The Role of the Internet in the Adoption of Computer Modeling as Legitimate High School Science

Bill Barowy and Catalina Laserna

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Abstract

We describe a recent project that explored combined use of Internet client-server technology and interactive computer modeling software for improving secondary science teaching. We envisioned a constructivist network in which teachers make contributions to the resources available. The purpose of the network was to promote the emerging field of computer modeling in high school science. Our approach coupled the networking and curricular initiatives with evaluation of changes in classroom core practices -- those which have a traceable impact on student learning. Distribution of work, ideology of science, teaching styles, and curricular goals come together dynamically to influence teachers use of modeling technology in the high school science classroom. A combination of Internet tools, each affording a different contribution to the spread of innovation, provides the best promise for future networks of this kind.

Introduction

Effective science teaching is becoming known as a dynamic professional field, requiring continuous growth of instructors' knowledge and new types of expertise (Kyle, 1995). Yet, the dearth of telephones, communication media, and meeting time with colleagues hinders teachers' access to new materials, resources, and methods (U.S. Congress, 1995). Teachers have lacked interactive means for teaming with others who are attempting to implement new curricula and more effective methods of teaching (Means, 1994). Thus, locally initiated innovations that transform core practices of teaching and learning, i. e. the manifestations of teachers' ideas about knowledge and learning in the classroom (Elmore 1996), seldom grow to larger proportions.

Can network initiatives provide a solution to this problem? It is generally acknowledged that computer networks have the potential to support teachers by facilitating collaboration and improving access to information about effective teaching and other resources (Harasim *et al*., 1995). Teacher networks may break down the isolation of the classroom by enabling teachers to communicate with others of similar interests; sharing lessons, exchanging project ideas (Newman, 1987; Ruopp, 1994), and reflecting on their practices (DiMauro and Gal, 1994). Thus, networks can offer support for experimentation and innovation with new materials by putting teachers in contact with others who have similar goals.

How can we measure the success of a teacher network? If we set out to improve core practice, then we must go beyond teachers' testimonies about their professional growth or records of their discussions. Determinations of success must include direct measures of teaching and learning. Evaluation must focus on teacher practices (Wood and Thompson, 1993) and student outcomes, as they occur in classroom situations (Curtin, *et al.*), while addressing the greater systemic context in which those core practices are embedded (Little, 1993).

Purpose

With support from the Applications of Advanced Technology Program at the National Science Foundation, we have developed and studied a combination of collaborative strategies coupled with curricular and telecommunication technologies, as a model for the use of wide-area networks in high school science teacher professional development. The project, called *Community of Explorers*, investigated using the Internet to support teachers in exploring and reflecting on a new approach to teaching high school science -- scientific computer modeling.

We hoped to change the core practice of science teaching and learning to be more like the work of scientists. Historically, scientists have constructed models in their quest to make sense of the world. Physical models, such as the use of water-filled glass spheres to represent raindrops, have been used as explanatory constructs (Harré, 1987). Concept models, which also may be physical, help scientists bridge theory and data (Hestenes, 1992; Watson, 1968). Mathematical modeling emerged as an attempt to derive physically relevant phenomena from simple theoretical systems (Ziman, 1979; Pritchard and Pritchard, 1994).

The advent of computer technology has facilitated and changed the way scientists have worked with models. Computer models express, through computer code, concept models or mathematical models to describe complex processes (National Research Council, 1985). Indeed, scientific computation per se has become a new endeavor. A number of scientists now specialize in computational modeling to create digital representations where analytic solutions are intractable and to visualize phenomena that are not possible to observe otherwise (Kaufman and Smarr, 1993).

We envision a similar paradigm shift in the classroom when students and teachers build and use computer models. Mellar and Bliss (1994) best capture our sentiment:

> It is about providing children with computer tools to enable them to create their own worlds, to express their own representations of the world, and also to explore other people's representations.

In the science classroom, the integration of computer modeling into the curriculum promises support for generative approaches (Wittrock, 1994; Webb, 1992), investigating new multidisciplinary ideas such as emergence or systems thinking (Resnick, 1994; Jackson *et al.,* 1996), engaging in thought experiments (Horwitz and Barowy, 1994), and coordinating experimental data with theoretical models (Richards *et al.,* 1992). We view computer models built by scientists as artifacts that represent the scientific concepts, methods, and processes scientists value while developing and testing their ideas. Through interacting with these artifacts, students and teachers come to experience the representations that scientists considered important. Experiments in teaching and learning with this genre of computer models have already demonstrated the potential to produce significant changes in core practices of the science classroom (Snir and Smith, 1995; Roberts, *et al*., 1996).

We provided to teachers modeling technology developed at BBN and other institutions, primarily under NSF funding. Where possible, we also supported teachers' exploration of other related tools and materials. The ensemble of modeling tools included:

- Explorer (Richards *et al*., 1992),
- Model-It (Jackson *et al*., 1996),
- RelLab (Horwitz and Barowy, 1994), and
- Star-Logo (Resnick, 1994).

Network Design

We began building a distributed network of science teachers in San Diego, California and Massachusetts by recruiting teachers, providing full Internet connections, and running workshops on curricular and client-server telecommunication software. The full Internet client-server technology ensemble comprised SLIP and Appletalk Remote access -- supporting FTP file transfer, SMTP/POP3 e-mail, Gopher, Netnews, and WWW.

The Internet ensemble addresses Riel's and Levin's (1990) call for ease of use and efficiency, as well as the problem of wide-scale network access (U.S. Congress, 1995). Client-server technology offers a significant advance in ease of use over terminal-host connections. In addition, the Internet, per se, enabled us to design a system that would serve as a technical model for networks that scale up to national dimensions.

In the development and formative evaluation of the network, we tested new technologies and styles of interactions between teachers, mentors, and scientists that held the promise of improving teaching. E-mail affords the reflective interaction between participants (Harasim, 1990) that is understood as necessary for teachers' reconceptualization of their practice. Client-server e-mail further offered richer than text communications through files enclosed in messages.

We intended the network technical design and interaction styles to support teachers' appropriation of modeling technology by:

- helping teachers conduct explorations with modeling technology in their classrooms,

- disseminating their lessons plans over gopher and WWW protocols, and

- conducting video teleconferences and workshops for sharing expert practice.

Working within a framework of the social construction of knowledge (Hutchinson and Huberman, 1994; Koschmann, 1996; Riel, 1994) we distinguish between networks that serve as a central delivery mechanism and those in which initiative and expertise are distributed among the members. In contrast to using the network primarily for dissemination, we focused on activities through which teachers themselves created curricular materials for exploration and discussion, with project personnel providing support.

By moving away from content delivery to resources constructed by the participants and expertise drawn from the network, we envisioned two positive outcomes. The first was that the process built capacity for the network to become self-sustaining and to scale to national dimensions. The second was the improvement of participating teachers' practices, with which we concern ourselves here.

We structured networked collaboration so that knowledge was situated in a practice relevant to teachers -- the development of lessons befitting their own students (Brown, *et al.*, 1989). Teachers' explorations into the use of modeling technology lasted anywhere from one hour to several weeks. Generally, researchers organized events, engaged with teachers as co-investigators in the classroom application of modeling tools, and shared developers' views of the design of computer models and how they fit into the classroom. Researchers also answered teachers' questions concerning technical issues. In several cases, teachers' experiments became quite extensive. Where possible, we supported or initiated dissemination of these experiments through conferences and publications (Duffy and Barowy, 1995; Barowy *et al.*, 1995; Barowy and Patten, 1994). Several teachers also contributed to a web site of lesson plans they developed and resources they had used (BBN, 1995).

We investigated the sharing and development of expert practice (Collins *et al.*, 1989; Crichton, 1993) in which project personnel provided opportunities for teachers to model their classroom practices through examples and commentary. Teachers participated as leaders in workshops and video teleconferences, giving presentations of modeling tools and engaging others, as students, in inquiry role playing. We examined the expertise we, ourselves, brought to the project and how that could become distributed among others on the network.

Picturetel video teleconferencing was of special interest to us, because we expected similar capabilities to be available in the near future over the Internet. Picturetel video-teleconferencing transmits high-quality, real-time video and sound between roomfuls of participants (15-20). The rooms at each site seat participants in tiered semi-circles, allowing easy identification of the speaker. The video camera can be zoomed more narrowly on one speaker, survey the entire group, or focus on a computer screen.

evaluation

Our evaluation centered on the design of a constructivist science teacher network to support the transformation of teachers' practices with modeling tools. We have focused on understanding the forms of technology, types of social interactions, and project agency required for teachers to utilize modeling resources, to explore and innovate, and to make contributions to the resources of the network. Formative evaluation influenced the design of the network.

The data include written observations, video and audio recordings of:

- classroom practices,
- workshops, and
- video teleconferences.

We have conducted interviews with teachers and solicited their accounts of teaching experiments and workshops. Based on the framework of communities of practice (Lave and Wenger, 1991), we analyzed the way in which different expectations concerning teaching experiments, workshops, and video teleconference events shape the social roles enacted. The themes include the ranges of valued products, goals, and styles of collaboration and design of technology.

E-mail interactions between project participants have been stored in archives. In January 1994, a technology and telecommunication survey was sent to all high school science teachers in the San Deigo School district (Levin, 1995). The instrument examined the extent to which computers and computer networks were being used by teachers and students in high school science classrooms.

During the three years of the project, we observed, videotaped, and audio-taped 161 hours of activities, covering 157 class sessions, involving 18 teachers at 8 high schools. The videotapes also include 7 teacher workshops (18 hours). We also have 40 hours of audiotape of class sessions, workshops, and informal discussion with teachers. Before and after classes and during prep and lunch periods, project staff discussed issues related to classroom activities and the Community of Explorers Project (CoE) with the teachers. The majority of observations took place in class sessions where modeling tools were in use. However, for comparison, the same classes were observed and recorded doing other types of lessons and using other CD ROM technology and software. Our data include the following software tools: Genetics, Cardiovascular and Photosynthesis Explorer, RelLab, MBL, Eudora, and Mosaic.

To establish what types of information exchanges occurred with client server e-mail, we modified the Macintosh e-mail client, *Eudora*, that we distributed to participating teachers. With the modified version, archiving is accomplished simply through an address on the "cc:" line that is automatically inserted on all new messages. Participants can see that a "carbon copy" will be sent to the archive and can delete the "cc:" if they wish their message to be private. The need forprivacy emerged as an important precursor for teacher participation during formative evaluation. This issue had been recognized in other contexts (Little, 1990). While the "cc:" option constrained the inferences that we were able to make from the data, it was necessary for teacher participation. We have analyzed the e-mail archives, primarily using header information, for constructing maps of interaction patterns on the network. This allowed us to document the status of the network.

Our observations define a qualitative database on students and teachers that is broad enough to allow analysis of patterns of interaction associated with differences in computer resources, types of lessons, pedagogical approaches of teachers, and classroom environment. The video and audio recordings provide data concerning students' developing knowledge of computers and science content, co-evolution of teachers' lesson plans and experience with the hardware and software, and classroom practices. We have conducted case studies and ethnographic analysis to identify the dimensions of the participants' organizational and classroom environments, and network and curricular activity.

Findings

We describe several categories of results. Distribution of work, ideology, curriculum goals and teaching styles come together dynamically to influence teachers’ use of modeling technology. General patterns in teachers' adoption of modeling tools appear, including substituting the technology in ways that preserve older practices. We trace the substitution technique to student learning and examine the relation between distribution of expertise and changes in teachers’ core practices. We have identified Internet communication functionalities that facilitate the appropriation of curriculum tools. We include excerpts of teachers' comments to enrich our findings with their perspectives.

Distribution of Work and Expertise

The organization of work in schools, arising from time constraints, curricular goals and the conventional division of labor, fosters ad hoc approaches to many concerns that are not high priorities. Teachers know that knowledge and resources to solve many common work problems are distributed in the school environment. Attention to the management of classroom activities, however, can inhibit their participation in the development of a technological system to provide these resources.

Taking advantage of opportunities to distribute their labor is a standard operating procedure. Walking into a colleague's room to borrow software or consult about a computer problem, borrowing curriculum, are all events that result from opportunistic responses to unplanned activities. While researchers traveled from one school to another during a day or week, teachers would ask them to relay messages or transfer resources that they could have accomplished over the network.

There is a flip side to the division of labor and, correspondingly, the distribution of expertise. For example, one teacher asked a prior student to build the RelLab simulations that accompanied her curriculum. Not only did the teacher find a solution to the limited time she had to explore the software, but her student gained considerable expertise in the physics of relative motion. Another teacher, who had several years of experience with formative evaluation of educational technology, delegated learning almost every part of technology to his students, from the modeling tools to the Internet. During a video teleconference, he shared his expertise and approach in a rather matter-of-fact manner:

> I don't care whether I am comfortable with it or not. I say "Kids, here -- go, get into trouble. You can't do the program any harm."

The social ecology of the teachers' work predominated their participation in the Community of Explorers. The typical distribution of work in high schools does not support the type of collaboration and innovation regarding curriculum development that we had hoped it would, i.e., wide-spread exchange of resources and consultation among teachers and researchers over the Internet. However, within the existing organization of school, teachers did find ways to take advantage of the project resources, often through their students. Schools that were able to make the most of the resources we offered also tended to have local cultures of collaboration, in which teachers had established practices of distributing expertise.

Our contributions, which we term "project agency," were significant. We brought expertise in the coordination of tools and science content that helped teachers in their experiments with the technology. An important role we played was in making legitimate, and building awareness of, the use of modeling tools in the classroom by sharing the visions of the software developers and facilitating teachers' contact with them. Beyond early assistance with Internet connections, we also contributed to the distribution of labor during teaching experiments. We helped teachers set up computers with the software, learn technical use of the tools, and design activities. The first item required our on-site support. We accomplished the latter two items mostly over the Internet.

It is no surprise to find that adoption of modeling technology is influenced by the time constraints noted in schools (National Commission on Time and Learning, 1994; Fullan, 1991). It is a pleasant surprise, given the start-up time to learn technology, that modeling software occasionally became a solution to the problem. Being able to conduct simulations on a computer provided biology teachers with a way to handle the complexities of teaching genetics. In this domain, teachers must overcome experimentation difficulties that arise from live subjects and limited student observation skills, while aiming to foster conceptual understanding and problem solving in what is recognized as a difficult subject.

> In biology I like to use simulations because they save time, they allow students to manipulate variables, they provide the student with immediate feedback. Also, particularly in genetics it allows the students to perform experimental crosses that are impossible to do in a high school lab situation. In particular, I prefer the genetics simulations over the live fruit fly labs because of the time factor as well as the students' lack of observational skills to detect sex differences and mutations. In the past I found that the fruit fly labs were very unsuccessful and I was looking for an alternative.

More generally, the modeling tools have fit into niches in school science, satisfying a variety of pragmatic concerns. For example, the problem of direct observation on the time scale of ecological phenomena resulted in biology teachers finding Explorer Ecology and Model-It attractive for exploring the effects of changes in ecological systems.

Ideology and Legitimacy

Underlying the adoption of modeling technology is its perceived value. Where simulations address complex problems, such as in genetics, teachers assimilate them into existing practices -- but not when beliefs about the nature of teaching or science carry stronger weight. Stevenson and Hassell (1994) describe teachers' ideology as "systematically related beliefs about teaching." Teachers' ideas about who controls the learning process and their role as one who "knows the answers" are examples of beliefs that have hindered appropriation of modeling tools.

Like Hewson *et al.* (1995), we have found that teachers' beliefs of what is science weigh in the criteria for what they choose to do in class.

> [The district specialist] got me involved in a district project to investigate the efficacy of using multimedia devices including computers as a vehicle to support the regular classroom instruction. This lead to my association with [Community of Explorers]. All of this coincided with a departmental decisionto purchase a large number of computers to help with instruction. (I was against this purchase. I'm an old inquiry-based teacher who prefers REAL labs to simulations. I like the excitement and uncertainty of not knowing exactly what will happen and how things will turn out -- real sciencing) Since we got the computers I felt an obligation to justify the expenditure and began a major commitment to computer use...

The view of science progressing by a continuous confrontation between theory and experiment has deep roots in science methodology (Popper, 1959). The perspective that the determining factor is experiment, "Only experiments can score decisive victories" (Lakatos, 1978), is not limited to texts on philosophy of science. It can be found appearing in discussions in popular science readings (Weinberg, 1994) and making its way to the classroom as the "scientific method" in the textbooks students and teachers use everyday.

"Real Science" is a term that has also made its way to the science education literature (Jackson *et al.,* 1994). It characterizes a value system which frames what resources and activities are legitimate. Simulations are not seen as real science -- they provide vicarious experiences not subject to the influence of nature. In contrast, Microcomputer Based Labs (MBL), which allow students and teachers to make measurements with the computer, have been popular.

> ...I am afraid that simulation may be too ideal to deal with real world problems and true scientific work.

When pedagogical concerns outweighed science ideology, teachers looked for rigorous relationships between the models and measurement. A considerable fraction of biology teachers found ecological modeling software attractive. Pedagogically, teachers were interested in the systemic interrelationships represented by the models. It was not enough to model generic systems though. Teachers repeatedly asked for ways to incorporate data from specific ecosystems with data measured therein.

Technology Adoption and Existing Practices

Like the ACOT schools, we have found it useful to describe teachers progressing through a developmental sequence in the use of technology (Dwyer *et al.*, 1991). We have also found that how quickly teachers move through phases of development (entry, adoption, adaptation, appropriation and invention) is largely determined by the mapping between the actions the teachers want to take and the affordances of the technology (Norman, 1990). Some immediately begin to invent new uses. Others simply replace older materials with newer technology, leaving established routines unchanged.

The picture is far more rich and complex than painted in technology marketing terms (Moore, 1991). Nearly all teachers participating in Community of Explorers could be considered "Innovators" or "Early Adopters" by their willingness to engage in the project. Generally, the participants enjoy exploring new technology. Their innovation, however, occurs on a very different plane in which technology fits, or doesn't fit, into what they are trying to accomplish in the classroom.

Modeling technology has often been substituted in ways that preserve many of the functions of teachers’ existing practices -- even with those that quickly transform the use of the tools. In the day-to-day concerns of managing classroom activities, some teachers' application of modeling technology appears incremental. For example, tutorials have often been starting places because students can work on their own. This strategy enabled the classroom to begin using modeling tools even when the teachers do not have enough time to learn the software themselves.

Many teachers start using technology in a way that lowers the risk of adverse consequences. At one extreme, pre-packaged modeling activities directly substitute for individual lessons in genetics and photosynthesis. At the other extreme, one teacher who quickly moved to innovate with RelLab over a three week period, did so at the end of her physics course when the seniors had graduated. This enabled her to work with a smaller number of students and with less concern over the material coverage necessary for college preparation.

Whether the modeling tools were used for a single lesson or for periods of weeks, it was often because teachers were trying to achieve specific outcomes with their students. Teachers' articulated values of real sciencing, figuring things out, problem solving, learning specific content and greater student-interaction. The following teacher's perspective illustrates how the RelLab software met her goals:

First, the initial experience with RelLab demonstrated that the simulation was a tool which allowed me to create a learning environment in which students were engaged throughout the class period, repeatedly challenged to think and solve problems, and receiving non-stop feedback from the computer and from their partners. I took on a new role, circulating through the classroom and acting as adviser in what was THEIR learning experience, not MY teaching experience.

Student Learning

One specific teaching experiment stands out with respect to the synthesis of local school leadership, innovation, teaching styles, and the evaluation of computer modeling on student conceptual understanding and critical thinking skills. Through the initiative of the science department chair, teachers in one school focused on evaluating three strategies for teaching photosynthesis and plant respiration: traditional, constructivist, and computer-facilitated constructivist. The constructivist approach followed the teaching sequence described by Driver and Bell (1986) and is detailed in the Children’s Learning in Science Project (1987). The experiment was conducted over a three week period.

The computer-facilitated constructivist strategy consisted of Photosynthesis Explorer being substituted in place of teacher-centered presentations of the school science view in the CLIS unit. The software replaced the lecture in order for students to learn the topic through their own interactions with the model rather than through passively listening to lectures. Students interacted twice with the simulation while working on written activity sheets that guided their investigation with the software.

There were no overall differences in the three classes learning of photosynthesis and plant respiration content and thinking skills. In three separate measures, a test of conceptual change, and two open-ended items, one of the three classes, the traditional class, had a superior, though barely significantly so, score. We find it plausible that any differences in learning result from the teachers’ level of comfort with teaching traditionally and his 25+ years experience with the appropriate actions to take in a traditional class. The types of questions that students can ask of a teacher in a lecture are very different from the types of questions that students can ask of themselves using a computer model. A separate paper outlines the details on student learning as well as issues that emerged (Duffy and Barowy, 1995).

The Role of Internet Communication

Teachers used e-mail not simply in terms of pedagogical resources that contribute to their expertise and to innovation, but in terms of its relevance to the organization of their work (Saferstein and Souviney, 1996). Most of the teachers don't use e-mail the way researchers do. However, comparing the work environments of researchers and teachers reveals that researchers have a lot of cultural support for their use of the technology. This includes contracts, personal contacts, publications, etc. that support interaction over e-mail. Teachers that engaged with researchers in these activities utilized e-mail more closely to the way researchers do.

For the most part, teachers employed a discourse in their e-mail communications consonant with concerns of their own classrooms. E-mail was often used to conduct "shop-talk" (Gal, 1993) . The subset of teachers who collaborated more closely with researchers began to shift their discourse toward the reflectivity of researchers. This act of reflecting may include an intellectual separation in perspective between doing and observing. One teacher writes in third person about her class:

> Rather than instructing, the teacher acts as a consultant. Students bounce ideas for experiments off the teacher, they ask for technical help with the computers, and they occasionally need to be moved gently out of blind alleys they may have become stuck in the course of explorations.

Several teachers contributed to a web site of lesson plans they developed and resources they had used (BBN, 1995). Some were hesitant to contribute at first -- they felt their lessons needed to be of publishing quality. When it became understood that this were not the case, the lessons were forthcoming. Revising the materials was still necessary, however! Much of the knowledge teachers use in executing lessons is internalized and must be articulated for the materials to be used by others. Hence, we discovered an unexpected benefit: Our helping teachers prepare their materials for the Web provided the context for them to reflect on their materials. The lessons became the artifacts around which the teachers expressed otherwise tacit goals and ideas and reconsidered improvements for the next implementation.

Client-server technology did not meet our initial expectations that "richer than text" communications would build a new culture of practice. The client-server ensemble offered the most advantage when teachers and researchers worked together and began to share the same goals, values and activities.

In contrast, we have found video teleconferencing to be promising for the sharing of expertise. This technology requires little start up time for teachers to benefit from its use. Like face to face interactions, Picturetel video teleconferencing allowed the synchronous sharing of simulations, i.e. when one teacher ran the simulation and animation on the east coast, teachers on the west coast viewed it as it ran. Experienced teachers were able to show how they operated the software, worked around problems they had with it, and used the simulations in contexts they considered legitimate in the classroom.

The modeling of software use and classroom applications created a common experience that enabled East and West coast teachers to share concrete information about student learning. In the dialogue below, Eric explains how his students made sense of special relativity in terms of an early experience with the RelLab light bulb scenario.

Eric: In a new situation [the students] would come up with an explanation, and then to see if, basically to test their explanation or their idea, they would refer back to this situation that they knew was something that they had experienced in the past, you know, something that they felt was true. They could go back to it and say, well, if you think about that light bulb and the spaceship, is that consistent with my new idea? So, yes, I think that's how they used it to test ideas.

Rick: And one student would use that image to get the idea across to another student?

Eric: Yes, we definitely have that on videotape, whether students are talking about setting up a new scenario and they're talking about some situation involving simultaneity and one would say, "Oh, wait a minute, it's just like the light bulb." In fact we have them walking down the hall saying that to each other. "It's just like the light bulb." with the ring of light and "it's not in the same position...the center isn't in the same place in different frames."

We believe this discussion of student learning is possible only because the teachers on both coasts had participated together in their own learning experience with the light bulb scenario. This was made possible because video teleconferencing is highly interactive. Participants may view and listen to each other, or view the simulation in real-time. There is presently no Internet equivalent.

Less experienced teachers were able to inquire about software use in relation their classroom needs such as distributing expertise among students. In the following dialogue, Rick asks about Eric's experiences with RelLab .

Rick: Did the less confident or less active student in the relationship, ever use the image to then teachsomebody else who was less confident than they? So a student not quite confident about what they were learning then understands the image, and can use that image as a reference point to a student who might have begun at even a lower level of understanding?

Eric: ...There was one case certainly where there was a student who was extraordinarily frustrated. She's a student who really wanted some kind of concrete understanding at every step of the way, and became very frustrated at one point because she just wasn't understanding what was going on. She spent about an hour after school working with the program and finally came to what she felt was a pretty good understanding. She felt wonderful about it. The next day when we came into class, she worked and taught a group of about 5 other students who were really falling behind, what she had learned. And she's animated when she's going through this and showing them the, she was using the computer throughout, she's saying, "You've got to see what happens here. Now look what's going on with this thing here. Notice that this, you know, where the rocket ship is and where the light wave is," and clearly this had a very strong impact on her, being able to work on the computer and her confidence changed dramatically in going from the day before when she was extraordinarily frustrated to be working it through herself, and then she felt very confident about what she had learned from the computer, and was very excited about showing other people that information.

We expected the video teleconferences to stimulate the interchange of e-mail and resources between teachers in the Boston and San Diego areas. Poignantly it did not. Subsequently, however, discussions arose between teachers in the San Diego area about the practices of the Boston area teachers. One east-coast department chair asked permission for several of the teachers in his school to become involved in the project. Generally, we note that the exchange of information tended to occur primarily between those who already participated in face-to-face interactions. Teachers in the San Diego area had been involved in the Teacher Education Program there, and many teachers in the Boston area had participated in formative evaluation of BBN software. The roots of the network were buried in pre-existing geographic organizations and associated practices.

Discussion

We have conducted an exploratory investigation in the combined use of the Internet and modeling tools to change core practices in science instruction. We have identified dimensions of teachers' beliefs, concerns, teaching styles, and the organizational environments they work in, that provide the pushes and pulls for teachers' participation in a constructivist network. We have traced how the confluence of these forces influence the use of modeling tools in the classroom. Our study of curriculum and telecommunications technology has begun to uncover how these technologies support or fail to support changes in core practice.

The organization of work that isolates science teachers from one another has been apparent in precluding their participation with technological resources to bridge this isolation. Teachers continually make complex decisions in schools, balancing curriculum goals and needs, time constraints, and perceived payoffs. Their decisions are weighted by their beliefs in the nature of science and what is effective learning and teaching. Consequently, new technological tools take root in classroom practices when teachers perceive the actions they allow (affordances) to be situated within the work upon which teachers place priority.

We are left with an essential tension in the use of curriculum tools for changing core practices. Teachers have often misappropriated open-ended modeling tools because the software design allowed that possibility. On the one hand, tools that enable actions only within existing school practices simply amplify those practices. On the other hand, tools designed in a research environment tend to afford actions valued within the research environment. If these affordances are too far outside of school practices, the tools are not viewed as legitimate. It continues to be a question as how to design tools that can be immediately adopted, yet will conspicuously enable new activities. We believe that tools closest to the popular view of science offer the greatest leverage against ideology.

It must be remembered that the appropriation of tools does not occur in a cultural vacuum (Newman *et al.*, 1989). We organized activities in which the modeling tools played a role. Workshops and teleconferences provided the opportunity for discussions necessary for establishing the legitimacy of the modeling activities. The greatest effect of project agency has been when teachers engaged with researchers in teaching experiments with their own students. During these interactions, researchers were able to discuss or model the use of the software and relate its design to the emerging needs of the classroom. Discussions of abstract pedagogy were grounded in explaining the activity of the students.

Our preliminary analysis of telecommunications technology - video teleconferencing, e-mail, and the world-wide-web, revealed possibilities for the spreading of innovative practices among a network of teachers. Video teleconferencing offers the opportunity to make new practices and technology legitimate quickly through real-time modeling and participation. E-mail affords reflective communication - but mostly when influenced by reflective researchers. The World Wide Web allows the sharing of lesson plan and activity artifacts, around which reflective discussions, situated in the teachers’ practice, can occur. We see that a combination of these tools offers the best potential for the growth of innovation, experimentation, and reflection leading to wider changes in classroom practices.

Conclusions

Our vision of teachers' practices becoming more like scientists must be positioned with respect to our findings. It is lugubrious that teachers' beliefs of science per se have militated against adopting the emerging scientific practice of computer modeling. It is ironic that one solution to this dilemma is for teachers' to become more like scientists on a higher plane (Kuhn, 1977):

> To assimilate [new discoveries and theories] the scientist must usually rearrange the intellectual and manipulative equipment he has previously relied upon, discarding some elements of his prior belief and practice while finding new significances in and new relationships between many others. Because the old must be revalued and reordered when assimilating the new, discovery and invention in the sciences are usually intrinsically revolutionary.

Clearly one does not reach the goal of changing classroom practices directly, but through some intermediate structures. The development of intermediate structures, materials and technologies to reach this vision are best informed by existing routines in schools. Should technologies or restructuring help solve the problem of day-to-day management, then curricular innovations may gain more of a foothold. Teaching styles, which appear to be tied to teachers' beliefs on teaching and learning, are sources of resistance if the affordances of the technology do not match the actions the teachers wish to take. Yet it is clear, in the long run, that the actions the teachers want to take now will not be the same as the ones they will see as legitimate with a new and different understanding of science and science education.

The distribution of expertise is an important practical and theoretical problem to solve in the building of constructivist network. Outside agency is necessary to influence teacher participants to change their practices, i.e. act in ways foreign to their existing organizational environments. That agency changes in a constructivist network as the practices change and as participants take on new roles. The nature of that agency and how to distribute it must be better understood for networks of this type to become self sustaining.

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