C in Fruit Juices</u>	<u>The initial and final levels of NaOH in a buret during a titration are shown. What volume of NaOH was delivered?</u>	0.40	0.55	0.25
	<u>The end point of a titration is reached when:</u>	0.64	0.94	0.83
<u>Copper Cycle</u>	<u>When copper metal is dissolved in concentrated nitric acid, a clear blue liquid is formed. When 6 M sodium hydroxide is then added to the solution, a white cloudy precipitate is formed. What is the precipitate?</u>	0.48	0.50	0.04
	<u>Which of the following is a redox reaction?</u>	0.33	0.42	0.13
<u>FTIR Analysis of Greenhouse Gases</u>	<u>Nitrogen gas (N₂) is used to blank the FTIR spectrometer. Which of the following gases could also be used to blank a spectrometer?</u>	0.39	0.45	0.10
	<u>Infrared spectroscopy records</u>	0.25	0.47	0.29

Stewart *et al* Figure 5

