Physical Chemistry Online: Maximizing Your Potential

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Abstract: The Physical Chemistry On-Line (PCOL) consortium has developed and conducted a series of short-term projects for use in the physical chemistry curriculum. The projects involve faculty and students from geographically dispersed institutions, are short in duration (~4–6 weeks), and use email and the World Wide Web for communication and information distribution. They are designed to enhance physical chemistry at colleges and universities that may have limited resources available for physical chemistry by offering an alternate pedagogical approach. This paper will highlight the motivations of the participants, outline the specific projects used to date, and provide some evaluation of the pedagogical effectiveness of the approach.

Motivation

Recently, there has been significant interest in developing improved physical chemistry curricula [1, 2]. Motivation has largely been derived from the belief that the "traditional" curriculum does not reflect the current practice of physical chemistry. Additionally, student interest in physical chemistry, one of the traditional gateway courses into the profession, is low. In response to these concerns, there has been increasing interest given to the development of new experiments for the physical chemistry laboratory, those that employ more sophisticated, modern experimental techniques [3]. Some have pursued the development of activity-based instructional methods [4].

Despite these important educational advances, physical chemistry instructors who wish to be innovative often find themselves isolated in small departments that cannot provide the equipment necessary to offer recently developed laboratory curricula and do not have the institutional or collegial support necessary to support innovative classroom practice. An obvious solution to this problem, given current communication technology, is to use the Internet to link geographically dispersed physical chemistry classrooms. The Internet becomes the vehicle by which to transform and improve educational practices.

Although much has been written on the potential benefits of using the Internet as a tool to educate chemists, there are few examples of studies that assess the impact of the technology on chemical education or provide actual working examples of Internet applications in the chemistry classroom [5]. At the college level the work has too often been parochial with the most common application being examples of web-based syllabi. In these cases, the technology is aimed at enhancing a single lecture class by providing a common and convenient location for educational resources. This route is innovative only in that a unique delivery method is used for the material. This is all the more disappointing given the exceptional technology that has been developed to provide interactive web material and enhance the ability to communicate chemical ideas online [6–8]. Some exceptions have been highlighted in recent CHEMCONFerences organized by the American Chemical Society's Division of Chemical Education and managed by the Committee on Computers in Chemical Education (CCCE) [9].

The limited current use of Internet technology is not surprising given the standard practices used in most classrooms. It is generally true that communication technology has not been adapted to the classroom. For example, movies, radio, tape recorders, television, and video tape machines, technologies that appeared as much as 80 years ago, are applied very little in today's classroom and, when applied, they are generally used to display images of a lecture, or at best, to show lecture demonstrations [10]. It is no wonder that the Internet has been applied mainly to distribute syllabi and course notes.

The PCOL consortium members believe that the pedagogical advantage of the Internet lies in constructing an innovative curriculum that provides substantial content *and* takes advantage of the asynchronous instructional potential of electronic interactions. The curricular content must be presented in a context that is both stimulating to students and pedagogically sound. The faculty participants in PCOL are endeavoring to provide this content by adapting strategies that include cooperative/collaborative learning, case studies, and discovery based learning to the Internet. We believe that the Internet, by its very nature, is well suited as a tool to implement these learning strategies in our classrooms [11].

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Table 1. PCOL Curriculum Developers through May 1999

Faculty member	Institution, location
George Long	Indiana University of Pennsylvania, Indiana, PA
Deborah Sauder	Hood College, Frederick, MD
George Shalhoub	La Salle University, Philadelphia, PA
Roland Stout	University of North Carolina, Pembroke, NC
Marcy Hamby Towns	Ball State University, Muncie, IN
Gabriela Weaver	University of Colorado at Denver, Denver, CO
Theresa Julia Zielinski	Monmouth University, West Long Branch, NJ

Table 2. PCOL Modules Implemented Through May 1999

Module title	Topic	Date
How Hot is That Flame?	Determination of adiabatic flame temperatures	Fall 1996, Fall 1998, Spring 1999, and Fall 1999
It's a Gas!	Non-ideal equations of state and nonlinear curve fitting	Fall 1996 and Fall 1999
The Structure and Spectroscopy of Iodine	Classic experiment to determine potential energy surface parameters from visible absorption spectra	Spring 1997
Doc Z's Bungee-Jumping Emporium	Thermodynamic and experimental investigation of polymer elasticity with applications	Fall 1997
Shady Laser Corp	Classic experiment to measure the absorption spectra of conjugated dyes, and develop several models and correlate absorption characteristics with dye structure	Spring 1998 and Fall '99

Projects To Date

Over the past three years we (see Table 1) developed and tested five modules (see Table 2) as pilot projects that linked several geographically dispersed physical chemistry classes for short-term intercollegiate online activities.

An online physical chemistry activity is an interactive exploration of chemical concepts by an electronic learning community composed of groups of students from three or more institutions. During an online event, students obtain resource materials over the Internet. One faculty member serves as facilitator for the activity. The facilitator's role is to provide guided inquiry directions as the students work their way through the module. Students in the learning community work in groups at their local campus and then share and discuss their results with all other groups or with partner groups on the other campuses. Projects may require students to perform mathematical manipulations using a program such as Mathcad, implement molecular modeling using software like Spartan or Hyperchem, or engage in more traditional laboratory experiments. Data and written results are shared by email or by postings on a web page, or both. Some form of student peer review is an integral part of each online project. The time span for an online activity is usually four to six weeks, running parallel with normal classes and laboratories, but usually substituting for some experiments or lecture material.

PCOL activities use the ability to collaborate via the Internet to help students learn chemical principles. The sphere of collaboration of individual students is broadened beyond their own institutions, giving each participating student a greater perspective on physical chemistry and a better appreciation for the challenges inherent in understanding the field. A team of faculty designs the projects, and thus they have contributions from several faculty perspectives as well. Therefore, each project is multidimensionally collaborative—collaboration occurs among students on a single campus, among student groups across several campuses, and among faculty on several campuses. The outcome is that together we can do more than any one faculty member can do alone, and our students get more collegial interaction than is possible in any one small, individual physical chemistry class.

One philosophical principle guiding the development of the online projects is the concept of a learning community [12]. The learning community provides an organizational framework useful for encouraging group learning and discovery. We have chosen to use this model to develop a more interactive, student-centered perspective from which to use the Internet. Support for building such communities comes from three areas: empirical research on learning outcomes, research on the personal and intellectual development of college students, and research on motivation and cognition [13–18]. This diverse body of research supports the notion that students learn when they are engaged in actively seeking and building knowledge. Getting students actively involved in asking and responding to questions is, therefore, critically important, and it is a primary goal of any PCOL project.

The structures and pedagogical content of the five PCOL projects developed and implemented so far are outlined below. More substantial information, including some digests of the online interactions, is available on the WWW at the addresses linked to the next five sections of this paper, which describe the modules tested thus far.

Project 1. How Hot is That Flame?

Principal author: Theresa Julia Zielinski
Online facilitators: Theresa Julia Zielinski and Deborah Sauder

This module was the trial run for the project sponsored by the CCCE in 1997. [19, 20]. Three classes with a total of 20 students participated. Designating one faculty member to facilitate the online work of the students was found to be successful. A major difficulty was student access to computer terminals. During the Fall 1998 semester we ran this project again with seven participating colleges and 50 physical chemistry students [20]. The project materials were revised and reorganized for the Spring 1999 implementation, which involved three faculty and 19 students [21].

The project began with students accessing a web page that included an essay describing a chemist who was idly watching a fire in a fireplace and wondering how hot the flame was. The essay went on to outline some factors that one might take into account in order to determine the flame temperature, provided some thermodynamic parameters, and asked students to check a preliminary calculation to determine the flame temperature.

In the online implementation, student groups generated a variety of answers on their first attempts to calculate the flame temperature. This provided strong motivation for the students to write in a professional manner about the details of their calculations as they attempted to reconcile the results of their multiple calculations of "the same" phenomena. The facilitator's role was to provide encouragement to students as they extended the calculation and included some more realistic considerations of the chemical processes occurring in a flame.

In the Fall 1998 and Spring 1999 semesters, the project was expanded. Student groups were asked to repeat their calculations for a variety of hydrocarbon fuels, share their results, and draw some conclusions about the relationship of chemical structure to computed flame temperatures.

There were interesting results from the Spring 1999 implementation, which included students from LaSalle University, Monmouth University, and Utica College of Syracuse University. First, students from two campuses did not participate in the online discussions, even with the constant encouragement of the professors and the consequence of getting a zero for the work undone. The facilitator, Professor Zielinski, worked with the one remaining school, Utica College. In the end, only two students, one from Utica and, surprisingly, one from LaSalle, submitted completed analyses for publication on the project Web page. The completed reports are included in the link to reference [21] at times when a Flame project is not in progress (at other times contact one of the facilitators for the URLs for these reports). The quality of the work was good and demonstrated that students could complete this project. The fact that students from two campuses refused to participate is an outcome that professors interested in using this technique must see as a real possibility. Our ability to foster student collaboration is directly proportional to the benefit they perceive coming from the project. Even a "grade carrot" may not foster student participation. The projects may well flounder if they are dropped into a traditional classroom setting in which students have little experience with group work or in using Mathcad as a tool. As always, students can and do decide their level of participation and cooperation in any particular course or course project.

During this same semester, however, the facilitator received an encouraging letter from the parent of one of the successful students. In part it stated:

> I remember getting up about 3:00 AM and going to the kitchen for a drink of water and finding (my son) in the basement office at the computer. There was opened the 50th anniversary edition of the CRC Handbook of Chemistry and Physics and a Physical Chemistry textbook that I used in the 1960s. He explained the project and by morning he finished his way of solving the problem. I did not make a big thing out of this, but now I am very happy that (my son's) was one of the posted solutions to the problem.
>
> In my opinion, this kind of involvement by students at different schools is really good and should be encouraged. You are doing a great job at this."

The contrast in response among students involved in the same project illustrates that the novelty of an online activity is not sufficient to motivate student engagement. Nevertheless, meaningful engagement of a student in learning is clearly an important requirement for success with any project or course.

Project 2. "It's a Gas!"

Principal author: Theresa Julia Zielinski.
Online facilitator: Theresa Julia Zielinski.

This project, during the Fall semester of 1996, involved physical chemistry students from four different institutions [22, 23]. Students in the project read a play conveying a conversation between two chemists who were discussing gas behavior and nonlinear curve fitting. Students were assigned a set of gas data (*P* vs. *n*) at fixed *V* and *T* and asked to determine the best-fit parameters (as determined by the standard deviations) if the data set was described by the ideal gas law, the van der Waals equation, and the Redlich-Kwong equation. They were then asked to use the F-test to decide which equation best described the data. This was not a trivial task, as the students (and we) discovered.

Network brownouts and a hurricane, which took the North Carolina participants offline for a week, revealed the hazards of technology used for delocalized instruction. The strengths of the project were the interaction between students, the use of Mathcad and modern technology, and the student experience of solving an authentic problem, not an exercise. The project suffered from technological difficulties, insufficient interaction among the students, and student inability to extract the clues in the play to formulate questions and develop strategies to solve an ill-defined problem. The suggestions for improvement focused on facilitating interaction between students and clarifying tasks and goals for them [5]. Both the resources provided to participants and an archive of the online discussion for this project are available at the URL in reference 22 [22].

Project 3. The Structure and Spectroscopy of Iodine.

Principal authors: George Long & Deborah Sauder
Online facilitator: Deborah Sauder

The format of the online project during the Spring of 1997 changed dramatically in response to our evaluation of the Fall 1996 activity [5, 25]. The web pages became more important in directing the discussion. Stepwise interaction kept the students focused and firmer local course requirements increased student participation in the intercollegiate discussions. Both the resources available to the students and an archive of the online discussion are available [24].

A full exposition of the concepts and depth of learning possible with technology can be found in a recent article prepared by the consortium [26]. This project began with some very simple questions about visible absorption and asked students to measure absorption spectra and convey their experimental procedures and results coherently to their colleagues via email. It then led them through several Mathcad documents designed to establish the fundamental models and outline the calculations that allowed the student chemists to extract parameters describing both the ground and excited state potential energy surfaces from the absorption spectra of diatomic iodine. Revised versions of the Mathcad documents used in this module, and descriptions of the documents are available at the JCE Internet site [27].

Project 4. "Thermodynamics of Bungee Jumping"

Principal authors: Theresa Julia Zielinski, George Long, and Deborah Sauder
Online facilitator: Deborah Sauder

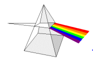
In the Fall of 1997 we conducted the most successful project to date. This project focused on the thermodynamic properties of polymers. Although the iodine project was successful in leading students through a structured-learning process, we wanted to employ a less didactic approach better suited to the asynchronous nature of electronic communication and more likely to encourage a mature student analysis of the problem. The bungee project was successful in meeting both of these goals.

Initially, students used a listserver to respond to general questions designed to bring out their prior knowledge of polymers and guide them towards a laboratory investigation of polymer properties. The conversational tone of the opening discussion helped students get comfortable communicating with their intercollegiate partners online. None of the participating classes had considered polymers before the project started, so students were referred to several texts to gather background information on polymer thermodynamics in addition to being asked to search the World Wide Web for reliable information [29, 30].

Students were then referred to Williams' "Thermodynamic Properties of Elastomers" [31] and asked to use the resources available at their institutions to design laboratory experiments to determine the stress–strain relationship of rubber bands at a variety of temperatures. The results were posted to their class home pages. During a guided discussion facilitated by a PCOL faculty member, the students considered trends in the data sets and drew conclusions. Students then applied their insights to real bungee jumping, and performed calculations to provide virtual technical advice (appropriate thickness and length of cords) to the bungee jumping emporium owner, Doc Z.

A particularly successful aspect of this project was the final segment where the students wrote papers on topics related to the thermodynamic properties of polymers, such as the development of artificial muscle or the Challenger disaster. Papers were peer-reviewed by partner groups at different institutions. Revised papers were posted to the web and a student–faculty discussion of the papers occurred on the listserver. Copies of the materials used by students, an archive of the online discussion, and some sample student papers can be accessed through the link at the beginning of this section [28].

This student-centered activity, included at the suggestion of PCOL member Roland Stout, successfully combined and implemented the proven instructional strategies of collaborative learning and writing in the discipline in an online environment. Participating faculty observed that the paper writing and peer review, in particular, helped students to develop the teamwork and communication skills necessary for the workplace.



Project 5. "Shady Laser Corporation"

Principal author: George M. Shalhoub
Online facilitator: George M. Shalhoub

In this modification of the classic conjugated dye experiment, students were asked to imagine they were members of the Shady Laser Corporation research team. They were to examine the absorption spectra of a number of conjugated dyes and use their data to recommend a chemical structure that would produce a laser dye with a specific set of optical characteristics. The diversity of dyes, solvents, and concentrations employed by the various student groups provided a nice enhancement of this activity vis-à-vis its use in an isolated classroom. Students were asked to agree on parameters for both 1D and 2D particle-in-a-box models for describing the absorption characteristics of the dyes. They also used the molecular modeling software available on their campuses to model dye behavior. Students at some campuses used Spartan to generate structures for the dye molecules and then taught themselves how to use Chime and created models that others could rotate and view at their home campuses.

The materials distributed to students for this project and some sample student work are available.

Pedagogical evaluation

A strength of the PCOL initiative is the interactive mutual encouragement of the faculty during the development and execution of the curricular modules. The group draws on the multiple technical expertise of the participants that spans from thermodynamics through kinetics and on to spectroscopy and computational chemistry. In addition, disciplinary-specific pedagogical experiences have been shared, providing the collegial support necessary to sustain innovative classroom practice.

Another especially important aspect of the collaboration is the collegial interaction required from student participants. Requiring collegial interaction develops the student's ability to work with others while they construct understanding of a chemical concept. Group work within one class is complemented by intercollegiate group activities that draw on multiple student competencies. These interactive skills will be required of future chemists, as we all know from experiences with CHEMCONF and other online professional activities. Further, PCOL modules represent the type of student-centered activities that faculty often find difficult to implement in smaller physical chemistry classes.

Assessment of the above pilot projects, through post-activity surveys of the student participants and their faculty, revealed that students, like their faculty counterparts, engage in professional online activities and are enthusiastic about using the Internet and World Wide Web for learning chemical concepts, *once they get started*. One thing we have learned from PCOL is that the anonymity of online communication offers no advantage compared to the exposure of the classroom setting when it comes to engaging students in chemistry projects. Engagement needs to come from the curricular materials themselves, and be supported by the facilitator's encouragement and guidance during the implementation of a module.

As teachers, we are always looking for a "hook" that will engage students in the creative process that leads to enhanced learning. This is the power of the undergraduate research experience. For this reason, an important goal of PCOL's efforts is to provide curricular frameworks for real problems, mimicking the research experience, so that students become actively engaged with the project. Active engagement enhances learning and empowers students to think of themselves as independent learners. Context-based teaching helps students to learn and to retain concepts and to envision the use of those concepts in new situations. We believe it empowers students and helps imprint life-long learning habits.

One might ask if some content is sacrificed by infusing the online modules into the curriculum. Research in chemical education shows that there is too much content in the curriculum for any one physical chemistry semester [1]. It is time to streamline and modernize. This consortium of faculty believe that by reducing content we will allow students time to develop critical-thinking skills and life-long learning habits. Ultimately, this will permit them to learn more and learn it more effectively throughout their careers.

Using technology, the web specifically, and proven pedagogy—especially active learning and collaborative group work—will provide students with an opportunity to develop life-long skills to a greater extent than is possible when content is delivered in lecture format, which is too often passively received and therefore easily forgotten. We expect, based on our own experiences, that the content learned using web modules is more deeply rooted in student conceptual frameworks, that is, the structure of concepts and behaviors characteristic of the knowledge base of a practitioner of a discipline. This more than compensates for the content not covered.

The Future

The PCOL consortium members agree that the "Thermodynamics of Bungee Jumping" project was our most successful to date. We are continuing to modify our existing projects to maximize their value to us and to our students. Ideally, every PCOL project will encourage student and faculty collaboration by:

- establishing a real world context for learning physical chemistry,
- including both experimental and theoretical components in an open-ended format, one that is rich with student-centered activities that model the scientific process,
- motivating student interaction by requiring introductions and an initial set of questions designed to bring out prior knowledge,
- requiring students to collaborate in the writing of a report or paper to increase engagement with the topic and provide the application of concepts in a new situation,
- facilitating students' constructive peer reviews of each others' efforts.

We are actively developing new curricular modules with these goals in mind. In addition to topics commonly covered in a physical chemistry course, we will include topics relevant to the current practice of physical chemistry, such as ozone kinetics and atomic force microscopy. We anticipate taking advantage of improving technologies and advances in software to encourage students to confront challenging chemical questions and savor the satisfaction of successfully answering them.

Recently, we merged with the Spartanburg consortium [35]. This group, led by David Whisnat, has independently developed online activities for physical chemistry [36]. With NSF funding the combined consortium will develop, refine, test, evaluate and publish 8–12 modules over the next five years. Dissemination via both electronic and traditional print media is anticipated. Interested colleagues are invited to learn more about PCOL modules and outcomes at the upcoming BCCE and National ACS meetings. All current PCOL activities can be accessed through the PCOL website [34].

We welcome any group of collaborating faculty to use the materials identified in this document in their classrooms, as they see fit. Our experiences would lead us to recommend that three to five faculty may successfully participate in any one project with perhaps a total of 20–35 students. This is a manageable size for one facilitator; it requires enough active participation to keep all the students engaged and provides a variety of student and faculty perspectives to keep things lively. Individual faculty with large classes could also use the materials for intracollegiate cooperative learning activities in a single chemistry course.

We have all benefited tremendously from the formation of the PCOL learning community. Using the Internet to link geographically dispersed physical chemistry classrooms has provided us the vehicle to transform and improve our educational practices. Our best projects have engaged our students, improved their communication skills, and helped them learn and apply physical chemistry.

Nevertheless, for interested faculty considering the approach, we do not want to underestimate the labor required. In addition to the PCOL members who have acted as project authors, online facilitators, and internal reviewers of documents, we want to highlight the fundamental importance of PCOL's web master and primary server manager, George Long at Indiana University of Pennsylvania. We certainly could not have conducted any of these projects without him. In addition, we need to recognize the institutional contributions from IUP, the University of Colorado at Denver, and Monmouth University for the allocation of web space and support of listservers.

We endeavor to maximize our effectiveness as teachers and our students' success in physical chemistry by continuing to improve our online pedagogy and continuing to take advantage of the rapid technical advances we all experience everyday. We invite you to try the approach, too.

Please visit our new PCOL website.

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35. The members of the Spartanburg Consortium are David Whisnant, Department of Chemistry, Wofford College, Spartanburg, SC 29303, email: whisnantdm@wofford.edu; Lisa Lever, Division of Natural Sciences and Engineering, University of South Carolina, Spartanburg, email: llever@gw.uscs.edu; and Jerry Howe, Department of Chemistry, Converse College; email: jerry.howe@converse.edu.
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