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ABSTRACT

Over the past 10 years high performance computers and communications have had a profound impact on the way science is done at research universities. This impact has extended into the undergraduate curriculum and has also been felt at the secondary school level through programs such as the SuperQuest program. This paper describes the background and development of the SuperQuest program, reviews the effect of the program, and identifies critical issues that have emerged over the course of the program. This program was designed to bring the technologies of high-performance computing and the methods of computational science to high school students and their teachers through a national competition where teams of students and their teacher-coaches propose computational science or mathematics problems to investigate. Program evaluation data indicate that winning schools have enacted a variety of programs intended to extend the impact of computational methods to other students and teachers within the school as well as in neighboring schools. Another reported impact of the program was that participating teachers developed new courses in computational science, modified existing courses to include new material and approaches, offered in-service workshops for other teachers, and established new computer facilities within their schools. (JRH)

SuperQuest: A Historical Retrospective on a Computational Science Program for Secondary Schools

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Abstract

Over the past ten years, high performance computers and communications have had a profound impact on the way science is done at the research university. This impact has extended into the undergraduate curriculum and, through the SuperQuest program and other efforts, has been felt at the secondary school level. This paper will describe the background and development of the SuperQuest program, including its goals, objectives and programmatic activities; review the effect of the program on students, teachers, and schools; and identify some of the lessons learned and several critical issues that have emerged over the course of the six-year history of the program.

Introduction

High-performance computers, sophisticated applications software and visualization tools, and network connectivity have collectively given major impetus to the development of what is now known as "computational science." The modalities of experiment and theory are well-known and understood by scientists and science educators alike. The methods of computational science, however, are only now becoming well-established in graduate and undergraduate science education. These methods bring together the mathematical techniques for expressing a model of a physical phenomenon, a computer implementation of that model, and the actual investigation of the phenomenon by varying the parameters, the data and the assumptions expressed in the model (Worlton, 1991). Computational science thus brings together mathematics and computer science in the investigation of a scientific problem. SuperQuest, a National Science Foundation (NSF) supported program, was designed to bring computational tools and techniques to high school students and their teachers, with an ultimate goal of incorporating computational science into the high school curriculum.

Computational science would seem to provide some unique opportunities for students and science teachers. In the typical school setting, the study of mathematics, computer science, and the various disciplines of the sciences is compartmentalized into separate and distinct areas. The problems taught in a computer programming class seldom incorporate any of the ideas of, for example, random number generation or linear algebra, nor do students examine problems from the physics curriculum like, for example, linear motion or gravitational fields. Conversely, typical science textbooks in chemistry, physics and biology do not include laboratory experiments that make use of computer models. Computational science provides an opportunity to integrate science with mathematics and computer science, while investigating problems which themselves are of a multi-disciplinary nature.

The tools of computational science, in addition to the techniques of mathematical modeling, also include scientific visualization tools and networks for communication. Practicing scientists increasingly use visualization tools both to communicate the results of their work to colleagues and to gain insight into the phenomena they are exploring. Visualization can provide insight into the spatial relationships of three-dimensional objects as well as complex, multi-variate data sets which vary over time (Pea et al., 1994). The enthusiasm and excitement of students and teachers exposed to high-end graphics workstations suggests that these tools can have a tremendous motivational impact as well. Finally, data communications provides access to the numerous information and computing resources on the network as well as a valuable opportunity for teachers and students to communicate with colleagues, mentors, and scientific experts.

The SuperQuest program was designed to bring the technologies of high-performance computing--the high-speed computers, the applications software and visualization tools, and the networks--and the methods of computational science--the mathematical models, the computer implementation of those models, and the process of investigation by running the model--to high school students and their teachers. SuperQuest has done this through a national competition, wherein teams of students and their teacher-coaches propose computational science or mathematics problems to investigate. The winning teams are selected by a national review committee. Winners attend three-week summer institutes at a SuperQuest Center, where they learn how to use high-performance computing and visualization to solve their scientific problems. The winners' high schools receive workstations and communications links to the internet. Follow-up technical support for the teachers and students is provided throughout the academic year as the students complete their projects and the teachers begin to use these technologies in the classroom. The details of this program, as well as the changes that have taken place in the program, are described next.

Program History and Goals

The SuperQuest program was created in 1987 by ETA, a subsidiary of Control Data Corporation. In 1988, four finalist teams were selected, and the overall winning school, Thomas Jefferson High School for Science and Technology in Alexandria, Virginia, was awarded a supercomputer of its own. In the fall of 1988, ETA announced the second year of SuperQuest but, because of corporate problems, ETA canceled the program just as project proposals were being accepted. The Cornell Theory Center acted quickly in designing a revised program and with funding from the National Science Foundation and IBM Corporation conducted a modified program for the 1989 participants. A crucial modification occurred in the prizes that were awarded to the winning teams. Instead of providing a small supercomputer to a single winning high school, the modified SuperQuest program with support from the IBM Corporation awarded each of the four finalist teams a local configuration of workstations which would be connected to the infrastructure of the internet. In 1989, few if any high schools were connected to the internet, which had only recently become well-established at colleges and universities. Indeed, as the Cornell Theory Center worked with regional providers and funding agencies, we often encountered the question "Why would a high school want to be on the internet?" Despite the delays and difficulties in providing connections, which included the full range of problems from getting telephone lines put in classrooms to timely equipment delivery to inadequate technical support, we succeeded in providing full internet connections to the four winning schools. This group of schools served informally as a model for others who wished to link to the internet; their usage of the network provided justification for others to join.

The Cornell Theory Center has coordinated the SuperQuest program since 1989, with continued funding from the NSF and numerous corporate sponsors, including Digital Equipment Corporation, IBM, Cray, and others. From its inception, the SuperQuest program has been guided by two overarching goals:

- to encourage and involve high school students in the investigation of computational science problems; and
- to stimulate the integration of computational science and its tools into high school science and mathematics curricula.

The core mission of the SuperQuest program has been to bring modeling and simulation into science and mathematics education through student investigations and the stimulation of curricular change.

In 1991, SuperQuest evolved into a collaborative effort with the National Center for Supercomputing Applications (NCSA) and the University of Alabama at Huntsville (UAH), expanding the participation to 11 winning teams with 40 students and 12 teachers. The SuperQuest program expanded for the second consecutive year in 1992, with Reed College and the Oregon Graduate Institute, and Sandia National Laboratories joining as SuperQuest Centers.

The data from 1990 and 1991 showed that a nearly threefold increase in the number of requests for information and application booklets resulted in about the same number of teams actually completing applications to the competition (see Table 1). We conducted an informal survey of a sample from those teachers who had requested application booklets but did not apply to the program. Two issues were overwhelmingly identified as barriers to participation: the teachers stated that (1) they did not have sufficient *time* to put together a team and complete the application, and (2) they did not have sufficient *knowledge* to develop a computational science project with their students. In response to this feedback, along with the input we received from the SuperQuest Advisory Committee, we made several changes in the competition. We extended the time period during which teachers and students could develop their project ideas by making application materials available earlier in the school year. We significantly revised the materials to suggest project ideas that would be more accessible to a broader base of students and teachers. Perhaps most importantly, however, we modified the rules to allow for either a single team project or four individual projects. The approach of individual projects appeared to favor magnet schools and specialized schools in mathematics and science, where individual student projects, especially for seniors, were more the norm. The use of team projects, however, made it possible for a teacher to identify just a single project (rather than four) for a group of students to work on. Significantly, the number of applicants in 1992 showed a dramatic increase and this was accounted for almost entirely by team projects. Nearly all of the new schools who applied that year submitted team rather than individual projects.

Table 1

SuperQuest Participation 1989-1994

year	requests	applications	SQ Centers	# of students	# of teachers
1989	–	44 teams	1 center 4 teams	21	4
1990	356	39 teams	1 center 4 teams	16	4
1991	915	41 teams	3 centers 11 teams	40	12
1992	1074	71 teams	5 centers 20 teams	74	39
1993	1186	85 teams	4 centers 16 teams	64	29
1994	658	103 teams	2 centers[a] 8 teams	30	16

Note. [a]In addition to the two centers for the student/teacher teams, there were two centers (NCSA and MCNC) that piloted a program that was focused on curriculum development with teachers.

Two additional changes took place in the program in 1992. With supplemental funding support from the NSF, we encouraged the student/teacher teams to include two teacher-coaches on the team rather than just one, thereby doubling the number of teachers participating in the institutes. Nearly forty teachers were able to benefit from the training in computational science at the institutes and from the increased collegiality and interchange that was possible by having larger numbers of teachers involved. The additional numbers of teachers allowed us to have more focused teacher-training sessions at the institutes and, even more importantly, provided mutual support for the teachers within their schools following the institutes. A summary of the interest of the community and the actual participation in SuperQuest is provided in Table 1.

A final change that occurred in the competition in 1992 was the allowance for the use of software packages in the development of the computational science projects. To date, nearly all of the student projects had been written in Pascal or BASIC, with a small number in FORTRAN or C. However, because we wished to encourage a broader base of participation, we modified the competition rules to allow projects to use applications software, such as STELLA, Mathematica, or Matlab as the primary vehicle for the development of the model. This change had no impact on the applications whatsoever.

The SuperQuest winning teams have represented both public and private secondary schools, small rural schools as well as larger suburban districts, and schools from geographically diverse locations— Alabama, Louisiana, Texas, New Mexico, California, Utah, New York, and North Carolina, as well as other states. Among the winning SuperQuest schools, several have won the competition two or more times, including:

- Bronx High School of Science, Bronx, New York
- Evanston Township High School, Evanston, Illinois
- Highland High School, Albuquerque, New Mexico
- Illinois Math and Science Academy, Aurora, Illinois
- J. Oliver Johnson High School, Huntsville, Alabama
- Louisiana School for Math, Science & the Arts, Natchitoches, Louisiana
- Monte Vista High School, Danville, California
- Montgomery Blair High School, Silver Spring, Maryland
- Reagan High School, Houston, Texas
- Thomas Jefferson High School for Science and Technology, Alexandria, Virginia

The projects proposed by winning teams have been diverse, spanning the scientific disciplines and involving a variety of high-performance computing techniques. These winning proposals have included:

- "Environmental Impact of High Rise Buildings," a 1992 winning project from the Providence Day School, Charlotte, NC, used Bernoulli's equation, the equation of continuity, and a wind profile equation to calculate stresses and pressures on high rise buildings given varying wind conditions.

• "Chaotic Cardiac Arrhythmias," a 1990 winning project from the Thomas Jefferson High School for Science and Technology, relied on computer simulation techniques to demonstrate irregularities in the rhythm of the heartbeat, representing the interaction of biological oscillators in terms of a phase response curve and a finite difference approach.

• "Interpretation of Language Using Supercomputing," a 1991 winning project from the Bronx High School of Science, focused on the development of computer programs to more accurately translate documents from one language to another, using vectorization and parallelization to increase the speed of the program.

• "Numerical Simulation of Crowd Dynamics in an Enclosed Space," a 1992 winning project from East High School, Salt Lake City, UT, modeled large crowd movements as cellular automata to gather data about the number of casualties, injuries, and collisions that could occur in an enclosed space.

• "River Erosion," a 1992 project from Monte Vista High School, Danville, CA, used fundamental equations of geophysics to explore how the earth's landscape has been dramatically altered by a myriad of forces, including river erosion.

Using computers to investigate these problems through the development and refinement of a simulation represented a dramatic departure from the typical use of computers in science and mathematics classrooms in 1989. In his analysis of the data from three national surveys conducted in order to learn what computer resources schools had and how they were being used, Becker (1993) found that in 1989 both math and science teachers were more likely to report that they taught their students word processing than to report the use of spreadsheets, simulations, or programming languages. Drill and practice programs dominate the use of computers in the math and science classroom, with almost no time given over analytic investigation or problem solving. Becker reports:

> Only 3% of *computer-using* math teachers had students use graphing programs on more than five occasions during the school year, and amazingly, only 1% had students use spreadsheets in their math class that often. Similarly, only 1% of computer-using science teachers used (on more than five occasions) computer programs that interfaced with laboratory equipment. (1993, p. 70)

Thus, the explicit goals of SuperQuest to encourage and involve students in the investigation of computational science problems and to stimulate the integration of those tools into the science and mathematics curriculum represented a significant departure from the conventional use of computers in the secondary school classroom in 1989.

Program Activities

The SuperQuest program conducted three major activities designed to meet the program goals:

- a national competition to encourage and identify the best computational science projects in the country,
- an intensive three-week institute in computational science and its tools for the winning teams at each SuperQuest Center, and
- the installation and support of a configuration of workstations and network access for one year to the Center's supercomputers for the continuing investigation of student projects and for wider use by students as these resources are integrated into the schools' science and mathematics curricula.

Information about the SuperQuest competition is distributed to all high schools across the country through a combination of direct mailing and advertising in secondary school science magazines. Each competing high school must put together a team of four students and one or two teacher-coaches. A team can propose either individual projects for each student or a single, larger project for the group. These science or mathematics problems must require computer resources for their solution. Projects are judged by a national committee of scientists and mathematicians according to scientific content, effectiveness of computational approach, creativity, and clarity. The number of repeat winning schools is limited each year, thereby increasing the range and diversity of winning schools.

Each entry includes an abstract describing the problem to be solved and the proposed method of solution. Specific details about the computational aspects of the solution include the equations and/or mathematical basis for the proposed solution. A prototype version of the solution should implement some elements of the basic algorithm, using computing resources available at the local high school. Finally, each entry includes a brief bibliography of the sources that have been used in the development of the project.

The teacher-coach must submit a plan that outlines the school's proposed use of the advanced computational tools in the school's science and mathematics curricula and extra-curricular activities. This plan must describe ways in which existing courses will be expanded to take advantage of advanced computing technologies. The plan should include a description of the intended content and schedule for these courses and it may include proposals for the development of new courses in computational science. The school must propose curricular and extra-curricular activities that include: (1) the involvement of other students in science projects requiring computational solutions; (2) plans for hosting workshops, visits, and/or classes for area high schools; and (3) programs for establishing cooperative ventures with local colleges, universities, and businesses.

The winning teams attended a three-week summer institute, described more fully below, and each member of the team received a modest stipend. Each teacher received a $1500 stipend and each student received a $500 stipend. Following the institute, each winning school received a permanent equipment award of a workstation and was granted access to the internet for one year. These resources enabled the students to continue to make progress on their projects and provided an environment for the teachers to use in other areas of their science and mathematics curricula. During the academic year following the institute, the teachers received technical support from the SuperQuest centers as they work on these broader activities and as the students continued to complete their original projects.

Institute Objectives and Activities

The student/teacher institutes were designed to accomplish three objectives:

- to train the students and teachers in the use of high performance computing tools, including program development tools, vector and parallel processing, and visualization techniques;
- to provide students and teachers with an understanding of some of the fundamental numerical methods and approaches central to numerically intensive computing; and
- to further the investigation of the scientific problems proposed by the students as well as to expose the teams to a breadth of scientific applications and approaches.

The SuperQuest institutes provided a balanced program of lectures, demonstrations, hands-on experience, discussion sessions, and informal interactions. Together, the students and teachers received an introduction to the operational features of the supercomputer and an overview of the architecture. Prior to their arrival on campus, the teams received an appropriate textbook to use in preparation for moving their prototypes to a programming language or an application package. The institutes provided instruction on the fundamentals of advanced numerical methods, including several areas of linear algebra, vector and matrix computations, and solutions of systems of equations. Additional sessions covered a selection of topics, such as the development of numerical models, the use of mathematical software libraries as tools for program development, eigensystem analysis, computer generated random numbers, issues of precision and accuracy, and the solution of ordinary differential equations.

Students were given ample time during the institutes to develop and implement their programs and investigate their problems. The students participated in general discussions of research methodology and had opportunities to interact with research scientists who gave specific attention to the techniques and methods used in the disciplines represented by the student projects. The program included sessions on using the research libraries, writing technical papers, and preparing scientific presentations. A member of the technical staff at the SuperQuest Center was the "team consultant" and worked one-on-one with his/her students. Each Center identified scientists who have research interests aligned with the student projects and who serve as mentors to the students. The mentors organized small working group meetings with the students and their teacher-coaches. The last day of the institute was devoted to student presentations. The experience of presenting their work both to their peers and to research scientists was an extremely valuable one. Each participant prepared for this presentation during the final week of the institute.

Throughout the institute, senior staff at the Centers, team consultants, and mentors met with the teacher-coaches. These interactions provided extremely valuable information to the center staff regarding student progress and enabled staff to respond more effectively to the students during the institute. The teachers were able to broaden their thinking about changes in teaching and learning. These meetings provided the teachers an opportunity to develop group support, to exchange information on the curricula and programs at their home schools, and to share ideas on various student projects. At the close of the institute, each student and each teacher completed an institute evaluation. These evaluations were reviewed by Center staff for the on-going improvement of the institute activities.

As students continued to investigate their problems during the academic year, the SuperQuest Centers encouraged them to present their work at various science forums at local, state, and national levels. Each year, a number of SuperQuest teams have attended the IEEE Supercomputing Conference to participate in the education discussions and to present poster sessions. At the end of the academic year, student participants from all the SuperQuest summer institutes submitted a final paper to a Best Papers competition. SuperQuest awarded three scholarships of $1500 (Best Paper), $1000 (Second Best Paper), and $500 (Third Best Paper). Submitted papers were evaluated by a committee of scientists and educators using the same criteria used to select the winning teams.

Program Development

In 1994, the North Carolina supercomputer facility (MCNC) and NCSA developed and implemented a computational science institute for science and mathematics teachers as a part of the SuperQuest program. This institute brought together master teachers, science curricula experts, and teacher trainers in science and mathematics for a three-week workshop. The objectives of the institute were to:

- enhance the knowledge of mathematics and science master teachers who will serve as role models for incorporating computing, networking, and computational science into mathematics and science education;

• create computing, networking, and computational science materials for mathematics and science classrooms that will engage students' curiosity and enhance their ability to solve problems.

The three-week institute consisted of one week of instruction followed by two weeks of materials and curriculum development. During the first week, the participants received training in using computing and networking tools and in the techniques of computational science. Instruction covered the following areas: networking, visualization, computing software tools, symbolic math, programming, a review of existing discipline-specific software, high performance computing, and curriculum development approaches.

The two-week materials development session is accomplished by teams of two teachers working with the discipline and curriculum development experts. The materials are being developed for use on computer platforms in the high schools today and for use over the internet, where appropriate. The materials produced are being field tested by the teachers and their local colleagues during the 1994-95 school year. The teachers will provide written reviews on a specified schedule, recommend improvements for existing materials, suggest future ideas, and may produce additional materials during the field-test year.

Impact

The national SuperQuest program has been a model for similar state and regional science competitions. The New Mexico Supercomputing Challenge, begun in 1990-91, is an academic year-long program in which teams of high school students and a sponsoring teacher work on computational science projects using high performance computing. The University of Alabama's program for high school teachers provides in-service training for high school science and mathematics teachers and provides network access to the supercomputer over the Alabama Supercomputer Network. The program also includes an annual Exposition that awards prizes to outstanding student projects. The Oregon Department of Education launched a statewide SuperQuest program in the summer of 1993. EarthVision, the Environmental Protection Agency's (EPA) Grand Challenge for High Schools, is an educational program for high school teachers and students that helps them develop environmental research programs using computational science and access to high-performance computers. Although EarthVision is currently being piloted in the Saginaw-Bay City-Midland area, the program is expected to be available throughout the state of Michigan in 1993-94 and may expand to the Great Lakes region and beyond in later years. The goals, rules, project guidelines, and awards for winners in many of the these programs are similar to those of the national SuperQuest program.

Program evaluation to date has relied on self-reported questionnaires from participating teacher-coaches and students. These data have included evaluations completed at the end of the summer institute, interim reports the following December, and final reports submitted in April along with the students' final papers.

Participant evaluations of the SuperQuest Summer Institutes have been obtained from both students and teachers to address issues relative to lecture, workshop, and training session content. Feedback from these surveys has led to improved quality of the Summer Institute sessions, improved methods for publicizing the SuperQuest program, and more understandable application materials. However, information about the uses of equipment awards in the high schools' curricula has been largely anecdotal. Further, these efforts have been difficult to monitor because of a lack of staff knowledgeable in educational program evaluation and because of dependence on the self-reporting of teacher-coaches.

Interim questionnaires completed by teachers and students midway through the academic year following the Summer Institute provided some quantitative information about how much they were using the awarded resources, how many students were involved in computational science projects as a direct result of SuperQuest, and how many teachers were planning to incorporate computational science into their curricula. The achievements by individual SuperQuest students have included success in the Westinghouse Talent Search, collaborations with research scientists, and participation in professional conferences and meetings:

- Two students who attended the 1992 Summer Institute at the University of Alabama, Steve Chien and Elizabeth Mann, both of Montgomery Blair High School, submitted their projects to the Westinghouse Science Talent Search and were among the top 10 winners (eighth and ninth place respectively).

- Mike Montemerlo of Jefferson High School used the internet to communicate with Dr. Peter Cheeseman, an expert on Bayesian inference at the Ames Research Center. Mike was also among the finalists in the Westinghouse Science Talent Search.

- Jed Pack, from Gompers High School, gave a presentation in August to the North Shore Amateur Radio Club in San Diego.

- The team from Del Norte High School was invited to present its project at the Physics '93 Conference to be held in Albuquerque on June 1-4, 1993.

- David Rudy from Louisiana School for Math, Science and the Arts was invited to work with Dr. Brown at the Florida Institute of Technology on a project in designing a massively parallel machine and in writing the operating systems and compilers for the machine to take advantage of job-specific processors for enhanced speed.

- Students from the East High team that attended the SuperQuest summer institute at Reed College gave a presentation in December at the Educational Networking Consortium.

• Students from duPont Manual Magnet High School have given two open houses on their SuperQuest project at their high school, one for prospective students and one for alumni. They also participated in an NFIE Learning Tomorrow Workshop last November which resulted in the establishment of network communications with Edgewater High School in Orlando, Florida. They gave a presentation on SuperQuest at the National Council of Teachers of Mathematics Conference in Seattle, Washington as well.

Data collected thus far indicate that some winning SuperQuest schools have enacted a variety of programs intended to extend the impact of computational methods to other students and teachers within the school as well as those in neighboring schools. SuperQuest teachers have developed new courses in computational science, modified existing courses to include new material and approaches, offered in-service workshops for other teachers, and established new computer facilities within their schools:

• The North Carolina School of Science and Mathematics in Durham, a 1989 winner, developed a course entitled Chaos and Fractal Geometry.

• Clear Lake High School in Houston, Texas, sent students and instructors to speak at seminars statewide on the applications of their awarded workstations and conducted in-service seminars for teachers from other schools.

• Montgomery Blair High School has implemented both formal and informal curriculum changes. The formal are in the form of new, semester-long courses added as electives to the computer science curriculum, and the informal are in the form of modifications to existing courses, beginning in the ninth grade.

• The integration of awarded workstations into the curricula of five courses at the Thomas Jefferson High School for Science and Technology, according to self reports, involved more than 200 students. In addition, a new interdisciplinary course was developed for Fall 1992 that integrates chemistry, mathematics, and computer science, and another course covered computer networking.

• At J. Oliver Johnson High School in Huntsville, AL, 44 additional students were reported to have benefited from the SuperQuest program through integration of computational techniques in biology, physics, and calculus. Two new courses—Introduction to Supercomputing and Supercomputing II—were developed as a result of SuperQuest and were offered in Fall 1992 to approximately 25 students.

• Twenty-two students were expected to be involved in computational science projects at Robinson High School, Waco, TX, a 1992 winning school.

• Marlboro High School, Marlboro, NY, a 1991 SuperQuest winning school, introduced a new course—Programming in C— in which a small group of students was expected to participate. In addition, this school reported incorporating the awarded workstations into an existing course—Computer 12X—also in which 15-18 students were to participate in independent research.

• The principal from the Bronx High School of Science indicated that the workstation donations and the SuperQuest Summer Institute training his students and teacher received in 1991 gave him the impetus he needed to begin a revolution in how classes are taught at this school. Computational science is becoming a part of all physical and biological sciences classes, in addition to providing the basis for courses in BASIC, C, and Pascal programming, computer telecommunications, and computer technology. He reported that this impacted more than 300 students.

• Providence Day School reported plans to conduct an orientation session to acquaint other teachers at the school with how to use the awarded workstations.

• SuperQuest Northwest institute staff solicited support from the University of Louisville, which has generously agreed to provide continued internet access for duPont Manual Magnet High School, Louisville, after the NSF-funded year is up.

• Providence Day School, Charlotte, NC, reported plans to conduct an orientation session to acquaint other teachers at the school in how to use the awarded workstations.

• At Bronx High School of Science, Bronx, NY, 40 students were using awarded workstations for computational science projects in 1992, and 100 students were expected to work on such projects in Spring 1993.

• Twenty-five (25) students at Highland High School, Albuquerque, NM, were expected to use the awarded DECstation 5000 system in two courses in which the system was incorporated. Three teachers were also expected to be involved in these courses.

• SuperQuest staff at Reed College, working with the Oregon Department of Education, have been planning and securing funds for a 1993-94 statewide SuperQuest program. Though modeled on the national program, it will attempt to reach a greater number of students and teachers using local mentoring and multiple connections to the internet. Reed College hosted a 3 day "kick-off" session for the local program at the tail end of the national 1993 SuperQuest Summer Institute.

• As a result of the SuperQuest program, Claremont High School had 21 students enrolled in two separate independent study courses involving supercomputing, modeling and simulation.

• Berean Academy reported that the SuperQuest program has had a great impact on their computer department. The school remodeled the computer room, installing conduits for their LocalTalk network, which connects their Macintoshes to the DECstation. Their programming classes are now using the Macintoshes and have moved from BASIC to Pascal.

While these successes provided encouragement and continued enthusiasm for the positive impact of the SuperQuest program, we were at the same time faced with several challenges for the future growth and development of the program and hampered in part by the lack of systematic evaluation of the positive impacts as well as the lack of more detailed knowledge about sites where fewer results were seen. Nonetheless, several valuable lessons have been learned over the history of the program.

Lessons Learned

During the early years of the SuperQuest program, we were faced with considerable challenges in establishing the network connections to the schools. This often led to frustration on the part of the teachers and students, exacerbating the difficulties already inherent in the computational projects that the students had undertaken (Doerr, 1992). This lag time (in some cases up to a year) meant that they were unable to practice and use their newly learned skills of using the networks, with tools that were considerably more primitive than the easy-to-use mailers, browsers and transfer mechanisms that are available today. In response to this problem, the Cornell SuperQuest center developed a strategy of providing both a "day one" networking solution and a long term solution. Typically, the "day one" solution consisted of a modem and a telephone line, with the longer-term solution generally being a full internet connection. In all cases, we were careful to work closely with the teachers and administrators at the local school to implement a solution which the school would be able to maintain and support both technically and financially after the year of SuperQuest support.

Not surprisingly, many teachers found that the implementation of new technologies into their classroom practice took considerably longer than they would have anticipated, in contrast to their enthusiasm at the conclusion of the institute. Many of the changes to classroom practice that occurred as a result of SuperQuest appear to have occurred a full year or more after the institute program and teachers often reported that their SuperQuest participation was a precipitating or catalyzing event within the overall school setting. This suggests that any evaluative study of the impact of SuperQuest needs to address indirect and long-term effects as well as immediate impact. We have anecdotally seen two very different kinds of effects: those schools where winning SuperQuest strengthened and provided impetus to activities (such as the enhancement or development of courses or relationships with local businesses) that were already underway at some level; and those where SuperQuest precipitated events (such as the acquisition of new computer labs) that would not likely have happened otherwise.

A unique component of the SuperQuest program has been the creation of an educational setting wherein teachers and their students are both learners of new technologies and applications. The students, in general, were highly motivated and quickly focused on their own specific needs, which arose from their project. The project provided the base from which they investigated and pursued a more in-depth understanding of the scientific principles involved and the development of particular mathematical methods for solving their problems. As is the case with much scientific research, we found that nearly all student projects were modified from their original objectives through this process. In most cases, the scope of the project was considerably narrowed, although in some cases the students expanded scope of their investigation. The teachers, on the other hand, largely functioned as facilitators for the students' learning while at the same time working towards establishing their own base of knowledge about computational science. From the very first institutes, the teachers have consistently identified their own need for more in-depth and sustained training in computational methods. One of the perceived benefits of this student/teacher program is that the students are sources of ideas and topics for projects. This provides both focus and motivation for their investigation. To the same extent that we have witnessed students benefiting from project-based learning in teams, we hypothesize that teachers, too, might benefit from this approach. This would suggest abandoning the familiar lecture oriented, practice exercise strategy in favor of more open-ended projects for investigation. Such a strategy would need to identify fruitful sites for investigation related to core areas of the science and mathematics curriculum while simultaneously providing teachers with materials and resources that they can use in their classrooms.

The opportunity for team projects clearly enabled a much broader base of participation in the SuperQuest program. However, this change also presented new challenges that needed to be addressed both in the institutes and in the follow-up work during the academic year. Team projects greatly simplified some of the instructional problems of the institutes, since we were able to focus on a smaller number of topical areas (since the projects in general come from any area of science or mathematics) and to take full advantage of the students working together in a single problem area. At the same time, we now found it necessary to work with the students in certain aspects of group processes, something with which they had only the most limited experience in science and mathematics classed. In addition, in most cases, but not all, the teachers had little experience with explicit discussion of group processes and roles within a group.

One intended side effect of the team projects did not fully materialize: the hopes of increasing the level of participation of girl students. Over the course of the program, the number of girls applying to the competition rose from 10% to 25%. This would generally be about one or two girls on a team. This was more than offset by the number of all-boy teams which applied; only a very few all-girl teams applied. In addition, the success rate of teams with girls was sufficiently lower than the success rate of all boy teams that the resulting level of girls on the winning teams over all years of the program was about 19%. This disheartening result gives serious cause for concern about introducing computational approaches to science and mathematics, a career area where women are already underrepresented. The phenomenon could be explained in part by a filtering effect which occurs through the introduction of the use of computers. While the enrollment of boys and girls is almost equal in secondary mathematics and science courses, Becker (1993) reports that in a minority of computer classes, some 20%, the boys greatly outnumber the girls by a ratio of greater than 2:1. Apple (1992) also presents the claim that two out of three students in computer classes are boys. Nonetheless, the participation of girls in this program remains well below the general participation of girls in mathematics and science classes. This disproportionate participation may call for a fundamental re-conceptualization of the program's design to increase its effectiveness in involving female students.

Despite the change in the competition rules to allow for computational problems that were based on higher-level applications software, only rarely did any applicants submit such projects. Programming languages, despite their difficulties, would appear to be more familiar to students and teachers, likely through traditional, although diminishing in enrollments, computer programming courses. The use of spreadsheets, symbolic algebra packages, simulations, visualization tools, statistical analysis packages and iconic modeling environments such as STELLA have had only the most limited use in secondary school mathematics and science classrooms (Becker, 1993). Yet, these software tools would appear to be much more amenable to the widespread use of computational approaches to mathematics and science problems than the direct use of high-level programming languages such as FORTRAN, BASIC or Pascal. While the SuperQuest program has certainly fostered and facilitated the use of the networks, the essential core of the program has been oriented towards the use of modeling and simulation in science and mathematics education. To this end, it would appear essential to develop suitable computing environments that are at a much higher level than programming languages, while at the same time recognizing that many, if not most, of the problems that would be investigated by secondary school students do not require the power of today's supercomputer but rather need to begin to take advantage of the power that is available on today's desktop computer--a computer whose power exceeds that of the supercomputer when SuperQuest began.

With support from the NSF, the Cornell Theory Center has contracted with the Center for Children and Technology at the Education Development Center to conduct a detailed, systematic external evaluation of the SuperQuest program to assess and understand the impact of the program on the high schools. The range of schools that have been part of SuperQuest provides a body of natural variation to study the different models of implementation and the conditions of success. Specifically, the evaluation is designed to answer the following questions:

• What is the range of models for implementing SuperQuest activities in the schools that have participated in the program?

• What has been the impact of SuperQuest participation within the different schools on the students, the teachers, and the curriculum and learning environment?

• What can be learned in general about how advanced computing resources are most effectively and efficiently made available, supported, and used in schools?

• What kinds of professional development experiences are required for teachers to use computational resources well?

• What kinds of outreach took place to the broader community?

This systematic analysis of the SuperQuest program should provide a better understanding of those school settings where SuperQuest appears to have had a greater impact and establish a firmer foundation for developing educational programs that can achieve a much more broadly based diffusion of technology.

Concluding Remarks

One of the primary conclusions of the last decade of research, design, and implementation of technologies in schools is that the process of integrating technologies effectively to change learning is far more complex than simple access to technological resources. The development of curricula that take full advantage of technology-based resources, the professional development of the teachers and other educators, and the reorganization of schools, districts, and states to support new learning environments are all central to the successful exploitation of technologies for learning. These issues will only become more important and complex as the technologies advance, and as telecommunications increasingly link schools to far more extensive learning resources.

The national SuperQuest program has contributed to and built on the infrastructure provided by the national networks to promote collaborative learning among new communities of learners and broad access to scientific resources. Teacher education and training need to be more strongly focused as a central component of any computational science education program. Such teacher development needs to be closely linked to the necessary curriculum and materials development. Such materials should encompass the full range of computational platforms from personal computers to supercomputers. The external evaluation of the SuperQuest program to date should be invaluable in better understanding how advanced technologies and networks can best serve the needs of science and mathematics education and in identifying how to scale programs such as SuperQuest more broadly.

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