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Computer in Chemistry

Online Cooperative Learning in Physical Chemistry

ROLAND STOUT[1*], MARCY HAMBY TOWNS[2], DEBORAH SAUDER[3], THERESA JULIA ZIELINSKI[4], AND **GEORGE LONG[5]**
[1]The University of North Carolina at Pembroke, Pembroke NC 28372-1510 Stout@nat.uncp.edu
[2]Ball State University, Muncie IN 47306, 00MHTowns@bsu.edu
[3]Hood College, Frederick MD 21701, Sauder@nimue.hood.edu
[4]Niagara University, Niagara University NY 14109, TJZ@niagara.edu
[5]Indiana University of Pennsylvania, Indiana PA 15705-1090, GRLong@grove.iup.edu

There are certainly new and novel possibilities offered through use of the Internet.

The use of cooperative learning in an online setting is examined using the online segment of a recently offered physical chemistry course as an example. The nature and function of classical, face-to-face cooperative learning are outlined. The online course segment is outlined and is analyzed with regard to the criteria for classical cooperative learning. Though this specific course segment functioned poorly when taught as online cooperative learning, it is possible to structure online courses to take advantage of the strengths of cooperative learning. The possible structure and function of an online cooperative learning community are explored, concluding with a specific model for online cooperative learning.

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Introduction

The Internet offers tremendous potential for connecting people with one another and with its myriad sources of information. The power of the Internet to make connections has caused a great deal of excitement in the educational community. The use of the Internet for educational purposes has, at least so far, generally involved adaptations of existing didactic methods, which are based on established educational practices. As Long and Zielinski point out [1], using the Internet to teach in the "traditional mode" offers little advantage (except perhaps for distance learning in the case of geographically isolated students) and may impede the educational process. There are certainly new and novel possibilities offered through use of the Internet. These may well evolve into new and more powerful educational methods. Long and Zielinski would have us search for those uses of the Internet that will make students more active participants in their own learning. This work examines a well-researched, nontraditional didactic method which does just that. Here we consider the potential for adapting cooperative learning to the Internet.

The online course segment described in this paper was taught over a three-week period in September and October 1996 [2] and has been described elsewhere [3–6]. It was part of the usual physical chemistry course at the institutions of four of the five authors. The primary goals of this miniproject involved having students solve a significant, research-like physical chemical problem. Another set of goals was less quantifiable, but no less important. We wanted the students to recognize both the importance of working in groups to solve difficult problems, and the power of the Internet as a tool that allows collaboration among people who are widely separated geographically. It was our intent to model the research environment and the scientific workplace, where collaboration and the use of the Internet to facilitate collaboration are becoming, if they are not already, the norm. Cooperative learning, as defined below, was not among the specific goals of the project, but the potential for it was implicit in the course design. Having identified this aspect of the course segment, we examined whether, and to what extent, online collaboration can become online cooperative learning.

The kind of collaboration we are trying to provide our students is valuable long after their course work is over. Recruiters continually tell us that many companies expect to spend much of a new employee's first year "finishing their education." This often

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includes teaching them how to function in a small group, dealing with all the interpersonal issues that arise, and how to work collaboratively in solving the kinds of problems common in that industry. Felder has reported a longitudinal study of chemical engineering students who experienced a cooperative learning environment throughout their engineering course work [7, 8]. These students discovered that their abilities to function cooperatively and in a small-group environment were valuable selling points in job interviews. Once hired, these students hit the ground running and advanced more rapidly than many of their counterparts who did not experience a cooperative learning environment in college. We are convinced that using computer networks for both information retrieval and collaboration will be essential skills for our future graduates.

There have been only a few instances of online chemistry courses where *undergraduate* students at different institutions used the Internet for communication and interaction. These have been documented, and archives of these discussions are available on the WWW [4, 9, 10]. While each of these experiences was very positive in its own right, the interaction generated could not be described as cooperative learning in the strictest sense. The purpose of this paper is to evaluate the structure of our recently completed physical chemistry online course segment as an example of cooperative learning, and to recommend how future online courses or course segments might be structured to take better advantage of the strengths of cooperative learning. There is no a priori reason to expect that online cooperative learning will look or function anything like face-to-face cooperative learning. Teaching techniques useful in face-to-face cooperative learning may or may not be applicable to online cooperative learning. Techniques for online cooperative learning, that do not apply to a traditional classroom, probably have yet to be discovered. This paper will compare online cooperative learning with formal face-to-face cooperative learning. It will evaluate the online cooperative learning process and note those aspects that by necessity differ from the face-to-face process, those that are similar, and those that offer certain advantages to online cooperative learning.

Cooperative Learning

Cooperative learning has been actively studied for a number of years and its strengths are well known [11, 12]. It has been successfully applied in chemistry, both in classroom and laboratory settings. Its most commonly reported applications have been

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to general [13, 14] and analytical [15–17] chemistry courses. There are few reported applications to physical chemistry courses, but Combs [18] has presented an approach to teaching physical chemistry that includes some elements of cooperative learning.

It should be emphasized that students merely working together is not cooperative learning. Students studying around a table is usually not a good example of cooperative learning. A group project in which only a few of the group members do most of the work is also not cooperative learning. Working in a group can, at its best, be an example of informal cooperative learning: a group of students thinking aloud as they discuss an experiment, question or problem. It is best to begin with the formal (structured) case to consider cooperative learning. Cooperative learning involves students working in fixed groups, on structured learning tasks, under conditions that meet five criteria [11]:

1. **Positive Interdependence.** Group members must rely on each other to accomplish a goal.
2. **Individual Accountability.** Members should be held individually accountable for doing their own work and mastering the material.
3. **Face-to-Face Interaction.** The group members should do all or some of the work together.
4. **Appropriate Use of Interpersonal Skills.** Group members should (when needed) practice and receive instruction in leadership, decision-making, communication, and conflict management.
5. **Regular Self-Assessment of Group Functioning.** Groups should periodically reflect on how they are working together.

To fully utilize the opportunities provided by cooperative learning, the learning tasks used in cooperative learning are, in most cases, structured differently from those in the Socratic model. One difference can be the use of challenging problems that a student working alone could not typically solve, but that a group of students working together could often solve [10–12]. The “jigsaw” method [11] divides a problem into subtasks assigned to each student in a group. Each subtask requires specialized knowledge

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which is that person's responsibility to learn in order to fulfill the subtask. This model has been used in a number of laboratory settings [14–17].

There are a number of advantages to cooperative learning [11, 12]. Each student working in a group is, at different times, a learner, a teacher, a facilitator, and a leader. As learners, students learn better for the extensive peer tutoring they receive. As teachers, they learn better for having to understand well enough to explain. As facilitators, the students maintain the function of the group, resolve conflicts, and keep group members involved. As leaders, they lead their group into new ways of thinking about a question or an idea, or on to a new question. In formal cooperative learning, students typically learn the course material more completely, learn and hone their interpersonal skills to function effectively in a group, and grow personally for having done so. Each group builds a rapport that, over time, allows its members to shift into a "group mentality" more quickly, and to be generally more productive.

The Internet as an Educational Tool

The Internet, which is still in its infancy, offers a powerful new tool for education. Though a number of educational activities already use the Internet, how it can best be utilized to is still an incompletely answered question [19]. Dix recently wrote a small booklet [20] listing chemistry related materials on the Internet (as of early 1996). The Internet was first used, and is most often used today, as a communication tool and thus as a source of information. The Internet has been used for a number of years to bring together widely separated persons with common interests in topical discussion groups. (For listings of a number of chemistry-related discussion groups, see Dix [20] or the chemical information Website maintained by Wiggins [21].) As one of many examples, consider the chemical education discussion list [22] which has over 1300 members from around the world. This discussion list is used primarily by faculty to share ideas, experiences, and materials, and to discuss interesting questions and issues. While students may, and occasionally do, join this group and ask questions, it is not primarily a tool for directly educating students.

There are also a number of sources of course information on the web. There are hundreds of departments which have home pages that provide program and course information. From many you can access information about specific courses including syllabuses, assignments, schedules, and more [20, 23–25]. As an example, consider the

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"hypersyllabus" [23] for a Science and the Public Interest course. There is a huge body of course materials available on the Internet [20, 24–28]. How these myriad resources are used educationally depends on the creativity of the instructor, just as it did when information came only from printed materials. Information sifting is a significant concern while the Internet and its resources expand.

A number of course segments, short courses, and entire courses have been taught using the Internet as a distance learning tool [9, 24, 25, 29]. Until quite recently, most of these were targeted at the professional or graduate levels. Most are adaptations of the lecture–discussion format through an email discussion group. Problem-oriented courses that might be considered online laboratories have been offered [2–6, 10]. The literature-seminar format (reading and discussing papers, not searching the literature) has also been adapted to the Internet as electronic conferences. ChemConf93 [30] and ChemConf96 [31] are examples of this.

The Present Example

The content of the physical chemistry online course segment was an exercise in curve fitting and model testing specifically applied to the fitting of the van der Waals and Redlick–Kwong equations to data for a real gas. Zielinski wrote a short play introducing the problem through a dialog between an enthusiastic, innovative, assistant professor, Dr. Reni Redikong, and a kindly, traditionalist professor emeritus, Professor Van D. Wall. The text for this play is available on the WWW [2] and contains a number of hot links, including links to the data necessary for the project, a study guide [32] including the goals and objectives for the project, and an extensive bibliography [33] on gas laws developed using the computerized index of the *Journal of Chemical Education* [34].

This course segment, and one offered in the fall of 1995 dealing with flame temperatures [35], are the first two in a series of case studies we plan to develop. (These are available on The Physical Chemistry Education Resource Center home page [36]). We hope to offer students a significant exploration into topics of the discipline so, having completed the project, they will take meaningful learning experiences with them.

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This online physical chemistry project was designed so that students would work together in groups to facilitate their progress and to emphasize the importance of group work for solving complex problems in chemistry. The number and size of groups varied. On one campus, 14 students formed four groups, on another, six students worked together in a single group. The groups on each campus were encouraged to communicate with each other using a discussion list format, asking each other questions, providing insights and offering suggestions [3–6]. To promote this online interaction, the faculty at each participating campus stepped outside the faculty role, referring questions to Zielinski who assumed the role of an online facilitator for the project. The facilitator's role included providing a neutral voice to respond to student questions and writing notes to student and faculty participants to encourage communication across the online community. We hoped that other students would answer most of the questions posted to the list creating the collaboration we were seeking. We later recognized that what we had set up might be considered an intercampus, online cooperative learning experience. The question, which we consider here, is to what extent the collaboration we intentionally tried to create was cooperative learning.

An interesting but unanticipated outcome of this course segment was the spontaneous self-organization of the participating faculty into a learning community. Working as a "supergroup," we developed this course-segment concept further than any one of us could have alone and solved a problem that no single faculty member can solve: giving our students wider exposure to other students' thoughts and comments. This is quite valuable to a student on the verge of becoming a professional chemist, particularly those in small classes and smaller departments, as it exposed them to the idea of a professional community in a way not always possible at a smaller institution.

In many ways this supergroup functions as a cooperative learning group. As indicated above, we exhibited positive interdependence. Individual accountability and appropriate group interaction were fostered through self-motivation for both personal and professional reasons. We have not assessed the function of the supergroup per se, but comments made in our electronic correspondence suggest that we have all benefited from our stimulating discussions. One comment (TJZ) sums it up well, "...At the faculty level we learn quickly from each other and interacted several times a day as our other demands allowed." We also have a secondary assessment of our supergroup's function through our own written evaluations of our online course

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segment. This supergroup continues to function with three anticipated results: a detailed evaluation of the course segment described above [37], the development of the next course segment in this series (which will consider the vibronic spectrum of iodine vapor), and the offering of this course segment in the spring of 1997. This new course segment continues the examination of collaborative online courses as a new educational paradigm.

Online Courses as Cooperative Learning

Comparing the structure and intended function of the online course segment described here with the criteria for cooperative learning gives some valuable insights into the nature of the process. First, we note that the online course segment did use fixed groups of students. On one level, each participating class was a member of the online group. On a second level, each class was divided into smaller fixed groups, which were themselves members of the online group. On yet a third level, each student could be considered a member of the online group. Cooperative learning is thus potentially operating on two levels, within the groups on each campus and among the groups on all the campuses.

The problem chosen for this course segment was sufficiently complex that we doubted that any student working alone would be able to solve it. We encouraged the students to post questions to the list, to offer insights and ideas, and to answer the posted questions if they could. Despite our attempts to encourage intercampus interdependence, we could not ensure it. Students always had their local groups to fall back on. To the extent that this impeded the formation of an online community of learners, it detracted from the online cooperative learning taking place.

The criterion of individual accountability was met as each student was graded by their local professor. Specific grading criteria varied, but each student earned their own grade.

Face-to-face interactions were not possible online, but did occur within the groups on each campus. The appropriate use of interpersonal skills is less of an issue online than it is face-to-face in the local groups. Both criteria are involved with the development of interpersonal skills and the maintenance of a good working relationship within the group. The concept of “group,” in the sense of cooperative learning groups, is

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stretched to the limit in the case of online learning. Does a group exist at all? If so, what does it mean in this context? What kind of interpersonal skills are necessary to maintain its function? These are all valid questions, and must be answered before we can truly understand what it means to use online cooperative learning. Our interest is in the practical aspects of making it work as an effective teaching tool. There is ample room for a theoretical study of interpersonal interactions on the Internet, and their impact on online cooperative learning. We leave this question for others with more expertise in this area.

Something like a cooperative learning group can exist online if we relax the face-to-face criterion of cooperative learning. We will assume that such a group can exist and will examine some of the consequences of its operation online. We first note that the operation of an online cooperative group will be quite different than that of a local (face-to-face) group. The nature of the interaction and students' motivation to be involved are both different. The forces that cause students to be involved in a learning group in a local setting are of three types: course requirement, peer pressure, and a desire to succeed. Put differently: outside or imposed pressure, peer pressure, and self-motivation. The first and third are present in both local and online groups. Only the peer pressure is fundamentally different. Peer pressure of a sort may exist in an online group, but it is clearly of a different nature and seems less important. Should any student want to, they can turn off their monitor and ignore their online peers. However, on each campus there may be local peer pressure to become involved with the online group.

Face-to-face interaction also implies instantaneous feedback. The feedback online is delayed from several hours to a day or more. When a question is posted to the list, others may not be online. Ideally, they will read their email sometime within the next 24 hours and then respond. The questioner may then be offline and will find the answers later when they next log on. This asynchronous communication has some advantages [1] as it allows students to work on their own schedule. It is certainly possible to collaborate this way; many scientists routinely do. But spontaneous discussion, through which a group works together toward insight, is not possible. It remains to be seen how effectively asynchronous group collaboration can be transformed into group learning.

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The success of an online cooperative learning group appears to depend more on the self-motivation of its members than is the case for a local group. It functions much more on a intellectual level than an emotional level, in contrast to a local group in which emotions can play a significant role. The interpersonal skills criterion in group learning is primarily needed to deal with the emotional and interpersonal issues that arise in a group and to keep it functioning as a group. An online group will typically be unaware of the subtle nuances needed to recognize or to deal with any emotional reaction any specific member has to a message posted to the group, or to any member's emotional state. Interpersonal skills are then perhaps less useful in an online cooperative learning situation. Those that are most useful deal mainly with the etiquette of online communication (netiquette) and not with the issues that keep a group from functioning efficiently. On the other hand, the local groups might be able deal with the emotional baggage, keeping each of its members functional, both as a member of a local group and of the online group. Interpersonal skills then assume perhaps an even greater importance.

What is clear is that the nature and the group functioning of an online group are different from those of a local group. Exactly what these differences are and what group skills are needed to maintain group functioning remain to be understood, and may be questions best left to social scientists. We are more concerned with finding the best structure for an online course segment to take advantage of cooperative learning. We suggest a possible structure below.

The last criterion is for regular self-assessment. This can certainly be built into the structure of an online course segment. The short duration, three weeks for the course segment described here, will limit the opportunities for a *regular* self-assessment, particularly if this information is to be used to modify the course structure or operation, but will not prevent it. The nature of this assessment and its eventual use depend on the nature and functioning of the group, and remain to be addressed.

It is our belief that an online course can be structured to extend the cooperative learning taking place in the local groups on each campus to the online group via the Internet. The nature and functioning of such a course, and the interpersonal skills necessary for its maintenance are incompletely understood. It seems clear that the success of such a course depends more strongly on the students' self-motivation than it does in more traditional cooperative learning. Its use at the college junior–senior level

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therefore seems appropriate, given the personal and intellectual maturity that most of these students exhibit.

Online Course Experience

Brief summaries and preliminary evaluations of this course segment have been published [4, 5] or presented [3, 6], and a more detailed analysis of the course segment, based on detailed student and faculty evaluations, is being prepared by Towns [37]. This analysis will include an examination the application of cooperative learning to this course segment through the student groups formed on each campus. Intracampus cooperative learning will not be considered here except as it influences intercampus cooperative learning.

The first experience our students had with this course segment was that just about everything that could go wrong with the technology seemed to do just that. Several problems including the sheer volume of local Internet traffic as students returned to school, and the installation and upgrading of Internet links, not to mention the hurricane that knocked one campus off the Internet for several days, all combined to generate a very frustrating online environment for the students. On the second day of the online session, the designated online project facilitator (TJZ) received this message from a student on another campus: “Dear Dr. Z, this operation is beginning to become frustrating. To date I have not received any email messages from anyone. Would you please see if there is any way that I can get these messages. Thank you.” Like most students, this one had a low tolerance level for nonfunctioning educational systems. Zielinski then became the distributor for all messages for the participants of the project. The next thing that the faculty noticed was that the students almost completely stopped sending email, even though they were continually encouraged to send it. Through personal experience they learned of the fragility of the technology involved and they became less willing to put their time and energy into the learning community beyond their local campus.

Possible reasons for the student unwillingness to invest themselves in the online community include frustration with the communication technology and reticence to ask questions in general, for fear of appearing “dumb.” These and other possible reasons are discussed in more detail elsewhere [3–6, 37]. It is sufficient for our purposes to note that the online cooperative learning community that we initiated and

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encouraged did not form. We must therefore admit that, as an example of online cooperative learning, this project was unsuccessful. However, online cooperative learning was not one of the stated goals of the project. What we are considering here is whether it might have been, or could have become, an example of cooperative learning. In terms of its stated goals, the project succeeded. On each campus, most students, working in their local groups, were able to make substantial progress toward solving the problem posed to them, and their intellectual skills and self-confidence grew considerably [3–6, 37].

We judge the overall project a success and while disappointed, are not discouraged by its failure to form an online learning community. We feel that since we have recognized the potential for online cooperative learning, there are ways to plan for it, to restructure the project to facilitate online interaction, and to better encourage the formation of a more active learning community. These are discussed below.

Thoughts on the Structure of an Online Cooperative Learning Community

It is clear from our experience that more must be done to facilitate and encourage the formation and functioning of the online community. The nature of an online cooperative learning group and the interactions of the people in it are quantitatively different from those found in local groups. The questions raised by this distinction need further study, and are perhaps better addressed by social scientists than by chemists. Nevertheless we have some ideas about these issues too.

Perhaps the most obvious improvement we could make to increase the potential for success is to be sure the technology works properly. Many of the difficulties we encountered were beyond our control, but there are ways to decrease the likelihood of problems. One is to ensure that the computer system used for the project's email server has sufficient memory and communication bandwidth to handle both the online course and its usual campus communication traffic at peak usage times. This is an administrative issue at the campus housing the email server. Good statistical information about the email traffic patterns during past online courses would be helpful in the planning process. Developing a backup communication system through a different Internet node is a good idea, as we discovered.

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Students must be comfortable with the technology. In most cases, students will have been introduced to much of the technology, and may be using it, before they enroll in physical chemistry. This does not necessarily mean they will be experienced users. Most of our students had only limited experience with email and the mathematics software we used. Two had actively avoided using computers. We need to be sensitive to the possibility that some students may be computer phobic, and, if necessary, we should even be willing to describe the location of a computer's power switch. It might be helpful for an online course segment to occur later in the term. This would allow each instructor to introduce their students to the computers available on their campus, and to use them in their classes before the online course segment starts. Students would then become more familiar and comfortable working with the computers, and with using them to solve physical-chemistry problems.

The structure and interactions of an online cooperative learning group are probably the most fundamentally important issues to resolve. We propose that cooperative learning be structured as an extension of intracampus cooperative learning formats, rather than as a stand-alone cooperative learning effort. The cooperative learning groups on each campus would then each be a member of the intercampus learning group, creating an intercampus group of groups. We would encourage our students to post questions, comments, ideas, etc., to the larger group through their local group rather than individually. This would ideally cause increased local group interaction in formulating their postings to the larger group, keeping all the students intellectually engaged in the process. We further suggest making the local groups responsible for keeping their members involved. We note that if the local cooperative groups are formed and begin functioning well before the online course segment begins, local groups will already be keeping their members accountable. Extending this accountability to the online course segment should then occur naturally.

The use of a cooperative learning model is implied in each physical chemistry class taking part in the online course segment. While this is worthwhile on its own merits [7, 8, 11–13], it presents several concerns. Most physical chemistry courses are apparently not using a cooperative learning approach. Many professors are unfamiliar with cooperative learning methods. Those that begin using cooperative learning methods often find them to be initially difficult, and some faculty may actively resist using cooperative learning [38]. Should local classes not using cooperative learning be automatically excluded from taking part in an online course segment? We think not.

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There is much to be gained even if, on some campuses, individual students rather than cooperative learning groups are considered part of the online group. They can still benefit from the online discussions and work through the problem. They will, no doubt, learn a great deal through the process. They are also more likely to become frustrated when a specific part of the problem stymies them, and, with no local group to turn to for ideas and support, may be more likely to give up on the problem. It becomes the responsibility of the instructor at that campus to keep students engaged in the process, to encourage them, and to help them over the hurdles.

Cooperative learning is facilitated by using teaching methods well-suited to the nature of cooperative work. The jigsaw method [11] breaks down a large problem into smaller sections, which are assigned to different students within a group. Each student is responsible for solving their subproblem and communicating its solution to the group, which then takes all the pieces and assembles them to solve the larger problem. We suggest adapting this to an online course by giving specific local groups a portion of the large problem to solve in the local group and by collaborating with other local groups with the same subproblem. The solutions would be due by a specific date when all the subproblems and their solutions are shared and discussed online. This discussion should bring each local group up to speed with all the subproblems and then shift to the question, "How to proceed from here?" as they begin to refocus on piecing these subproblems together to solve the larger problem.

When faced with a complex problem, such as used in the physical chemistry project outlined here, it is often helpful for a group to have a spontaneous, free-flowing exchange of ideas. Very often, a few likely ways to approach the problem will be identified. Potential "road maps" to the solution will be outlined. With a starting point and an idea of how to proceed identified, the group members can then begin working more independently to flesh out the map and perhaps arrive at the solution. This exchange of ideas can be an example of cooperative learning and one which we would like to promote in an online course. It is, unfortunately, better suited to face-to-face interactions than to online interactions. It seems logical that the best atmosphere for spontaneous online discussion would be one in which all parties were simultaneously online, perhaps using chat line or videoconference technology. Individual schedules and time zones make these difficult, if not impossible. One alternative would be to set aside a specific time slot of half a day to a day or so for such an email discussion, and encourage participating local groups to check their email several times during that

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period. The near-synchronous communication during this time could be used for several purposes depending on the design of the class. If the jigsaw method is being used, this could be the time to share the results of subtasks with the larger group. It also would be an ideal time to assess the functioning of the learning groups, both local and online, and to check in with and encourage all the participants. Unfortunately, in times of high computer traffic, and particularly for sites connected to the Internet through a lower bandwidth link, email is occasionally delayed for many hours, making even near-synchronous communication difficult.

The next major issue to resolve, if we hope to improve the teaching of online courses, deals with encouraging increasingly fruitful online communication among the students in the course. Making the communication technology fully functional and as transparent as possible to the students are steps in this direction. So too is the proposed structure of the course segment given above, which provides for both keeping individual students engaged in the process and requiring at least some online interaction due to the distribution of different subproblems among the local groups. Linking the amount of email interaction to the grading of the course segment would also encourage more interaction.

We also need to provide a nonthreatening atmosphere for the students of physical chemistry in general, for working in learning groups, and for the technology and procedures that will be used in the online course segment. This is primarily dependent on the instructor at each institution, who could institute cooperative learning early in their course. Instructors could also acquaint students with the notion of solving open-ended problems, and with using computers to do so by assigning such problems from the beginning of the course and by spending some time teaching students how to use the relevant hardware and software. This might be an ideal way to revitalize the teaching of physical chemistry [39]. Another way to ease students into the rigors of physical chemical calculations is to start an online course segment with one or two less complex, “warm-up” calculations. These could be stand-alone problems, or might be the subproblems cited above.

The last issue to address is that of getting students to participate and to ask questions. We feel that the reticence of students to become involved in the online collaboration was an extension of their general, passive response to education. This response has three components. The first is the unexciting nature of physical chemistry, as it is

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usually taught [40]. The second is the passive nature of student involvement in a typical lecture format, and the third is the fear of embarrassment when they ask a question in class [41]. The first of these was largely overcome by having the online course segment deal with a "real world" problem in physical chemistry. Cooperative learning techniques have been shown to reduce or eliminate the last two components of this problem [7, 8, 11–13]. We suggest that using cooperative learning strategies at each local campus and extending these, as described above, to the online course segment will largely solve the problems associated with this last issue.

Conclusion

We are convinced that online cooperative learning can be done, though how it will function differs in some details from face-to-face cooperative learning. We believe that it may well provide a new, powerful teaching tool, going beyond what we had envisioned in designing the physical chemistry project described here. We propose a model for online cooperative learning:

1. Each participating class should be organized in a cooperative learning format at the beginning of the term.
2. The start of the online segment should be delayed to allow cooperative learning to take hold in each local class.
3. The online cooperative group should use the local cooperative groups as its members.
4. The online course segment should begin with a warm-up exercise, perhaps with subtasks of the larger problem to be addressed (jigsaw method).
5. Times should be planned for all the local groups to get together simultaneously, or as nearly so as possible, for assessment of how the project is going. If the jigsaw method is used, this time can also be used to communicate the results of all the subtasks of the larger problem to the entire group.

This model for online cooperative learning is as yet untested, though we plan to implement it in the spring of 1997 in a new physical chemistry online course segment.

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The approach suggested here is not the only possible way to structure a cooperative online activity. As this area of education is more fully explored, a rich and diverse array of methods will be developed, much as now exists for face-to-face cooperative learning. We further expect that the benefits of cooperative learning described earlier will be realized through learning experiences such as those suggested here, and will be exceeded to the extent that students learn to function in an extended collaboration online.

We end with a vision statement. In seeking to formally join two powerful teaching tools, cooperative and online learning, apparently for the first time, we stand at a cross road in how we will use the Internet for education. Long and Zielinski [1] recognized that such cross roads exist, and we are now at a branch point. One path, business as usual, is familiar and comfortable but has limited productivity. The other path incorporates both on-line and cooperative learning strategies to produce a vibrant, thriving, online, learning community among our students and us, but has more perceived risk. It may appear frightening to some teachers to give up control over their class, allowing students to interact with each other and with other teachers. The Internet connects the entire chemistry community, literally forming a global village. Here in this village of chemists, the African proverb "It takes an entire village to educate a child," rings most true. The students at our campuses need not be **your** students or **my** students, they can become **our** students through the Internet. Recognizing and acting on this, as we can attest, leads to a stronger learning community than any of us could create in our class rooms alone. Our students learn better, understand more deeply, and grow toward the independent thinking, life-long learners we hope they will become because of it. Can we afford to do less for our students?

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Note added in press

As this manuscript goes to press, the Spring 1997 physical chemistry online course segment has just been completed and its evaluation is beginning. This course segment was structured using many of the recommendations made in this paper and served as a first test of them. Our initial impression is that the course modifications fulfilled their intended purpose of creating an online atmosphere conducive to cooperative learning. We feel that the course segment succeeded both as a physical chemistry learning activity and as online cooperative learning. A description and evaluation of the spring 1997 course segment will be forthcoming.

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