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ABSTRACT

This study reports the efforts of the Water and Molecular Networks Project (WAMNet), a program in which high school chemistry students use computer simulations developed at Boston University (Massachusetts) to model the three-dimensional structure of molecules and the hydrogen bond network that holds water molecules together. This case study examined the changes of a chemistry teacher in one 10th grade (n=17) and one 11th grade (n=16) chemistry class that were using the WAMNet computer simulations. Results are discussed concerning changes in teaching strategies, student learning and motivation, changes in the classroom, and logistical issues in getting the computers and the network set up in the school. The study concludes that: (1) teaching models used in the class changed from teacher-centered to more student-centered; (2) students were on task for most of the time they used the computers; (3) students used e-mail to contact friends rather than enter into mentoring relationships with the graduate student programmers at the university; and (4) it takes considerable cooperation between the participating groups to pilot test this kind of high technology to a school and have it used in a productive manner. (MDH)

A CASE STUDY OF THE INTRODUCTION OF RISC-BASED COMPUTING AND A TELECOMMUNICATIONS LINK TO A SUBURBAN HIGH SCHOOL

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*A Case Study of the Introduction of RISC-based Computing and a Telecommunications Link to a Suburban High School**

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OBJECTIVES

This poster presents preliminary results from an ongoing study. The objectives of this research are as follows:

- To assess the impact of introducing RISC-based technology into a high school science classroom in terms of the effect of this innovation on the teacher and his teaching style.
- To assess the effect of bringing RISC-based technology into a high school classroom in terms of student learning and motivation.
- To document the impact of networking on all participants by monitoring how the high school students, high school teacher, scientists, post-doctoral fellows, graduate students and undergraduates use the telecommunications link between the high school and the university.
- To document the technological, financial, logistical, sociological, and organizational problems associated with bringing RISC-based technology and telecommunications into a high school classroom.

INTRODUCTION

Water and ideal gases are major topics in the study of science, particularly chemistry. Currently students study the macroscopic properties of water experimentally but must rely on books and lectures to learn about the molecular nature of water. With the advent of Reduced Instruction Set Computing, (RISC), the speed and graphics capabilities needed to model the three dimensional, dynamic structure of water molecules are available. Funded by the National Science Foundation, Applications of Advanced Technologies division, graduate student and undergraduate student programmers at the Center for Polymer Studies at Boston University have been writing computer simulations for RISC-based systems. These

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simulations help students conceptualize the structure and properties of fluids on a molecular level.

Several researchers have examined what students believe about the macroscopic and microscopic properties of water. For example, Giese (1987) constructed and analyzed a written test on water pressure and found that middle school students in her investigation held numerous preconceptions. Novick and Nussbaum (1981) have studied student understanding of the particulate nature of matter. Griffiths and Preston (1992) recently published one of the most extensive studies of student preconceptions concerning water molecules. In their investigation, thirty high school students were interviewed extensively. Griffiths and Preston found that students held significant preconceptions concerning the structure, composition, size, shape, bonding, and energy of water molecules. Furthermore, Griffiths and Preston reported few differences between the preconceptions held by students with strong science backgrounds and their cohorts who had received little or no formal instruction.

Griffiths and Preston suggest three possible reasons why students hold preconceptions about water molecules. First, scientific models of molecules are typically presented in a way that make them appear abstract and unrelated to everyday experience. Second, the particle nature of matter is so innately complex and difficult to visualize that students are forced to construct creative and unorthodox conceptualizations. Third, in an attempt to help students visualize the sub microscopic world, textbooks often present contradictory models of atoms and molecules. Such inconsistencies may lead to additional confusion.

A possible way to improve student understanding of the molecular structure of matter is to use currently available computing power to develop visual, dynamic, and interactive simulations for the science classroom. Computer simulations that address student preconceptions concerning molecular water are being developed by undergraduate and graduate student programmers at Boston University. These visual, highly interactive simulations employ the speed of RISC-based (Reduced Instruction Set Computing) workstations to model the three-dimensional structure of molecules and the hydrogen bond network that holds water molecules together. By varying various macroscopic parameters (e.g. temperature and pressure), students can use these simulations to make and test predictions concerning the microscopic properties of water molecules.

The project that will be described in this paper put high powered computer technology in a high school classroom. The instructors teaching style changed as a result. An Apple Classroom of Tomorrow (ACOT) project found similar results when they introduced computers and associated hardware into classrooms (Ringstaff, Sandholtz, Dwyer, 1991). In their study 32 elementary and secondary teachers in five schools were studied. These teachers and their students had unlimited access to computer tools throughout the curriculum. Teachers involved in the study reported that they moved from being the sole purveyor of knowledge in the classroom to allowing the students to use available resources to discover for themselves.

Figure 1 is taken from the ACOT report. It describes their model of how technological innovations gradually become part of a classroom. At first the computers are used similarly to how a text might be used in a teacher-centered, lecture-based classroom. Gradually a shift is made to using the computers for project-based, cooperative learning that puts students in charge. This change in instructional strategy occurs gradually and as it is happening, the teacher still his/her established curriculum in the traditional manner. Eventually, in the adaptation phase, the established curriculum and the computer work become more intertwined and taught less traditionally. A similar pattern was found by the educational researchers involved in the WAMNet project, although the time scale was shorter. Mr. Jones started in the entry phase during the spring of 1992 and has moved through the stages into the appropriation phase.

Schofield, Evans-Rhodes, and Huber (1990) studied two teachers who used a geometry tutor program with their classes. They found that the amount of attention given to the weaker student increased as a result of using the tutor program with the class. In the classes where the computer was not used, the teachers paid more attention to the stronger students whereas the same teacher paid more attention to the weaker students in the classes where the computer was used. In addition they found that the teachers became collaborators with the students. By this they mean that the teachers worked with one or two students at a time rather than calling on students in front of the entire class. The teachers responded to students' requests for help rather than initiating the interaction themselves. The WAMNet research yielded comparable results.

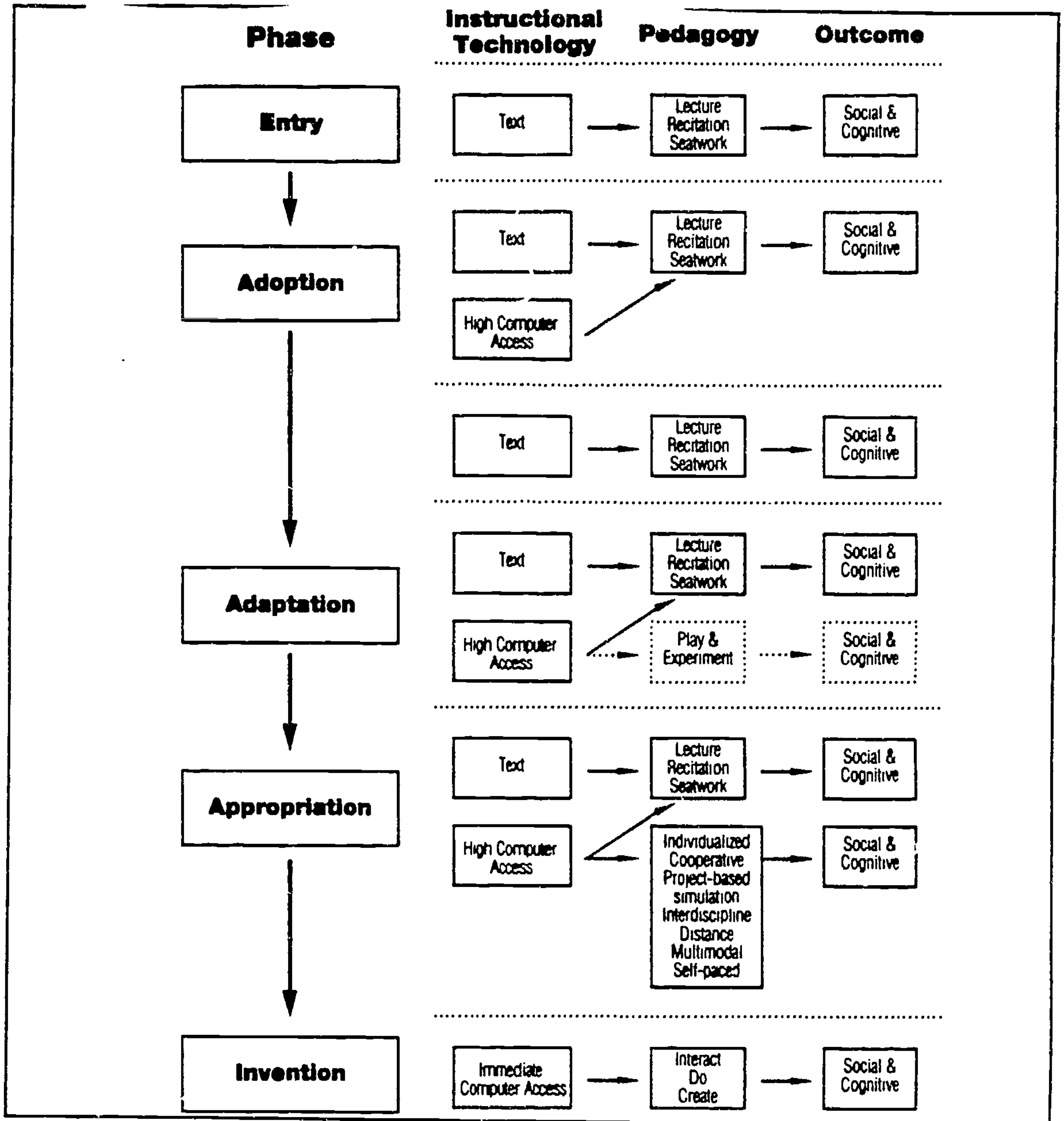

Figure 1 ACOT's model of instructional evolution in technology-intensive classrooms (Ringstaff et al 1991).

Electronic mail (E-mail) has been used to a limited extent to provide high school science classrooms access to university faculty and other resources. In the LABnet and STARnet programs, high school science classrooms have been linked together (Podany, 1990). In both programs, the telecommunications is used to connect teachers doing similar projects to each other and to university staff in charge of the projects. Lehman and Campbell (1991) are studying the use of microcomputer based laboratories (MBL) in high school science classrooms in Indiana. In the participating schools e-mail is used to connect teachers to each other and to the staff of the project. Stallard (1991) describes "smart schools" of the future. One of the characteristics of these schools is that they will be networked in so that they can share information and use e-mail. The purpose of the e-mail in the WAMNet project is to connect students and teachers to the university with the expectation that university undergraduate and graduate students would develop mentoring relationships with high school students.

OVERVIEW OF WAMNET PROJECT

The setting

The Center for Polymer Studies at Boston University is composed of physics department faculty, post doctoral students, graduate students, and undergraduate students. Several years ago they decided to use their expertise to bring current science to high school students. The first project, On Growth and Form (OGAF) concerned fractals in nature. As the project progressed, graduate students who were studying the molecular structure of water adapted simulations that they had written for their own research into simulations that could be used by high school students. The purpose of the high school simulations is to help students learn about the molecular nature of water and other fluids. These simulations form the basis of the WAMNet (Water and Molecular Networks) project. The simulations that are used in the high school differ from the original simulations used for research in that they are far more visual. The programs used for research do not have friendly user interface and the graphics are not updated as frequently. The researchers tend to use the calculating power of the computers to their maximum, but not the graphics capabilities. Mr. Jones and the educational researchers convinced the programmers that what was important for high school students was the visual nature of the simulation as well as its highly interactive nature. As a result the simulations are very visual, which also means that they are somewhat slower than the research counterparts because of the need to update the screen frequently.

The high school involved in the project is located in a middle-class suburb of Boston. One of the chemistry teachers at this school has been involved in the Polymer Center educational projects for the last four years. This year, ten RISC based machines were placed in his classroom. A high speed telecommunications line was also installed linking his local network directly to the Boston University computer network and, by extension, the rest of the Internet world. He has used the WAMNet simulations with his tenth grade honors chemistry class and his eleventh grade chemistry class.

The purpose

The purposes of the WAMNet simulations are threefold. The first is to teach students how the macroscopic properties of water and other fluids are related to their molecular nature. For example, students are told in science class that the higher the temperature of a substance, the faster the molecules are moving. With the computer simulation, they can increase the temperature and actually see the molecules move faster. They can also use the simulation to visualize the hydrogen bond network in water and see how the system changes by varying thermodynamic parameters.

This leads to the second purpose, which is to give students visual models with which they can experiment. The aim is to help the students work as researchers. The questions that they research may not be completely novel to scientists, but they will be to the students. With the simulations, they can design the experiments themselves and thereby learn important research skills such as keeping the number of variables to a minimum, collecting data and analyzing data. This kind of research is difficult to conduct in the traditional high school chemistry laboratory because of the limited amount of equipment and inherent dangers associated with chemistry laboratories. A teacher cannot simply let students freely explore in the chemistry laboratory. With simulated experiments there are no dangerous chemicals or expensive equipment (with the obvious exception of the computer) needed. Computers are also not expendable and therefore do not need to be purchased every year.

The third purpose of the computer simulations is to teach students that models are not perfect; they have limitations. For example, the simulations cannot show the molecular structure of water as it freezes. The students can decrease the temperature below the freezing point but the program will not simulate the hexagonal lattice. The reason for this limitation is very simple. In order for the simulation to work properly it must take into account the vibrational motion of the individual water molecules. This means that the time step must be 10^{-15} seconds. The time scale for freezing water is on the order of 10^{-3} seconds. Therefore one could theoretically freeze water using the simulation, but it would take a very long time. This is one way students learn that models and simulations work within limited boundaries. One student in the class did a quick calculation of the time necessary for water to begin to freeze in the simulation. His result: 31,000 years!!

The purpose of putting a high speed line into the school is to see how such technology can be used. The high speed network helps the programmers correct and update the programs and immediately send the updated version to the school. The connection to Internet also allows Mr. Jones and students to communicate with anyone around the world who is connected to an Internet node. Although the RISC machines are faster and more powerful than the computers typically found in high school classrooms, the high speed line also allows the students to run simulations on computers at Boston University which are even more powerful. For example, water simulations are being developed for the Connection machine, a supercomputer located at Boston University.

Currently the students can run the simulations either on the workstations in the classroom, or over the network on similar workstations at Boston University. While there is currently no advantage for the students at the high school to run the simulations over the network, it is possible for schools to have X-stations which can run the programs over Internet. Having workstations at the school allows us to test out this possibility with a built in safety feature. If the connection to Boston University goes down for some reason, the students can still use the simulations.

The simulations

Snir, Smith, and Grosslight (1988) call for the development of "conceptually enhanced" computer simulations which allow students to observe and experiment with what cannot be directly observed in the laboratory. Such simulations show the relationships between concepts. Snir et al believe that only with such simulations can educators truly address and change students' incorrect preconceptions. The designers of such simulations base the code of the program on the physical laws that underlie the system that is being modeled rather than simply programming a set of windows which will be viewed in sequence. The WAMNet simulations are conceptually enhanced computer simulations according to the standards set by Snir et al. They are not simply movies of computer screens but are driven by algorithms which represent the most current thinking about how molecules behave.

One of the simulations used by the honors chemistry class is called *Wasser*. It starts out with 64 water molecules. The molecules are represented by "sticks" which look like boomerangs. The student has the ability to vary the temperature, pressure, and density of the container of water. With a three button mouse the student can zoom in or out of the container and can rotate the container in all three dimensions. With the proper graphics card the simulation can also represent the water molecules three dimensionally as a combination two small hydrogen spheres attached to a larger oxygen sphere. Both of these representations are dynamic and the student could switch between them or have both on the screen simultaneously.

In addition the simulation allows for the insertion of an ion or salt into the system of water molecules. After choosing the type of ion or salt a two dimensional potential energy landscape is drawn. This is color coded for the students to show them areas of high and low potential energy in much the same way that a color weather map shows area of high and low temperature. Students can move a grid around the container to see the potential energy landscape of any slice they choose. They then can choose the place where they think they will be able to insert the ion or salt. If the place they choose is acceptable, the computer will tell them so; if not it will ask them to choose another place. Once the students have inserted the ion or salt they can watch how the water molecules and the hydrogen bond network react to its presence. In the case of the ion the water molecules will form a hydration shell. In the case of the salt the water molecules will slowly force the ions apart and dissolve the salt.

Another simulation that was used in both the honors chemistry and eleventh grade chemistry classes is called *XLJ*. *XLJ* stands for X-windows Lennard-Jones. X-windows because the simulation runs in the x-windows format. Lennard-Jones, because the simulation uses the Lennard-Jones algorithm to simulate the behavior of gas particles. This simulation allows students to adjust various thermodynamic parameters of a gas and observe how the behavior of the particles is affected. The students used this simulation to study the behavior of ideal gases, especially to discover what "ideal" really means.

All of the concepts embodied by the simulations are concepts that are included in many chemistry classes. However, these concept are not easily demonstrated in traditional laboratory experiments because one cannot create a macroscopic experiment which shows what is actually happening at a molecular level. In addition, what is shown in these simulations is the most current model that scientists have for how fluids behave at a molecular level. Most students are not exposed to current scientific thought and research methodologies in high school. What is called "modern physics" in schools is at least fifty years old. It is the intention of the WAMNet project to use current science as the vehicle to teach students the process of science and to show students that there is more to science than what is in standard textbooks.

METHODOLOGY

Subjects

The subjects in this study are Mr. Jones, a high school science teacher and his chemistry students. As stated previously, there are two main classes involved in the study. They are a tenth grade honors chemistry class with 17 students and an eleventh grade chemistry class with 16 students. The tenth grade class took physics as freshmen. The eleventh grade class took physical science as freshmen and biology as sophomores.

A few biographical notes about Mr. Jones. He has been teaching at this school for 18 years, his entire teaching career. Coincidentally, this is also the high school from which he graduated. He has a bachelors degree in chemical engineering and a master's degree in education. He has taught biology, physics, and chemistry and been involved in curriculum development. At various times he has been a wrestling coach, a soccer coach, a park committee chairperson, a cub scout and webelos leader, a scoutmaster, and an explorer advisor. Prior to being involved in this project had much experience with computers. He has had a computer at home for several years and has chaired a workshop on integrating the computer into the chemistry curriculum. He has also worked with another teacher writing physics simulations in Hypercard stacks.

Procedure

Observations of the participating teacher's physics and chemistry classes have been made twice a week since the spring of 1992. During the spring of 1992, the teacher used OGAF materials with his honors chemistry students. OGAF simulations run on Macintosh II series computers. Since September 1992, the teacher has been using the OGAF materials with honors and regular chemistry class as well as with a physics class. He has been using the WAMNet materials with his honors chemistry and regular chemistry classes. The research staff has been taking extensive ethnographic field notes of this class which are in the process of being transcribed and coded. They have also interviewed Mr. Jones and talked to students informally. All of this data is coded and analyzed.

RESULTS

Changes in Teaching Strategies

Our observations from last spring and early this fall show a teacher who was the source of information in the classroom. His lectures were in a Socratic style where would ask questions which the students would then answer. There was a constant dialogue between Mr. Jones and the students but it was Mr. Jones who either asked the questions or to whom the questions were asked. When asked about his teaching style, Mr. Jones agreed with our characterization. The following is an example of his style. It is excerpted from observer notes from the spring of 1992.

> *The class quiets down. CH [Mr. Jones] is still lecturing. The students have their books and notebooks open. All of the desks in the room are filled. CH asks questions and calls on students to answer.*
>
> *O.C. [observer comment] CH'S STYLE IS SOCRATIC.*
>
> *Both girls and boys raise their hands. after CH asks each question The class is involved in a discussion of what can change the rate of chemical reaction.*

CH asks if any students have already read the chapter. A few have.

Students call out answers. Ellen argues against "shake" as an answer. CH asks someone to defend it.

1:57
Ellen asks and answers a lot of CH's questions. CH asks other students to repeat what Ellen has said in their own words.

2:00
CH asks for someone new to answer a question. He probes for a more complete answer from a student. Even though CH asks a specific student a question others raise their hands. Some students nod or shake their heads.

There is no talking among the students.

While Mr. Jones made an effort to call on all students to answer questions, it was typically the stronger students who volunteered to answer and who in fact answered most of the question. This is reflected in the observer notes.

Mr. Jones has received support from school administrators and most parents for his work with Boston University. There have been some parents who feel that their children are missing parts of the "regular" chemistry curriculum in favor of using the computer. Some also feel that the work on the computers is taking too much school time. Mr. Jones reported to the observers that he has been able to convince many of them by showing them the programs and convincing them that depth of knowledge is at least as important if not more important than breadth. Mr. Jones also explained to the parents that the students are learning very important computer and experimental skills by working with the simulations.

Last spring and earlier this fall, Mr. Jones had always left the computer assignments to the end of the period. The result was that the students would have five to ten minutes at the end of a class period to work on the computer programs from the OGAF project (see Figure 2). When asked why he gave the students relatively little time to explore the computer simulations, he replied that last year he felt the materials were less well defined. There were no curriculum materials, just several hands-on activities to go with several computer programs. The links between the programs were not well defined. Mr. Jones, along with three other teachers who are pilot testing our software, spent the summer of 1992 developing activities. The time spent working with other teachers who had used the software helped Mr. Jones determine the best way to use the programs this year. Mr. Jones also spent much of the summer examining the WAMNet programs and learning basic UNIX commands. He made many suggestions as to how the WAMNet simulations should be modified. This process made him very invested in the project. When Mr. Jones started to introduce the simulations on the RISC machines in the fall of 1992, he began to give the students more time on the computers. Now the division of time is reversed. When Mr. Jones plans to use the computers he spends the first 10-15 minutes of class time discussing issues related to the simulations, such as what the students have seen while using the simulations and how to use them more effectively. He then gives the students the rest of the 50 minute or double period to work on the simulations. He walks around and gives help where needed or when asked, acting as their mentor and advisor.

Figure 2 is a graph of the amount of class time that was spent working on the computer as a percentage of the total class period. The data is only for days when the computer was actually used. The data from the spring of 1992 was taken from Mr. Jones's honors chemistry class when they used OGAF materials. The data from the fall of 1992 is from a different honors chemistry class (same teacher) using the OGAF materials and then the WAMNet materials. The graph shows how in the spring of 1992 and the fall of 1993, when using the OGAF materials, Mr. Jones spent most of the class time lecturing and only a small percentage of time using the computers. The graph shows a change in the teacher's strategy which may be a result of using the WAMNet simulations. As has been stated previously, Mr. Jones was very invested in the WAMNet project and felt reasonably comfortable with the simulation. His comfort with the WAMNet simulations seems to have encouraged significant changes in his teaching strategies.

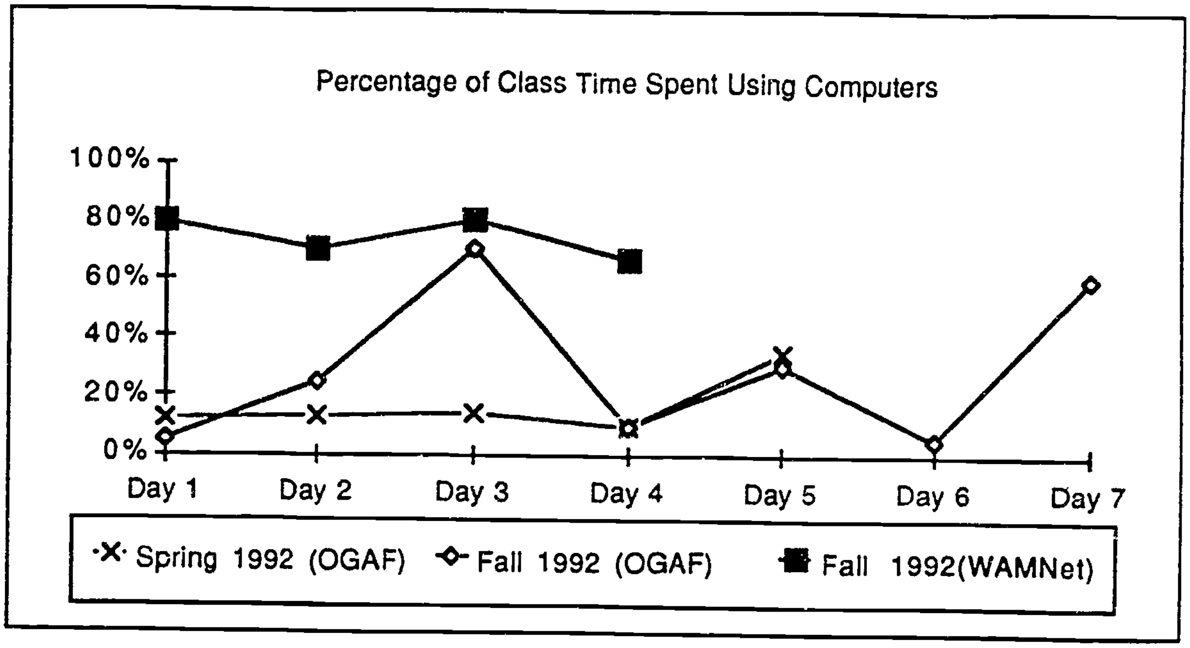

Figure 2: The percentage of Class Time spent using computer when computers where used.

The manner in which Mr. Jones guides students when they use the simulations has changed as well. In the spring of 1992, Mr. Jones gave the students very specific tasks on the computer without allowing them time to explore their own questions. During the 1992-1993 school year Mr. Jones has gradually allowed the students to determine for themselves the best method for reaching a particular goal. For example, prior to the first assignment the students had with the RISC simulations Mr. Jones gave the students very specific instructions on how to collect and analyze their data. They were to collect data and calculate the constant in Charles' Law.

For the second assignment however, the students were given much more freedom in designing experiments to prove what they were asked to prove. Mr. Jones gave them some suggestions, but they had to decide for themselves how to proceed with their investigations on the computers. The goal was clearly defined by the teacher; to use the simulation to prove Dalton's Law of Partial Pressures. The students made many mistakes on their way to proving Dalton's Law. They set the pressure and temperature in ranges that did not allow for ideal behavior. They allowed several parameters to vary at the same time. When they ran into problems Mr. Jones would step in and coach them our of their difficulties. Eventually, all the students managed to prove Dalton's Law.

Mr. Jones believes that the students learned some important lessons about setting up an experiment that they will never forget. For example, the students have been told many times in science classes that they should only allow one variable to vary at a time, but since they had never been asked to determine the variables in an experiment or how to keep them constant, they made mistakes. Having gone through this experience Mr. Jones believes they will be far less likely to make that same mistake again. The next step for the students was to design an experiment where the outcome is not known to them. For example when the honors chemistry class started using the *Wasser* program, they explored the conditions necessary for the insertion of ions and salts into water and the solubility of the salts. The students were free to explore any question they wished.

Mr. Jones has noticed changes in his teaching style. In our interview with him in December of 1992, Mr. Jones referred to himself "a coach." The researchers have documented his acting in that capacity; helping and guiding the students without giving them answers. The following is an example of his coaching the students from observer notes in taken in December of 1992. In these notes he is helping both the strongest and the weakest students in the class. The observers noted that Mr. Jones spent considerable time with the weaker students while they were using the simulations.

> *10:55*
> *Jay and Jim have both a and b particles. They first did all a and now they have 20% b.*
>
> *CH is talking with Robin and Jane.*
>
> *CH tells Sally that it is better if she presents him with a procedure rather than him telling her what to do. He tells her he will not let her go too far down a bad path.*
>
> *CH talks to Susan and Polly He tells them they should get enough data to validate the law. They need to decide how much is enough. He had previously said this to Sally and Jane*
>
> *Mark walks over to CH while he is talking to Susan and Polly. He talks to Evan while he waits. Gary comes over as well.*

CH talks to Evan. Mark waits to talk with him. He asks if they need to go down to 0 particles. CH says they can go until they validate Dalton's law.

CH walks around and looks at what the students are doing.

Mr. Jones told the observers during the December interview that he likes the role of a coach or mentor because it has allowed him to get to know this year's students much better than he has ever known his students in the past. He also stated that the mentoring role can be a tricky one because he has to try not to give the students too much guidance, but also must be careful not to lead them in the wrong direction. He told the observers that he is constantly struggling with the issue of when to stop the students from taking that wrong path and when to let them go. He realizes that students can sometimes learn a great deal from a supposedly wrong choice as evidenced by the story of Susan which will be told later in this paper.

One important reason why Mr. Jones got to know these students better is because he had them keep two journals. The students used a "notepad" facility which is built into the workstations. One journal was a personal dialogue with Mr. Jones in which they could ask questions about problems they were having with the material, questions on any topic in science, or even raise personal issues. The students were required to make one entry per week. Mr. Jones read the entries each week and commented on them. This allowed him to have an ongoing contact with each student, even the ones who were reluctant to talk to him in person. He told the research staff that he found the journals most helpful in learning about his students. In the past he has used written journals but found that the computer journals were much more efficient because the journals are kept in a place that both he and the students can easily access. Here is an excerpt from one student's (Jane) journal along with the response from Mr. Jones.

Dec, 17, 1992
Sorry I have not written in a while. I've been busy with basketball. I have a few questions involving the weather. Why can it be 30 degrees one day and be snowing hard, like this past weekend, and the next day be hot outside? I always thought the temperature change should be gradual. I

understand why temp. drops at night, but why doesn't the temp. go almost back to the same level it was the night before?

12/18 - This does not have a simple answer, otherwise they would probably do a better job at prediction. The large weather patterns that the meteorologist shows during a forecast move due to the prevailing winds and pressure regions shift air masses around the globe. In essence that means that a cold air mass can be replaced the next day by a warm one. CLH

The second journal that the students kept is not so much a journal as it is a lab notebook: a place to keep data and analysis of that data from the WAMNet simulations. The students had their notebook and the computer simulation on the screen simultaneously so that they can put the data directly into the notebook. At first some of the students still wrote the data into a paper notebook and then copied it into the computer notebook, but after a while they all realized that it was much more efficient to put the data directly into the computer notebook. There are two reasons for the reluctance to put the data directly into the computer lab notebook. One is that until they were reassured that the computers were backed up each evening, the students were afraid they would come back the next day and find that all their data was gone. The other reason that students were reluctant to use the computer notebook was that the students were accustomed to completing lab reports at home. Mr. Jones wanted them to do all the work in school, either during class time or during free periods. This created some problems for students as they tried to arrange their very busy schedules to allow for the after-school time they needed. Mr. Jones reported that sports coaches and advisors of extra-curricular activities have been supportive in allowing his students more after school time. Some students have even learned how to use a modem to access the computers from home. They can work on their notebooks over a modem line, but not the simulations themselves because of the need for high resolution graphics and high speed lines.

Mr. Jones has invested a great deal of time into the project. He feels ownership of the project and is the "expert" in his school on RISC-based workstations and Internet. He has been tutoring several other science teachers on how to use the simulations and two of them plan to use them in some way with their classes. One of the teachers also teachers honors chemistry and Mr. Jones reported to the research team that several students from her class have asked him to teach them how to use the simulation. Mr. Jones reported his students have been talking to her students about the simulations. This teacher has decided that she needs to learn how to use the simulations before all of her students figure them out first. The Advanced Placement (AP) chemistry teacher sees the applicability of the simulations to the AP curriculum. The school eased Mr. Jones's teaching load and scheduled all of his classes at the beginning of the day so that he would have all afternoon to work with students and other teachers. He has been using this extra school time and a great deal of his own time after school. He can typically be found at the school until five or six o'clock in the evening, occasionally even later.

In addition to changing Mr. Jones's relationship with his colleagues at the high school, the telecommunications capabilities of the system has enabled Mr. Jones to expand his relationship with colleagues at Boston University. He contacts both the educational research staff and the programmers on a daily, sometimes hourly, basis. He believes that the system would not have been up and running as quickly as it was were it not for his ability to communicate problems to the programmers and receive very swift responses. One of the programmers is located in Germany and the telecommunications link allows Mr. Jones and the programmer to communicate about problems related to his simulation, *Wasser*. At this time, the programmer is attempting to make the program work on a computer which is different from the one it was originally designed for. The high speed line allows him to actually work on the computer in the high school remotely from his workstation in Germany. Mr. Jones discusses classroom applications of the WAMNet simulations with programmers at Boston University over the telecommunications line.

Mr. Jones also comes to Boston University on a regular basis to meet face to face with the programmers in order to help develop new simulations and modify old ones. His input has directly affected the look and capabilities of the simulations. This obviously makes him an active participant in the project. He has also become the resident expert on computer simulations and e-mail at his school. He reported that his colleagues have been asking him to help them learn how to use the simulations with their own classes as well as how to use the e-mail.

Student Learning and Motivation

It is important to acknowledge several things about the students before discussing any results related to them. Both the honors chemistry and regular chemistry students were highly motivated before ever seeing the simulations. Some were motivated by genuine interest in science and others by a desire to achieve in school. It is therefore very difficult to say if the simulations affected their motivation. From the observer notes, however, it is clear that there was very little off task behavior while the students were using the computers. Off task behavior was defined as talking with other students about subjects unrelated to the simulation or any kind of disruptive behavior. There was occasionally some unrelated discussion usually lasting only a minute or two and usually occurring while the students were waiting for the simulation to do something that took more than one second. Another indication that students were intellectually engaged while using the simulations is that many times students neglected to take breaks during the double lab periods when they were working on the computer. They would completely ignore the bell that signaled the end of the first period. They often expressed disappointment well the bell rang to end the period and they had to leave to go to another class. Students who had a free period after the regular class period often stayed and continued to work. Students also spent a good deal of out of class time working with the simulations. Some students expressed frustration that they needed to use so much out of class time while others did it willingly. All managed to find the time and finish the assignments.

An anecdote related to one of the students is appropriate here. Jane, (not her real name), would answer questions very tentatively and with a rise in pitch at the end of a sentence which indicated hesitation. She was very unsure of herself when using the simulations and worked with other girls who were equally hesitant and unsure. They stumbled a great deal when using the XLJ simulation to prove Dalton's Law of Partial Pressures. They used temperature and density ranges where the gas was not ideal and they did not hold enough variables constant. Eventually Jane and her group managed to complete the assignment. Mr. Jones told me that she had been getting D's on tests but that on the test about ideal gases she got a B. All of the observers noticed that after that unit, her tentativeness was gone. Other students in the class have stopped making fun of her. She seems much more confident in her knowledge and far more willing to answer questions. While a dramatic change was noticed in Jane there was some change, although to a lesser extent, in the girls with w om she worked. It is difficult to decipher the specific reasons for the change. Was it the simulation itself, the attention she could get from Mr. Jones because using simulations allowed him the time to work with students who need a little extra help, or something else entirely?

Another anecdote is also illustrative of the kinds of discoveries the students made using the simulations. Susan, (again not her real name), worked very diligently on the Dalton's Law assignment. She set the temperature and density in the XLJ program to what she thought were appropriate values and then took readings of the pressure at those conditions. After spending several hours taking data, she discovered that Dalton's Law was not holding for the data she had collected. She spoke with Mr. Jones. He asked what she had done and she began to explain. As she explained she remembered that in the previous simulated lab involving Charles' Law the class had determined that there were certain temperature and pressure ranges in which the particles did not act ideally. She asked Mr. Jones if it were possible that the conditions under which she had taken her data were also not ideal. Mr. Jones asked Susan what she saw on the screen while she took the data. She said that the particles looked like they were clumping. At this point the student realized that if the particles were clumping they were not ideal and of course Dalton's Law would not hold under those conditions.

In relating this story to the researchers, Mr. Jones expressed the opinion that Susan would not easily forget, (1) what it means for a gas to be ideal, (2) how important it is to make preliminary analyses of data to check its validity, and (3) it is possible to learn something very valuable from a "wrong" path. Susan was not the only student to make this mistake and Mr. Jones talked with the entire class about the issues described above. Because the discussion occurred the students had struggled for awhile and because they gained ownership of the problem, they are certainly more likely to learn from their mistakes.

While they worked with the simulations, the students were usually in groups of two or three. Even when working alone, a student at one computer would confer with a student at the next computer. Interestingly, the students tended to arrange themselves in single sex groups. In each class there was one group that was mixed sex, and the rest (six or seven) would be single sex. They were constantly tutoring each other on the best ways to use the program. Mr. Jones told us that in the past he always had trouble getting students, especially the honors students, to work together in small groups. He tried to encourage it before but did not feel it was successful. The simulations seemed to force the students to work together and it carried over into other assignments. Mr. Jones reported seeing students leave the simulations and go into another room to work in small study groups on more traditional problems.

The students have been using the Internet to communicate with former students who are away at college. The college students have been very helpful in teaching the high school students how to use the computers and especially how to use the UNIX operating system. While this is certainly a good use of the telecommunications link, we want students to communicate with the programmers at Boston University. We hope that mentoring relationships develop between the students at the high school and the undergraduate and graduate students at Boston University. Mr. Jones and the research staff encouraged the students to send e-mail to the programmers with questions about the programs themselves or the theory behind them. The programmers themselves went to the school during the fall in the hope that the students would be more likely to send e-mail if they had an opportunity to meet the Polymer Center staff face to face. Mr. Jones was finally successful in getting students to send e-mail to the programmers by requiring them to ask a question related to one of the simulations. In the class discussion of the results obtained in one of the simulated experiments, the students and Mr. Jones were interested in better understanding one of the simulations. Mr. Jones told the students to ask the programmer who designed simulation their question directly rather than having Mr. Jones intercede on their behalf. The students sent the programmer e-mail and he responded. Since that time several students have sent e-mail to the programmers of their own accord, although we have not yet seen any mentoring relationships develop between high school students and the programmers.

Changes in the Classroom

Figures 3 and 4 show sketches of Mr. Jones's classroom during the 1991-1992 school year, before he had the RISC machines, and the 1992-1993 school year, the year in which he has had the RISC machine. During the 1991-1992 school year Mr. Jones's classroom looked like a typical high school chemistry classroom. The room contained desks, the type that are chairs with attached desktops, lined up in rows facing the front of the room. There were several lab tables in the back and along the sides including one in the front of the room for the teacher to use for demonstration purposes. The desks stayed in rows and the class always faced front. The only time that the students were not at their desks was when they did laboratory experiments or worked on the computers. Mr. Jones borrowed five Macintosh II series computers from the Polymer Center during the months of May and June in order to use the OGAF programs. The computers were located in a room across the hall. The room was very small and the entire class could not fit into it at the same time. This meant that Mr. Hurwitz had to split the class and have one half doing the hands-on activities associated with OGAF and the other half worked with the computers. Mr. Jones would move between the two rooms.

For the 1992-1993 school year, Mr. Jones switched classrooms with another science teacher so that his classroom would be next to the room with the RISC machines. The room for the RISC machines was a storage room. Mr. Jones moved or discarded a great deal of unused equipment and papers and the shelves they on which they were located. The change of classroom and computer room allowed for a free flow between the classroom and computer room. The classroom itself is very similar to Mr. Jones's room during the previous school year. The only major difference is that it is slightly larger. The computer room for the RISC machines is larger that the room for the Macintoshes, although when a full class is there it can be quite crowded. In general when the students sit in the classroom they sit in rows. When the students did small group work they moved the desks around. One day Mr. Jones had the students sit in a circle instead of rows. He was doing a demonstration/lecture and the observers were very surprised to see the students sitting in a circle. This signaled the observers that Mr. Jones was willing to try new classroom management techniques.

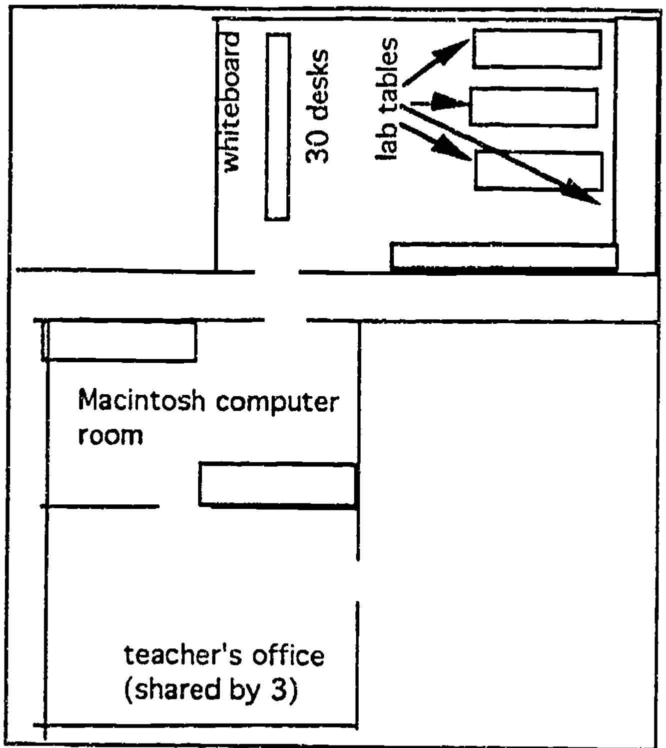

Figure 3: Mr. Jones's classroom and computer room during the 1991-1992 school year.

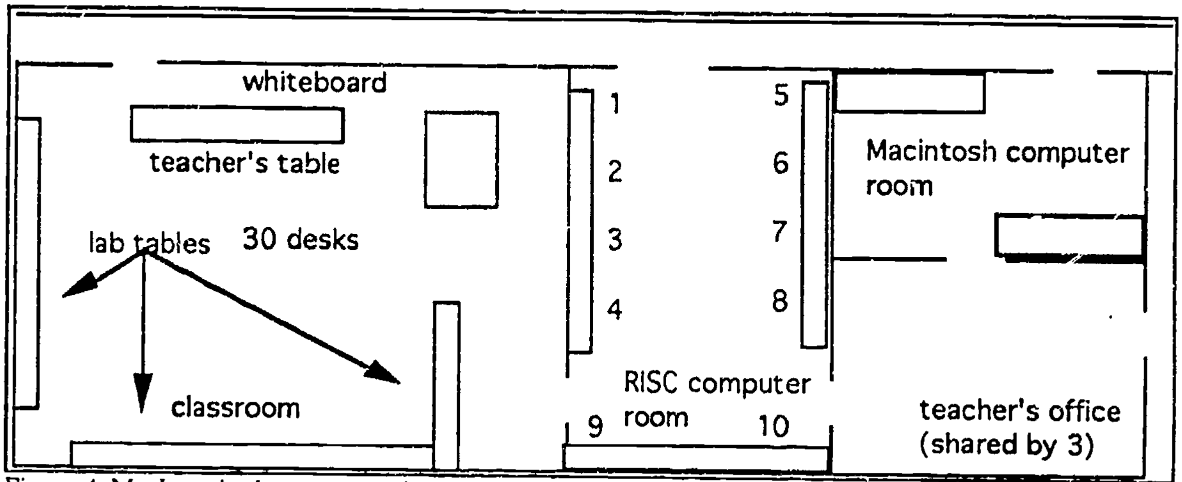

Figure 4: Mr. Jones's classroom and computer rooms during 1992-93 school year.

During the 1992-1993 school year the students moved much more freely between the classroom and the computer room than they did during the previous school year. This was due in part to physical reasons; the two rooms were attached rather than across that hall and the computer room is larger. Another reason is that Mr. Jones is much more comfortable with the simulations this year and therefore lets the students use them with less oversight. The desks moved around a bit more during the 1992-1993 school year indicating a loosening of control on the part of the teacher. Again, the research team believes that the use of the simulations helped the teacher to let his students have greater control of their learning.

Logistical issues

A variety of organizations were involved in getting the computers and the network set up. The school district provided a room, tables and chairs, an alarm system, and release time for Mr. Jones. He was released from one class and from his administrative duties such as monitoring the cafeteria. Mr. Jones himself did a tremendous amount of work getting the room ready. The room had been a storeroom and there was years of accumulated material to be moved. Mr. Jones and some student volunteers moved books, papers, and bookshelves during the summer. The Polymer Center provided the eight DECstations and two Silicon Graphics Indigo machines. They also provided the software and support. The Polymer Center had the machines in the school by mid-September of 1992. Unfortunately there were problems with New England Telephone and the high speed line was not installed for another two weeks. Then there was a problem getting a router from the Information Technology department at Boston University. That was installed the last week in September. After that a problem was discovered with the high speed line which New England Telephone fixed by the first week in October. Finally the line was working and the school was connected electronically to Boston University.

The connection to Boston University was very helpful to Mr. Jones as he started to use the simulations with his classes. As problems developed he could send e-mail to the programmers asking for help. He could also "talk" with them on-line to get immediate feedback. There were many small problems that came up. The machines are sensitive and can crash or freeze easily. Initially when these things happened, Mr. Jones needed help to get the machines back on line. He now is fairly adept at figuring out where the problem lies and solving it himself.

The high speed line gave the programmers the ability to access the computers at the school from their terminals at Boston University. This was very helpful when problems arose that Mr. Jones was not able to solve. It avoided the necessity of going to the school each time there was a problem. If they had been required to go to the school to fix every problem the machines would have been down quite a lot.

During January there was an electrical problem at the school which caused the computers to go down. When the problem was fixed Mr. Jones was able to get the computers themselves back up but the high speed line was down for two weeks. When one of the researchers went to the school during the first week the line was down Mr. Jones commented on how frustrated he was. "Do you know what it is like to have your umbilical cord cut?" was his comment. The line was repaired and the school was connected to the outside world once again.

CONCLUSIONS

Our observations show that the models of teaching used by the instructor is changing from one that is teacher-centered to one that is more student-centered. Why did the instructor's teaching style change? Because the simulations themselves force a teacher to make his classroom more open to letting the students explore. The students work in small groups which forces the teacher to move around the class and assume a coaching role. Schofield et al (1990) also found that in classrooms where there was extensive computer use, the teacher tended to work with small groups of students in a collaborative role similar to what the WAMNet research has called coaching or mentoring.

Another factor that contributed to a change in teaching style is Mr. Jones's involvement in the development of the project and the influence of the educational research staff. His students were testing out materials that he had a major hand in developing. Figure 2, the graph of time spent on the computer, demonstrates that when the teacher was using the material that he was most involved in developing, he allowed his students more time on the computer. Until other teachers use the simulations with their classes, teachers who are not as involved in the project and its development as was this teacher, it will not be known whether the simulations by themselves will cause a change in teaching style. We can say that in this classroom we have seen a teacher modify his teaching style as the simulations and students warranted. We have also seen that the tools the computers provided helped Mr. Jones get to know his students better than he had in the past.

ACOT's research (Ringstaff, Sandholtz, and Dwyer, 1991) described similar changes in teacher strategies. The teachers involved in the ACOT research became more open in their teaching style. In the ACOT study, however, the change took place over years. In the RISC study, Mr. Jones changed his teaching style dramatically over the course of a little more than one year. Why the difference? The researchers fee changes in this teacher's instructional strategies occurred more rapidly because of investment in the project. He helped to develop the programs and considered himself to be part of the project staff. The ACOT teachers were not developers of the software and hardware they used in their classrooms so they did not have as much of a vested interest in it. When teachers who are not involved in the development of the WAMNet simulations begin to use them, it may take longer to see the kinds of changes that were seen in Mr. Jones. On the other hand, it is possible that many of the teachers who choose to use these simulations may already be somewhat non-traditional.

The observations of the students showed that they were on task for most of the time they used the computers. Even though this research dealt with a motivated group of students, the fact that they worked as hard as they did for as long as they did shows that there was something about the simulation that was of interest to them. We will have to study students who are not as intrinsically motivated in order to determine exactly what aspects of the WAMNet project are motivating. One can speculate that the very visual nature of the simulations helps the students to anchor concepts that otherwise seem abstract. The simulations deal with concepts that cannot be shown dynamically any other way. The closest one can get to seeing the molecular nature of matter in a typical chemistry class is a picture in a book. As a high school student who came to Boston University to work with the simulations said, "If a picture is worth 1000 words, this program is worth 1,000,000 words because I can control this picture."

The majority of e-mail use in the project has been between Mr. Jones and the programmers and educational researchers. This is similar to the use described by Podany (1990) and Lehman and Campbell (1991). The students used the e-mail to contact their friends in various colleges around the country. From the amount of e-mail traffic one can conclude that the students became comfortable with this mode of communication. The WAMNet project had hoped that there would be more communication between the graduate student programmers and the high school students. There has been some but the mentoring relationships that had been anticipated did not come about. Mr. Jones encouraged students by telling them to contact the programmers directly whenever they asked him questions related to the theory behind a simulation or to the programming itself. Nevertheless, the students always asked their questions to the teacher first, perhaps because he was there and the programmers were at Boston University. Although several of the programmers had visited the school, they were for the most part unknown to the students. Perhaps with greater contact between students and programmers, such mentoring relationships will develop.

We have learned from our research that it takes cooperation from many groups in order to pilot test this kind of high technology to a school and have it be used in a productive manner. Without the time, space, and resources that the school provided to the teacher, the project might have failed. The programmers at Boston University spent a great deal of time making sure that the system ran smoothly and they fixed problems as they occurred. While extra support from the school was needed in this case since it was the first, there will still need to be support from the school in order successfully implement a curriculum involving high technology. The lessons learned in this experiment will need to be codified and referenced in the future so that schools will be able to use high technology effectively.

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