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Adventures in Supercomputing 1993 - 1994 Evaluation

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Introduction: *Background on the Adventures in Supercomputing Program*

The Adventures in Supercomputing (AiS) program, funded by the U.S. Department of Energy, was initially established in Iowa, New Mexico, and Tennessee in 1992, with Ames Laboratory, Sandia National Laboratories-Albuquerque, and Oak Ridge National Laboratory hosting the program in their respective states. In 1993, the program was expanded to include sites in Alabama and Colorado, hosted by the University of Alabama at Huntsville and Colorado State University, respectively.

The goal of AiS is to cultivate the interests of diverse populations of high school students, particularly students of color, girls, and economically disadvantaged students in science, mathematics, and computing. The AiS curriculum introduces students to the field of computational science, in which supercomputers are used to run simulations that form the basis of scientific experiments.

Over the last 20 years, computational science has emerged as a powerful method of analyzing a variety of problems in both basic and applied research, including product and process development, and many aspects of manufacturing. Computational scientists develop simulations that are based on mathematical or physical models that provide both qualitative and quantitative insights into many phenomena that are too complex to be dealt with by analytical methods and/or too expensive or too dangerous to study via material experiments. The availability of high performance computers, graphic workstations, and high speed networks, coupled with major advances in algorithms and software, have made it possible for computational simulations to replace more traditional laboratory investigations.

A computational scientist, using networking and visualization tools, works at the intersection of several disciplines: applied science or engineering, computer science, and mathematics. This multidisciplinary activity has enabled computational scientists to tackle a number of diverse phenomena, including:

- Numerical wind tunnel research. The use of computational techniques in this area has made experiments which would previously have been impossible to conduct in a real wind tunnel. For example, through computing and visualization, the flow over a planetary probe entering the atmosphere of Jupiter can be effectively simulated and researched.

- Computer crash testing of automobiles. Not only has this technique proven cost effective (real cars are not destroyed) it has resulted in more insight into crash dynamics than conventional crash testing with real cars has permitted.

- Pharmaceutical design. In simulated experiments researchers try to find molecules which will “fit” into active sites on a biologically-important substance. These molecules can then either activate or inhibit biological processes.

- Oil exploration and recovery. Seismic data is analyzed to locate potential sites for drilling. Optimal pumping strategies are determined for existing oil fields.

- Analysis of genetic data. This research includes the sequencing of the human genome, which if successful will be the foundation for curing many genetically-linked diseases.

Rationale for Program Development

The Department of Energy's efforts to introduce a computational science curriculum into high schools dovetails effectively with many of the educational reforms that are currently being proposed to support more engaged and substantial forms of student learning. The AiS curriculum supports students involvement with real-world problem-solving activities. Students are expected to conduct extensive research for their projects, and they are asked to design and execute programs or simulations that will aid in solving problems. In addition, a major component of both AiS and the educational reform agenda is the introduction of technologies, principally computing and communications technologies, to improve teaching and to facilitate learning. The goals of the AiS program are consistent with national educational goals, in that they are geared to using the most up-to-date resources available to improve mathematics and science education for all students (Means, et al, 1993). The AiS program brings girls, students of color and economically disadvantaged students into contact with computational scientists and with the technology those scientists use to conduct their own complex inquiries and analyses.

With its emphasis on independent and original student research, the AiS program is in line with current educational reform efforts (National Center for Improving Science Education, 1991; NCTM Commission on Standards, 1989; Task Force on Educational Network Technology, 1993; U.S. Department of Education, 1994). During AiS class periods, students are likely to be working in small groups, or independently, on activities related to these goals. These kinds of classroom activities differ significantly from usual high school science or math classes. High school students typically spend much of their classtime engaged in activities that stress delivery and retention of information, such as listening to teachers lecture, watching teachers work problems on the board, and taking tests (NSB, 1993).[1] AiS students, in contrast, spend their classtime refining hypotheses, collecting data, developing methods for analysis, and synthesizing the results of their work. These activities, which create greatly increased opportunities for student discussion and involvement, are far more likely to lead to conceptual understanding of material and better developed problem-solving skills (NCTM, 1989).

The AiS course also offers an opportunity for female students, students of color and economically disadvantaged students who are less likely to enroll in advanced mathematics and science classes to engage in independent research, and to pursue novel problems of their own invention. In addition to being in line with educational reform agendas, this curricular approach has shown promise in narrowing gaps in student performance (Collins, et al, 1991; Linn, 1992). Research has found that when novel problem-solving and integration of conceptual and procedural knowledge is stressed in curriculum and assessment, performance gaps that persisted in traditional curricula and assessment techniques are eliminated (Linn, 1992; Wellesley College Center for Research on Women, 1992). Because the AiS curriculum supports students as they engage with diverse and complex fields of scientific inquiry, the program presents an opportunity to examine the efficacy of substantive investment in high quality, innovative science and mathematics instruction for all students.

Selection, Training and Resources

In order to be selected to participate in the AiS program, schools must submit an application. The applications are evaluated by selection committees in each state to determine which schools are the most qualified to carry out the program successfully and reach a significant number of women, students of color, and economically disadvantaged students. Typically, selected schools either have a large disadvantaged student population, or the applying teachers propose specific means to attract such students into AiS classes.

Once selected, teachers receive extensive training in how to use computational tools and in how to design and implement a program that will work effectively in their local school community. Teachers attend a summer institute for training and participate in fall and spring AiS workshops. During the two-week Summer Institute teachers receive instruction in how to present introductory concepts in high performance computing to their students. They learn how to use scientific visualization software, and they experiment with the use of computational tools in modeling scientific problems. Teachers also develop a course outline and timeline that will work in their school environment.

The Summer Institute includes hands-on experience in the use of a range of technological tools: FORTRAN and parallel programming techniques, UNIX commands, pico (an editor), scientific visualization software, Macintosh familiarization, Claris Works (integrated word-processing, spreadsheet, and database software), and networking. Presentations are also made by DOE staff and visiting education and scientific professionals.

During the fall and spring workshops teachers receive follow-up instruction on technical applications. They also have the opportunity to discuss with colleagues the ways in which they are implementing AiS in their local schools and to explore strategies for resolving challenges they may be encountering, such as finding mentors and selecting projects.

Throughout the school year teachers and students have access to state-of-the-art high-performance computers, software, and networks, and expertise in computational science. All five states provide access to nCUBE parallel supercomputers through a UNIX workstation front end. AiS participants also have access to the National Education Supercomputer located at Lawrence Livermore National Laboratory, and are able to access all of the resources available on the Internet. Scientists and engineers working in various fields of computational science, applied mathematics, parallel computing, and computer science serve as mentors for students participating in the program.

AiS Curriculum

Because the program is targeted at students who are least likely to be attracted to scientific, mathematical, and computational fields, the AiS program does not require that students have prior programming experience. The only prerequisite for student involvement in AiS is Algebra I. As a result, a substantial part of the year-long curriculum is devoted to teaching students FORTRAN and parallel programming techniques. By the end of the school year students are expected to be able to apply programming solutions to scientific problems.

All participating AiS teachers are given a sample supercomputing course outline which they use as a guide in implementing the program in their schools. Teachers are encouraged to duplicate and adapt the material to suit their particular situations. In most schools, the AiS curriculum runs for an entire year. During the first several weeks of the course students are introduced to the field of computational science and the purpose of supercomputers. During the first half of the course they also begin to learn the essentials of FORTRAN. By mid-year they are expected to have identified and begun to develop their project topics; during the second half of the course students continue to conduct research into their topic area, consult with mentors on the design and execution of the programs they are writing and the computational tools they are using, and prepare for their final project presentations.

Evaluation Design

Because teachers' knowledge of and comfort level with any educational innovation is key to its success (Brunner, 1992; Hawkins, 1993; Sheingold & Hadley, 1990), a decision was made to assess student learning in only those courses taught by teachers who were beginning their second year of involvement in the AiS program. As a result, the evaluation was limited to students of the 1992-93 cohort of teachers in three states: Iowa, Tennessee, and New Mexico.

The educational goals and objectives that are central to student learning in the AiS curriculum emphasize the acquisition of thinking and problem-solving skills. Students engage in long term projects that require them to pose hypotheses, devise methods and procedures for solving problems, and draw on a wide array of resources including text and electronic sources, computer simulations, and human experts, to undertake their inquiries. The inquiry-based and analytical skills that students are asked to develop in the AiS program are not effectively measured by traditional paper and pencil tests. They require a form of assessment that enables students to demonstrate their understanding of the complexity of the task they have undertaken, that moves beyond the recall of facts and concepts toward demonstration and documentation of the processes and procedures that are used to solve particular problems. This type of assessment, known as "authentic," records and judges the qualities of actual performances, rather than inferring an ability to perform from indirect and decontextualized measures such as multiple choice tests.

A particular authentic assessment technique known as performance assessment (Hawkins, et al, 1993; Herman, et al, 1992; Linn, 1993; Rudner & Boston, 1994; Wiggins, 1990) was selected for the purposes of the AiS evaluation. This type of assessment focuses on student projects as comprehensive demonstrations of their skills and knowledge. Student projects are central to the AiS curriculum; they require a broad range of competencies, are often interdisciplinary in focus, and require student initiative and creativity. All students in the AiS program are expected to complete projects and demonstrate their proficiencies by presenting their work at a state Expo.

In accordance with the standard techniques of performance assessment (Frederiksen, 1994a; Frederiksen 1994b; Hawkins, et al, 1993; Herman, et al, 1992), the evaluation was structured to document student projects by videotaping student groups as they presented their project to a group of peers and experts. Group presentations give students the opportunity to explain in depth both the content and the process of their year's work, and allows for questioning by audience members. Because the questions and criteria deemed to be important (i.e., consistent with program goals) are known to the students, the teachers, and the program evaluators, this type of presentation gives the maximum opportunity for full and complete demonstration and documentation of student knowledge. Videotaping presentations allows for in-depth analysis of students' performances by coders who are familiar with the curriculum, and are trained in the interpretation and application of the coding system. Once collected, videotape documents are coded according to a set of student learning criteria and clustered to determine types of student achievement that result from participation in the AiS program.

Previous research on technology innovations indicates that factors such as teachers' prior experience with technology, the number of years teachers have been teaching, the number of technology-using teachers in a school, the school's overall investment in technology resources, and the ways in which teachers choose to interpret and implement a new curriculum make a critical difference in the effectiveness of technology-rich educational programs (Becker, 1992; Brunner, 1992; Sheingold &

Hadley, 1990). Therefore, in order to better understand variations in student learning established through the analysis of project presentations, three other types of data were collected. This data includes i) demographic information that characterizes AiS teachers, students, and schools;[2] ii) additional student learning data (learning process data) that explores the development and refinement of students' ideas and questions; and iii) contextual data that investigates the circumstances in which the AiS curriculum is being implemented.

1) Demographic data.
   a) Student demographic data was collected to determine the number of male and female students participating in AiS; their race, grade level, and age; their prior experience with computers; and their prior involvement in AiS.
   b) Teacher demographic data was collected to investigate variables, such as years of teaching experience, subject areas and grade levels taught, experience using computers for instructional purposes, and the availability of computers and modems at home.
   c) School demographic data was collected on a range of variables, including size of school, percentage of students who are below the poverty line, number of students of color enrolled, percentage of graduates that go on to college, amount of computer-based technology in the school, and the number of years teachers in the school have been using computers for instructional purposes.

2) Contextual data.
   a) School visits. Through visits to a sub-sample of AiS schools (15 of 19 schools) data was collected that investigated the ways that the AiS curriculum is implemented in different schools. During each visit the following information was collected: AiS classes were observed; teachers were questioned about the ways in which they were implementing the AiS curriculum; and students were questioned about their interest in AiS, the development of their project ideas, and their use of resources, such as AiS mentors and the Internet.
   b) Teacher interviews. Interviews were carried out with all participating AiS teachers to construct a systematic view of teachers' perceptions of the challenges and benefits of participation in the AiS program.

3) Learning process data.
   Electronic journals were collected on a monthly basis, querying students on topics including project topic selection, experience with mentors, problems encountered, and the modification and refinement of project ideas and questions. This learning process data is closely related to the learning outcome data documented in the videotaped student presentations.

For the purposes of the analysis, the learning process data and the demographic data were analyzed to determine those variables that correlated significantly with student project presentation data. Contextual data was used as an interpretive framework to elaborate on the possible significance or meaning of those variables found to be significant, and to help identify those significant variables which might be confounded.

The report is organized into seven sections. The first three sections present findings from the demographic, contextual, and student learning data collected. Implications of findings are discussed in each section. The fourth section presents findings from the performance assessment of students project presentations. The fifth section presents those elements of the demographic and learning process data which significantly correlated with findings from student presentations. A sixth section presents conclusions, and a seventh presents recommendations based on the findings.

Demographic Data: *Student Demographics*

Method

The profile of gender, race, age and grade level for students enrolled in AiS classes was derived from class lists compiled by AiS teachers. Data about access to and experience with computers was acquired directly from students through e-mail queries. The data reflects, in total, 370 students from three states and eighteen schools.[3] 42.2% of the AiS students (156) were from New Mexico. Iowa and Tennessee reported almost identical numbers of students—110 (29.7%) and 104 (28.1%), respectively.

Results

Sex and race. The AiS student population during the 1993-94 school year was 64% male and 36% female (see Figure 1). In Iowa and New Mexico the ratios were similar (65% male/35% female in Iowa, 66% male/34% female in New Mexico), while the gap narrowed somewhat in Tennessee (58% male/42% female).

Comparison of this student gender data with national data suggests that the AiS program is on par with AP/Honors Physics and AP/Honors Chemistry courses which enroll an average of 38.1% and 40.9% females, respectively. However, AiS differs significantly from AP/Honors Biology courses, which enroll an average of 54.5% females (NCES, 1993b).

The ethnic distribution of the AiS students is represented in Figure 2. 64% of AiS students were Caucasian, 22% were Hispanic, and 9% were African-American. Asian students accounted for 3% of the population, and Native Americans for 2%. More than half (56.5%) of the participants of color were Hispanic students from New Mexico. In Iowa and Tennessee, Caucasian students accounted for 84.2% and 82.5% of the AiS student population, respectively. In New Mexico, Caucasians accounted for 39.7% of the AiS student population.

Comparison of this student race data with national data suggests that, with regard to African American and Hispanic students, AiS enrollments are fairly similar to those of AP/Honors science courses. AiS enrolls a somewhat higher percentage of Hispanic students than these courses, but fewer African-American students. AP/Honors Physics enrollments were 58% Asian, 20% Caucasian, 15% African-American, and 7% Hispanic. AP/Honors Chemistry enrollments were 44% Asian, 25% Caucasian, 12% African-American, and 11% Hispanic, and AP/Honors Biology enrollments were very similar, at 40%, 25%, 15%, and 11%, respectively. (National data uses an “other” category to reach 100% for enrollments and does not have data to match our data on Native American students.)

Grade level and age. More high school seniors were taking AiS classes than those in other grades; 36.2% of the group were twelfth graders. 31.8% were eleventh graders, and 22.6% were in the tenth grade. Thirty-one ninth graders involved in the program accounted for the remaining 9.4% of the group (see Figure 3).

The mean student age was 16.2 years. 16- and 17-year-olds accounted for 66.9% of this group (33.3% and 33.6%, respectively). 18.3% were fifteen years old. The youngest students were 14 years old and accounted for 6.6% of the group. 7.5% were 18 years old, and there were two 19-year-old students in the program (0.6%; see Figure 4).

New Mexico had more students in higher grades (mean grade level is 11.2), while in Iowa and Tennessee the mean grade level was 10.7 and 10.9, respectively. The mean student age was lowest in Tennessee (15.9 years), and almost identical in Iowa (16.2 years) and New Mexico (16.4 years).

Experience with and access to computers. Of the students who responded to questions about computer use (n=202), most (37.5%) had less than two years of experience with computers. 31.6% had over six years experience; this group included some students (9.6 %) who had ten or more years of experience with computers. 30.9% of AiS students had three to five years experience using computers. On the average, AiS students had been using computers for 3.5 years.

49.1% of students (n=203) reported that they had a computer at home. This is consistent with national data (Anderson, 1993) which indicate that 51% of high school juniors have access to a computer at home. 26.7% of AiS participants (n=205) indicated that they had a modem at home.[4]

Teacher Demographics

Method

A questionnaire distributed to teachers at the three fall workshops was designed to collect information on teaching experience, general teacher demographics, subject area specialty, grade levels taught, and experience with educational technology. The data reported here reflect responses from 34 teachers: 7 from Iowa, 16 from New Mexico, and 11 from Tennessee.

Results

Years teaching. The majority of teachers involved in the AiS program were highly experienced educators (see Figure 5). Over half (58.8%) had taught for more than twenty years, while only 23% of teachers nationwide have taught this long (NCES, 1992). Educators with between 1-9 years and 10-19 years of experience each accounted for 20.6% of the AiS teacher sample. Both of these figures are slightly lower than national averages in which 43% of teachers had taught for less than ten years and 34% had taught for 10-19 years (NCES, 1992).

The average years teaching was highest for Tennessee teachers, at 23 years. Teachers from Iowa and New Mexico had similar ranges of experience, with a mean of 17 years in Iowa and 16 in New Mexico.

Teacher age, sex and race. The AiS teachers were also older than the national average: 47 years old, versus a national average of 40.2 years. While most of these teachers were between 40 and 49 years old (43.3%), a third of them (33.3%) were over 50. 23.4% of AiS teachers were younger than 40 (see Figure 6). Consistent with their level of teaching experience, the Iowa and New Mexico teachers were younger than their Tennessee counterparts: 43 and 45 years old on average, compared to 47.

The distribution of male and female AiS teachers was somewhat different from the national distribution. The AiS group was 61.8% female/38.2% male, compared to 71% female/29% male nationally (see Figure 7). The ethnic distribution of teachers was also comparable to the national distribution: Caucasian teachers account for 84.8%, African-American for 9.1%, and Hispanic, 6.1% of the AiS group, while the national profile is 88.1% Caucasian, 7.3% African-American, and 2.6% Hispanic (see Figure 8).

Primary teaching assignment and grade levels. Almost half (44.1%) of these teachers described their primary teaching assignment as some form of mathematics. Over a third (38.2%) of them were science teachers, and 17.7% taught computer science or programming courses (see Figure 9). These disciplines were equally represented among the Iowa teachers. New Mexico was dominated by science teachers (50%), while the Tennessee teachers were mainly mathematics specialists (72.7%). All of the AiS teachers taught tenth, eleventh, and twelfth graders; most (73.5%) taught ninth grade as well, and 11.8% also taught eighth grade classes.

Experience with and access to technology. The AiS teachers reported an average of five years experience with educational technology. However, this average represented a group which was almost evenly divided between highly experienced and novice users of educational technology. A survey of teachers recommended as accomplished users of educational technology, carried out by the Center for Technology in Education (Sheingold & Hadley, 1990), suggested that approximately five to seven years of experience using educational technologies in the classroom was necessary in order for a teacher to consider her or himself an accomplished and comfortable user of technology. Among the AiS teachers, 17 of 34 had used technology for educational purposes for only one or two years. Only one teacher fell into a mid-range of three to four years of use. The remaining sixteen teachers had all used educational technology for more than five years, suggesting that they were highly experienced and knowledgeable users. Seven of these teachers reported eleven or more years experience (with a maximum of fourteen years), which placed them in a highly experienced and unusual group. (See Figure 10 for a summary of this data.)

The AiS teachers in Iowa were significantly more experienced technology users than the teachers from New Mexico and Tennessee. While each state included at least one teacher with more than ten years experience, the average in Iowa was 8 years, while it was 4 in New Mexico and 5 in Tennessee.

Home technology access. 61.7% of AiS teachers reported that they had a computer at home, and of this number twelve also had a modem at home. In both New Mexico and Tennessee, the majority of teachers had computers at home (68.8% and 63.6% respectively), while in Iowa only 42.8% (3 of 7) reported having computers at home. Additionally, none of the Iowa teachers reported having a modem at home, while 46.7% of New Mexico teachers and 50% of Tennessee teachers did possess a modem at home.

Teaching AiS alone or with a colleague. Nearly half (51.6%) of the AiS teachers reported that they taught AiS alone, and almost half (48.4%) reported that they taught the course with a colleague. Solo teaching was predominant in Iowa and New Mexico: 83.3% of Iowa teachers and 57.1% of New Mexico teachers reported that they taught the course alone. In Tennessee, only 27.3% reported teaching the course alone.

School Demographics

Method

Information on the technology background of the AiS schools and the demographic profiles of their teachers and student populations was collected from the principals of participating AiS schools during November, December, and January of 1993-1994. Further demographic data on eighteen AiS schools was collected from Quality Education Data, a research firm which collects a range of data on schools and school districts. School demographic data provided insight into the various contexts in which the AiS program was functioning. Data taken from administrator surveys represented reports from eighteen schools: five in Iowa, eight in New Mexico, and five in Tennessee.

Results

Size and location of schools. The mean number of students enrolled in AiS schools was 1031.3, representing a range from a minimum of 160 students, to a maximum of 2,165. A majority of AiS schools reported in the administrator surveys were in rural settings: seven (39%) were in rural (but not farming) communities and four (22%) were in farming communities; four (22%) were in small cities, and one (6%) was in a suburb. This distribution of schools was somewhat different from the national distribution, in which 55% of schools are rural, 18% are suburban, and 27% are urban (NCES, 1992).

Student demographics. These schools' populations included an average of 38.1% students of color, ranging from less than 1% to 95%. An average of 34% of the student population in AiS schools was living below the poverty line—as indicated by percent of students receiving subsidized lunches. This number ranged from a low of 3.6% to a high of 99.5% and was slightly higher than the national average (25.9%) of students living below the poverty line (see Figure 11). The mean percentage of college-bound students from these schools was 45%, ranging from a low of 20% to a high of 70% (see Figure 12).

Technology use in schools. The principals of AiS schools reported an average of 9.2 years of educational technology use in their schools, ranging from a low of two years to a high of 20. They reported that 34.2% of their staff used computers in their teaching; this proportion ranged from a low of 5% to a high of 95%.

Student/teacher ratios. Student/teacher ratios for high school students in AiS schools ranged from 9/1 to 28/1, with an average of 20/1.

Contextual Data: *Teacher Interviews*

On-line interviews with AiS teachers were conducted during January of 1994. The goal of these interviews was to collect a systematic overview of participating teachers' perceptions of the challenges and benefits of the AiS program.

Method

Our interview was based on a protocol developed by the OERI-funded Center for Technology in Education, which was used to investigate teachers' involvement with long-term, collaborative, technology-rich projects. Questions were refined to reflect the goals and objectives of the AiS program. Issues covered by the protocol included: how the AiS program is similar to or different from other teaching assignments; the challenges and benefits of working collaboratively with a partner teacher; and the roles teachers have assigned to mentors in relation to student projects.

Interviews were solicited from all participating AiS teachers, including teachers teaching a dedicated AiS class, teachers teaching only an AiS club (not a class), and teachers not directly responsible for AiS students. Teachers were given two weeks to respond to the initial interview request. Late responses were followed up with a series of e-mail reminders. 26 of 30 participating AiS teachers (87%) responded to the interview questions. Teachers' responses were analyzed descriptively by a team of three researchers. Answers to each question were grouped, and examined for common themes.

Results

Objectives in teaching AiS. Teachers identified a range of objectives for their students' participation in AiS. Their objectives fell into two groups: *educational* objectives, focused on strengthening students' cognitive or social capacities; and *life* goals, focused on expanding students' preparation for careers. Educational goals included helping students to complete substantial, long-term project work; to increase their technical competence; to work successfully in teams; to improve problem solving skills; to discover connections between mathematics, science, and social studies; and to discover the methods of inquiry associated with computational science. Life goals included building readiness for a changing workplace, helping students to prepare for college, and assisting them in overcoming a fear of technology.

Project selection. Four issues emerged from teachers' descriptions of how their students selected project topics. Some teachers structured students' selection of a topic—which sometimes involved providing students with a list of acceptable topics. Some encouraged or required students to come up with their topics independently. Some teachers encouraged students to go through a process of investigation that would culminate in selecting a project topic (such as brainstorming, preliminary research, interviewing experts, etc.). Finally, some teachers reported that project topics were determined in an isolated exercise or conversation.

The most frequently used technique was helping students narrow the universe of possibilities by providing them with a limited set of options for project topics, and then expecting them to select from those options based on preliminary research. Some teachers used a similar kind of preliminary research, but allowed students to pursue a topic of their own choosing. Fewer teachers described topic selection as an isolated exercise.

Role of mentors. Teachers identified a range of tasks as appropriate for mentors. These included helping students to understand the science and/or mathematics involved in students' projects; providing suggestions for enhancing student projects; "translating" technical material for students; providing content information for students; helping students to pare down, focus, or simplify their project; assisting in programming; acting as a technical advisor; assisting in project topic selection; making research facilities available to students; reviewing projects for accuracy, thoroughness, etc.; and supplying students with necessary algorithms for project work.

Three themes emerge from teachers' discussions of AiS mentor's tasks. First, the majority of teachers expect the mentor to *help students understand the content they have taken on in their project*. Second, mentors are depended on for *technical assistance*. In the same way that AiS teachers frequently articulated that they did not feel adequately equipped to teach students about the broad range of subject areas they are investigating, many do not consider themselves capable of guiding students through the design and implementation of a program or the use of a complex simulation program, and look to mentors to help students accomplish these aspects of their project work. Teachers vary widely in the *degree* to which they expect mentors to intervene in students' technical work; some teachers expect mentors to provide pre-written programs whenever possible, while others believe they should only review student-written code when asked to by students. Finally, teachers sometimes look to mentors for help in *structuring students' project work*.

Collaboration with other AiS teachers. Teachers reported three levels of interaction with their AiS partner teacher. Close to half reported that they met and talked regularly with their partner teacher (about AiS curriculum, the progress of AiS students or to generally provide support) or that they co-taught their course. Some described their work with their partner as providing some limited form of support or interaction, such as sharing equipment concerns, keeping each other informed of activities, and assisting or providing backup teaching when necessary. A smaller group reported that they did not collaborate at all with their partner teacher.

Becoming involved in AiS. Almost all AiS teachers reported that they were the initiators of their school's involvement in the AiS program. A few reported being recruited by a principal interested in the program, or being "roped in" by a colleague.

Most exciting aspects of AiS. The access to technologies provided by the AiS program was overwhelmingly prominent in teachers' reports of exciting aspects of AiS. Almost all mentioned "access to new technology" or "Internet access" as one of the most exciting parts of the program. Factors related to student accomplishment or inspiration were also cited frequently, and included student excitement and project-based learning. Other factors were cited that related to increased professional competency or improved professional conditions: these included training opportunities, access to authentic resources, collegiality, newly acquired expert status, and teacher ownership of the program within their school.

Major obstacles encountered. Time constraints dominated teachers' reports of the obstacles that made achieving their goals for their AiS programs difficult. This is consistent with findings from other studies of technology-rich school innovations (Hadley & Sheingold, 1993; Honey & Henriquez, 1993). Teachers specifically noted the lack of time available for the extensive preparation that was often necessary for the class, and the lack of class time for students to complete their independent work.

The inadequate amount of hardware available for student and teacher use was also prominent in teachers' responses, and is also consistent with findings from studies of similar initiatives. Teachers also noted their own limited knowledge of and experience with the content and skills involved, and difficulties in finding enough effective mentors.

How AiS differs from other classes taught. Teachers raised a wide range of issues when describing how AiS is different from other courses they teach. This suggests that this program offers an experience for both teachers and students which is significantly different from their other experiences in mathematics and science education. Differences fell into three categories: pedagogical differences, changes in teachers' perception of their priorities and their role in the classroom, and logistical differences. Pedagogical differences included the expectation that AiS students will work independently; that they will work in multiple content areas; that their work is project based; that they work in teams; that they work with freedom and flexibility; and that hands-on learning and real-world problems are stressed. Differences in their role as teachers in the classroom included prioritizing process over content; acting more as a coach than a lecturer; and the challenges of keeping students on task. Logistical differences included the need for extra planning time, and the necessity of working every day with limited resources (i.e., too few computers).

Discussion

The ways these teachers described AiS as differing from their other teaching experiences, the difficulties they ascribe to the program, and their objectives for their students involved in AiS, all point to characteristics of the AiS program which are typical of a successful, but challenging, technology-rich school innovation. The overlapping issues raised in response to each of these topics - such as increased demands for time, increased student independence, and an increased need for extensive and authentic resources - suggests that there are ways in which this program is both exciting and difficult for teachers. AiS encourages teachers to set high goals for themselves and for their students, but there are particular hurdles that often become problematic when teachers begin to focus on achieving these new, higher goals and expectations. These challenges, which are often not easily solved by the individual teacher, require school- or district-wide restructuring (such as changing the length of class periods), and can make the process of achieving the AiS goals difficult for even the most enthusiastic teacher.

Looking across these categories, these differences describe an overall balance—or tension—which teachers seem to experience in relation to this program that makes it distinct from their other teaching experiences. Teachers report an overall sense of *willingness to engage in innovative educational practices*. They are aware of a fundamental openness in the design of AiS which is new and exciting for them—students are given freedom and flexibility, process is prioritized over content, students are working independently, and often using a single class period to engage in a range of activities. Concurrently, the program requires a *high level of maintenance and care*—supporting this flexible, independent group of students does not lessen the load on the teacher, but requires more planning time, creates an increased need for resources, makes it difficult to monitor student progress, and makes outside support, from mentors or program staff, increasingly important. This interplay of increased student independence and increased demands on teachers is a typical consequence of introducing substantive and innovative curricula. The interplay of enthusiasm and the need for additional support is a complex one for teachers, and goes hand in hand with educational innovation.

School Site Visits

Site visits were made in fall 1993 and spring 1994 by two members of the research team. The purpose of the site visits was to examine the particular ways that the AiS curriculum was being implemented in different school contexts, to find out what program issues were of primary concern to teachers, and to collect background information on students' project work. Establishing an understanding of the prominent ways in which school contexts, teacher experiences, and student experiences are similar or different among school sites makes it possible to predict and interpret variables which may later prove to be important in indicating student success in the program.

Method

The same pair of researchers conducted all site visits. They maintained a consistent pattern of interaction in classrooms, and shared a checklist of important topics to investigate in the course of the site visits. Extensive field notes were recorded after the visits, and were shared with all research team members. Fifteen of the nineteen schools included in this evaluation were visited at least once; thirteen schools were visited twice. Visits to AiS classrooms occurred on two occasions, midway during the first semester and midway during the second semester (3-4 weeks prior to state Expos at which students were to present their projects).

Results

The following summaries represent an overview of the topics that were most prominent in discussions with, and observations of, students and teachers during site visits.

Students. During site visits, students were observed interacting in project groups and were interviewed informally about their experiences in the AiS program. Conversations with student project groups focused on what they did in their AiS classes, how they proceeded in developing their projects and programs, how they selected and worked with mentors, how they used the Internet, and how they worked together in groups.

In the fall semester, AiS students were predominantly occupied with learning FORTRAN and project support applications such as SpyGlass, e-mail, and Gopher. Though they had identified preliminary project topics, many students had not yet begun to make systematic inquiries into these topics. Most had not defined key research questions. Instead, they expressed interest in broadly defined subjects and collected general data that they hoped would prove helpful as they developed their topics.

In general, students were excited and optimistic about the resources they perceived to exist on the Internet. Several students indicated that they felt Internet access was one of the most attractive features of the AiS program.

In the spring semester, students were evenly divided between those who had been doing content research for several months and were now trying to synthesize their knowledge into a final project and program and those who were still struggling to nail down their project topics. In both of these groups, students expressed concern about generating FORTRAN programs that would perform meaningful functions in their projects. However, students who appeared to be further along in their project work were able to visualize how their projects and programs might look when completed. In contrast, many of the more discouraged students mentioned that they had problems in obtaining relevant information and appropriate algorithms or in locating mentors. Though students continued to use the Internet, namely e-mail and chat, they expressed less exuberance about the resources that it offered them.

Several themes emerged from classroom observations and ongoing discussions with AiS students. These themes are described below.

- <u>Project development</u>. Many AiS students appeared to have difficulty integrating their first semester experience of learning FORTRAN and other applications with their second semester goal of completing a computational project. Some of these students were unsure about what they wanted their programs to accomplish and could not communicate what they expected their output to be. Others were unclear about how to write a program that would do what they wanted it to. Still others were uncertain about how they might visualize their data; they appeared to have forgotten about the auxiliary applications (such as SpyGlass) they had learned during the first semester.

  Some students, however, exhibited great facility with project work. In general, these students had defined concise project questions by the end of the first semester. During the second semester, they continued to explore their topics in a very methodical manner. They were able to integrate programming and content aspects of their projects because they appeared to have thought about what the program would contribute when they were defining project questions. These students made very deliberate decisions about aspects of their projects and were able to explain these choices. For instance, one student had planned to explore the effects of altitude, soil type, rainfall and location on the yields of various crops in her state. During the second semester, she decided to limit her study to corn crops. She explained that she had made this decision because of the availability and reliability of certain types of data.

- <u>Role of mentors in project development</u>. AiS students employed a variety of strategies to locate mentors. Their approaches ranged from relying upon their teacher to secure a mentor for them to posting requests for mentors on Internet BBSs, from targeting professors listed in university telephone and e-mail directories to asking for assistance from relatives and family friends. The tenacity with which students pursued the task of finding a mentor suggested that it was something they deemed very important.

  Students also interacted with their mentors in a variety of ways. For many of the students, mentors served only as programming experts. They provided source code for students to deconstruct and modify or they helped to debug student programs. For other AiS participants, mentors were content experts. These students looked to their mentors for pertinent literature and for algorithms that would enable them to develop a program on their topic.

The students who reported satisfying experiences with their mentors tended to interact in the following ways: (1) They used their mentors to obtain very specific pieces of information such as emergency room admittances over a certain period of time, or monthly dissolved oxygen concentrations for a specific stream; (2) They communicated with their mentors at least twice a month, during which time they discussed the progress they had made on their projects. Their mentors *asked them* questions, thereby helping them to clarify their project objectives as well as their understanding of the data.

Students also encountered difficulties, particularly when mentors were not able to anticipate their level of comprehension and background knowledge in relation to the relevant topic area. In one instance, a student received over 90 pages of text, including journal articles and textbook chapters, from her mentor. The documents contained many complicated formulas, and the student lamented that she could understand nothing beyond the introductory pages.

Conversations with two class mentors[5]—one a scientist from the DOE, the other a local robotics engineer—revealed insights that were consistent with this latter style of interaction. These two scientists commented that the students with whom they worked needed the most assistance in paring down their broad project topics and framing them as research questions that could be analyzed through computational methods.

- Telecommunications. As mentioned previously, AiS students were extremely eager to explore communications and research aspects of the Internet. During the first semester, they exchanged e-mail vigorously—most often with other AiS students from their state but occasionally with peers they had met on the Internet or with mentors. The students were also enthusiastic about synchronous chatting on the Internet, and in some cases, measures had to be taken to curtail their use of this feature.

Though e-mail and chat were by far the most common usages of telecommunications among AiS classes, students also made use of online information resources. Among the most frequented spots on the Internet were two BBSs (nebbs and Newton) and various university libraries accessible through telnet. Although most students were unaware of Usenet newsgroups (potentially, a great resource), a few of the students subscribed to groups about programming.

AiS students reported varying degrees of facility with Internet navigation tools. Many of the students noted that they were not familiar with Gopher, whereas others made substantial use of Veronica, Archie, and MOSAIC. Similarly, students indicated a range of experiences in locating relevant information on the Internet. For example, one student who was investigating the effects of stock market fluctuations on political events in the US. was able to retrieve closing stock market prices for every week of the last 50 years. In contrast, a group of students researching black holes expressed great frustration at being unable to find information on the Internet that they could understand or use. Students and their teachers remarked that locating valuable resources on the Internet was often a “hit-or-miss” situation.

- Group work. AiS project groups were formed in a number of ways. In some cases, students formed their own groups based on friendship circles or common research interests. In other cases, teachers put the students into groups, according to academic strengths or experience with computers. In two of the AiS classes, students were encouraged to work by themselves on projects.

  Within these groups, students interacted in a variety of ways. In some instances, one student dominated the group while other members performed ancillary tasks such as typing the report or designing the board for final presentation. Another common scenario was one in which students divided their project tasks into content and programming components, and members opted to work on one or the other task. The interactions that appeared most successful occurred when students divided the project work into tasks, assigned each member a particular section, and conferred regularly about whole project decisions. In such cases, the entire group was involved in making decisions about content, programming, and presentation.

Teachers. In the twelve classrooms observed in the fall, teachers were uniformly focused on teaching their students programming (most were learning FORTRAN, although some classes were learning C++ instead). A uniform method of teaching this material was observed in most classrooms. In these classes, the teacher handed out a worksheet with a brief program written on it. Students were to type the program into their computers, attempt to run it, and debug it as necessary. Students spent the period typing, asking questions about running the program, and asking each other and their teacher for help with the debugging process. In all cases observed, this activity was not related to any content area directly relevant to students' work.

In the fifteen classrooms observed in the spring, students were engaged in project work. In contrast to the uniform activities that characterized class time during fall observations, students in all classes observed spent their AiS class time pursuing diverse activities. The teacher played a coaching role at this point in the year, intervening in student work to monitor progress, answer questions, or help develop strategy. The level of teacher intervention ranged from substantial - the teacher spent the entire period moving from one group to another and was engaged with students for the entire period - to minimal - the teacher gave the students a brief directive at the beginning of the period and did not intervene further except when specifically queried by students.

Conversations with teachers included discussions of a wide range of aspects of the AiS program and its particular implementation in their school. However, there was a set of specific themes which were consistently raised by teachers across a variety of school contexts. These common themes are described below.

- Role of mentors. Teachers used a wide range of strategies to find mentors. Their judgment regarding the success of their students' mentoring relationships varied widely. Almost all teachers were interested in expanding the role of mentors in the AiS program. This was related to factors including: their own lack of knowledge in the range of content areas their students pursued; their need for support in teaching FORTRAN; their sense of professional isolation; and their belief that mentoring was a valuable experience for their students. Teachers were interested in creating more uniform pathways for findings mentors, and developing a training program for mentors so that they would come to the experience understanding the program and anticipating what would be expected of them.

- Relationship between project topics and programming. Many teachers expressed concern over whether their students' work had "enough" programming in it. Many also spent a great deal of energy diverting students from their original topic ideas to ideas that would be "easier to use programming with." Many teachers expressed a conflict between wanting to give students predetermined project topics which they knew they would be able to help students relate to programming, but also valuing students selecting project topics on their own. Some teachers noted that resolving this conflict would require increased programming skills on their own part (so that they could better understand possible applications and focus their students' programming skills accordingly), greater knowledge of the content areas their students were working with, and increased comfort with student-driven project work.

- Utilization of computer resources. Among those teachers with large classes and limited computer resources, there was a general feeling that their ability to teach programming and to support students in computer-based research and analysis was severely restricted by the realities of limited computers and limited class time. Teachers consistently reported coming to school early, staying late, and coming in on weekends to allow students to continue their work.

- Curiosity about other AiS classes. Teachers consistently asked how their class compared with other AiS classes. Most often they were concerned that other teachers' students were working on far more complex projects than their own students were doing. This concern was closely related to the concern about project topics and programming - teachers felt a basic uncertainty about what their students could realistically do that would constitute an appropriate computational science project.

- Student assessment. Several teachers discussed their concerns about how to appropriately assess their students after they had spent a semester or a year working almost entirely on unique projects, and working in groups. A number of teachers had begun incorporating self-assessments, and group assessments, into their evaluations. Teachers expressed a concern that standard letter grades were inappropriate indicators of the kind of work their students had done during the school year. They were also concerned that, as they would inevitably have to assign some sort of grade, they would have to do so based on little or no traditional evidence such as quiz scores, homework grades, etc. This concern was voiced as a criticism of their schools' grading policies, not as a criticism of the structure of the AiS program.

Learning Process Data

Because AiS students are spending an entire school year developing and revising complex research questions, an important component of the evaluation is understanding the development of their thinking over time. A list of journal questions was developed in collaboration with the project coordinators in September. These questions were intended to collect both specific pieces of information - such as students' project topics and whether or not they are working with a mentor - and to probe students' evolving understanding of the content areas involved in their projects and the process of developing and investigating an in-depth research project.

Method

Journal questions were distributed to teachers at the three fall workshops, and teachers were told that students would need to write responses to the questions once a month and send these responses to the evaluation team via electronic mail or postal mail (in cases where schools were not yet connected to the Internet). The teachers were encouraged to integrate the journal questions into their students' AiS experience in whatever way they thought most useful.

Structure of journal questions. Each month's journal questions were intended to solicit student comments about certain experiences and issues that might arise during work on AiS projects. Seven sets of these data were analyzed; December and May journals were omitted due to low response rates. See Table 1 for a schematic of the general structure of the journal sets.

Table 1

MONTH	ISSUE	SAMPLE QUESTIONS
September	Motivations for enrolling in AiS course; expectations for the course	Why did you decide to take this class? What do you expect it will be about?
October	Preliminary Project Topics	Tell us about your project topic.
November	Computer Integration early in project evolution	What computer resources are you using? How do you think using the computer will help you to answer your questions?
December[6]	Mentoring	Do you have a mentor for your project? How do you expect that he/she could help you?
January	Role of Programming in Project	Explain how you think your programming skills are going to help you to answer your project questions. How does programming fit into your project?
February	Project Questions	When you think about your project, what questions are your most curious to find the answers to?
March	Major difficulties and strategies for solving	Tell us what's most difficult about your project. What will you do figure it out?
April	Project Evolution and Changes	What about your project has changed since January? What caused you to make the changes you have made?
May	Self-evaluation	What would you have done differently in your project if you could go back and change it?

Response rates. Excluding data from December and May, monthly response rates to journal questions ranged from 42% to 70%, with an average response rate of 59%. On average, journal data represented slightly less than two-thirds of all AiS students. These figures are based on an enrollment of 370 students for the first semester and an enrollment of 334 students for the second semester.

Results: First semester.

Journal questions for the months of September through December investigated the factors that drew students into the AiS program and the early experiences that they had in the program. Students were asked what made them decide to take an AiS class and what they expected the class to be about. They were urged to articulate their early project interests and to describe how they were using computers in their classes and in their project work. Finally, they were questioned about their experiences with mentors—whether they had mentors, what they expected of their mentors, and how they worked with their mentors.

Student motivations and expectations. (n=259) In September, students responded to questions about why they enrolled in AiS and what they expected the course to be about. Motivation was coded as intrinsic or extrinsic, and one journal entry could describe both extrinsic and intrinsic motivations. Intrinsic motivations included: desire for personal enrichment; desire for social interaction (via telecommunications); enjoyment working with the technology; and the desire to invest in the future (most often this meant being prepared to join the workforce by having a working knowledge of computers). Extrinsic motivations—outside influences that drew the student into AiS—included events such as a guidance counselor or teacher recommending the course, having been in the club last year, or needing a course that would fit a particular slot in their schedule.

Expectations were broken down into the six aspects of AiS most often mentioned by students: working with computers; programming and working with specific types of applications (e.g., visualization tools); telecommunicating; doing research; and learning content relevant to other disciplines (e.g., physics). Multiple codes could be assigned to journal entries on each of these dimensions.

Students pointed to a number of factors that contributed to their decision to enroll in an AiS course. While it was common for students to have multiple motivations (both intrinsic and extrinsic) for taking the course, they described intrinsic motivations for taking the class nearly three times more frequently than extrinsic motivations. Three of the intrinsic motivations—personal enrichment (42%), enjoyment of the technology (36%), and investing in the future (43%)—were each mentioned by over a third of the AiS students. Investment in the future was the most commonly mentioned motivation of all, suggesting that students enter the course with a distinct expectation that "technology is important to the future." Many students wrote about the importance of learning about technology now, because it is becoming so important in the world.

Fourteen percent (14%) of AiS students indicated that they were drawn to the course by the prospect of meeting people and making new friends using telecommunications tools. Close to a third of all students (39%) also reported some form of extrinsic motivation for taking the course (see Figure 13).

Working with computers (53%) and learning programming or specific software packages (51%) were mentioned most often as expectations students had of what they would be doing in AiS. Other aspects of the program, such as telecommunicating (19%), learning other subject matter (15%), and carrying out research (12%) were mentioned as well, but less often (see Figure 14).

Preliminary project topics. (n=247) In October, students were asked to describe their preliminary project interests. Project topics were first coded by discipline and were later grouped into more comprehensive categories. For instance, Theoretical Science included topics related to physics, mathematics, and astronomy; Applied Science-Physical included engineering, earth science, and chemistry projects; Applied Science-Biosocial included projects with a content focus on biomedicine, ecology, agriculture, or social sciences; and Computer Science included projects primarily concerned with computer applications or architecture.

Ninety-nine percent (99%) of students reported having some kind of project topic in October. These preliminary projects represented a range of topical interests. Theoretical science (47%) dominated student interest at this time. It was followed in popularity by Applied Science-Biosocial (30%) and by Applied Science-Physical (18%). Only 5% of AiS students reported interest in computer science project topics (see Figure 15).

Computer integration early in project development. (n=246) In November, students answered questions about how they were using computers in the AiS program. Their responses were coded for five uses: learning about computers, communication, computation, data collection and research, and unclear.

Nearly half of AiS students (40%) reported that they used computers to do research and data collection. A substantial number (36%) noted that they were also using computers to perform computational functions. Fifteen percent (15%) of students did not know or were unclear about how they used computers in November; 11% were using computers to communicate or to make charts and graphs; and 5% reported that they used computers to learn more about hardware and software (see Figure 16).

Results: Second semester

Journal questions for the months of January through May probed the *processes* of project development. Students were asked to comment on the role of programming and computing in their project advancement. They were asked what questions were raised by their project work and what they thought the answers to these questions might be. They were encouraged to describe problems and difficulties they encountered as well as to articulate their strategies for solving these problems. Finally, they were queried about how their projects had changed over time, how they felt about these changes, and what they would do differently if given the opportunity to start again.

Role of programming in project development. (n=191) In January, students were asked about how they were using programming in developing their projects. Their responses were coded as being either unclear or explicit. Unclear responses included categorical statements such as "I don't know how programming will fit into our project. I don't know that it will" as well as ambiguous statements such as "Programming fits into my project cause we are always writing programs for our projects." Students who articulated an explicit role of programming in their projects offered statements such as: "Programming will allow me to read in several hundred or thousand values and do repetitive computations." and "The programming will allow me to test my project where I couldn't test it anywhere else."

At the beginning of the second semester, nearly two-thirds of AiS students (61%) were unclear about the role of programming in their projects; 39% of AiS students were able to communicate an explicit role of programming in their projects (see Figure 17).

Types of questions that emerge during student project work. (n=205) In February, AiS students were queried about the kinds of questions they had about their projects. They were encouraged to be specific and to speculate on possible answers to their questions. The questions they reported were grouped into three categories—content questions, logistical questions, or programming questions. See Table 2 for examples of student project questions that fall into these categories.

A majority of students (62%) indicated that they had questions about the content of their projects. Twenty-four percent (24%) articulated logistical questions, 8% of AiS students mentioned questions about programming, and 6% said they had no questions at all. It was not common for students to name more than one type of question in their journal responses. Over 99% of the students had only one type of project question early in the second semester.

Table 2

QUESTION TYPE	**EXAMPLE**
Logistical/ work management	• Will I be able to solve what I set out to accomplish? • I'm most curious about finding out how I'm going to set the project up. • The questions that I am most curious about is how are we going to finish this project thoroughly enough to make sense to someone who has no idea of what we were trying to prove. • I am most curious as to how far we will get on our program before it is due.
Programming	• When we think about our project, we are curious to know how to set up a program. • I am most curious to find out how to enter a fortran code that allows me to compute the movement of the robotic arm used in my project. • I think the most important question is how am I going to make a Punnett Square in fortran and have the square show up on the screen.
Content-Oriented	• How tsunamis form and how fast they move. • How does different types of soils affects the growth of tobacco plants? • How can you improve the structural buildings for earthquakes? How much would it cost to build more earthquake proof buildings in the most affected areas? • When I think about my project, I am most curious to find out how earth might be if there was no sun. And, if we could adapt and use alternative forms of energy. • Most of the questions that I have right now involve determining what the data that I am getting represents.

Project difficulties and strategies for overcoming them. (n=165) In March, AiS students submitted journal entries about the types of problems and difficulties they were encountering in their project work and about their strategies for overcoming these obstacles. Project difficulties occurred in the several areas: programming; understanding the project topic; finding information; project mechanics (such as concerns about logistics and presentation); and computational aspects of the project (such as finding, understanding, or applying appropriate algorithms). Strategies for dealing with these difficulties included talking with an adult or group member (consultation), forging ahead by trial and error, or performing further research on the problem.

Midway through the second semester, nearly half of AiS students (45%) reported having difficulties with programming. Thirty-eight percent (38%) had problems with computational aspects of their projects, 33% had trouble developing an understanding of their topics, and 24% had difficulties finding information about their project topics. Less than a fifth of the AiS students (19%) reported problems with project logistics , and only 2% were unclear about the types of difficulties they encountered (see Figure 18).

Students expressed a variety of strategies for dealing with project difficulties. The most common strategy reported (55%) was further investigation. Journal entries coded in this category included statements such as: “I will study it until I do understand;” “In order to figure it out, we will try to do as much research as we can;” and “[I will] Read thru [sic] the documentation included with the program.” A substantial number of students (44%) also reported that they would consult with adults or group members to solve their project problems. Seventeen percent (17%) of students indicated that they would use a “trial and error approach” to solve their problems, and 7% did not indicate any methods for overcoming project obstacles (see Figure 19).

Project changes. (n=136) In April, prior to presenting their projects at state Expos, AiS students responded to questions about how their projects had changed since January. Their responses clustered around five themes: no changes; positive progress; changes or improvements in their programs; more focused project topics; and radical changes. Radical changes included switching to a different project topic, altering group composition, or changing key questions within the same project topic.

Most AiS students (86%) reported that their projects had changed in some way since January. Nearly a third (32%) of AiS students noted that they had narrowed their project topics (scaled down the project or focused it), and another third (33%) indicated that they had made “radical” changes in their projects since January. Eighteen percent (18%) of the students indicated that they had made positive progress on their projects, and 23% reported changes or improvements in their FORTRAN code. It was possible for students to report more than one kind of change in their projects (see figure 20).

Consistent with data about “radical” changes in student projects, data from the videotaped sample of AiS students suggested that the greatest shift of project topics from October to May occurred in the area of theoretical science. Among the students that were videotaped, theoretical science topics shifted down from 48% of projects in October to 35% in May. This drop was largely due to topical shifts away from astronomy (from 31 projects in October to 13 projects in May) and mathematics (from 13 projects in October to 7 projects in May). The greatest upward shift for the students who completed projects and were videotaped occurred in the arena of computer science, from 5% of projects in October to 12% in May (see Figure 21).

Discussion

A composite portrait of student experience in the AiS program emerges from this data. A majority of AiS students entered the program for intrinsic reasons, most notably because they felt that it would better prepare them for the future, a future in which technological competence was perceived to be essential. Students expected the AiS course to be about computers and programming, and they reported (late in the first semester) that they were using computers to perform computational tasks as well to collect data and do research.

At the beginning of their second semester in the program (in January), a majority of AiS students (61%) were not clear about how programming fit into their projects. In February, when students reported the questions they had about their projects, only 8% indicated that they had questions about programming. Most students' questions indicated that they were still focussed on content issues (62% reported that they had questions about the content of their projects at this time) and had not yet begun serious work on their FORTRAN programs. By March, however, a substantial number of students (45%) were focussed enough on programming to report that they were experiencing difficulties in writing and developing their FORTRAN programs.

By the end of the school year, most AiS students had changed their original projects at least to some degree. A substantial number of students (32%) reported that they had narrowed the focus their projects since January; another third (33%) indicated that they had "radically" changed their projects. In terms of radical shifts in project topic, a number of AiS students (13%) of the videotaped sample moved away from topics in theoretical science (particularly topics in astronomy and mathematics); an additional seven percent (7%) opted to pursue topics in computer science. It may be that students move away from theoretical science topics in the second semester because they have pursued unreasonably large projects that exceed their knowledge in these areas. It may also be that students gravitate towards computer science projects at the end of the year because they have found the most information and support in this area.

Taken together, these data suggest that defining research problems that can be readily explored through computational methods is one of the most challenging aspects of the AiS program for students. This challenge is particularly evident in student reports of the questions they had and the difficulties they faced during project development. Additionally, a considerable number of students reported making radical changes to their projects as late as April, which suggests that defining a workable topic was a substantial hurdle to overcome.

Student Project Presentations

Method

The centerpiece of the AiS evaluation focuses on student learning as evidenced in videotaped performances of students' final project presentations. A subset of students were required to present their final AiS projects to an audience of Department of Energy program staff, state site coordinators, and their teachers. Videotapes were scored on criteria developed at the Center for Children and Technology through an NSF-funded research project on the use of video as a tool for documenting students' performance-based assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Frederiksen & Collins, 1989; Hawkins, Bennett, & Collins, unpublished).

Two criteria were used to select the schools where videotaping was carried out: i. evaluation staff had conducted school site-visits; ii. the school had a dedicated AiS class (not a club or after-school enrichment program). Videotaping was carried out at twelve schools, and a total of 79 videotapes were made. A subset of 65 projects, out of a total of 180, were selected for analysis.[7]

The final subset of students whose presentations were analyzed included 137 students, from twelve classes in nine schools. Demographically, the subset compared favorably to the full pool of students included in the evaluation. This subset comprised

37% of the full pool of students, and was 62% male and 38% female. The racial distribution was also similar to the distribution of the full pool; the subset was 74.3% Caucasian, 11.9% Hispanic, 8.3% African American, 4.6% Asian, and less than 1% Native American (N=109).

Learning process data for the subset was generally consistent with the responses of the full sample. There were a few notable distinctions. In response to questions about how they were using computers in their projects (November), students in the subset were somewhat more likely to give specific explanations. They reported that they were using the computer for computational functions and for data collection more often than the full sample did (42.3% compared to 36.4%, and 46.4% compared to 40.1%, respectively). The full sample was more likely to be unclear in their expectations (19.3% compared to 12.4% of the subset). In response to questions about how students thought programming was going to fit into their project (January), students who were able to give an explicit explanation were over-represented in the subset (38.7% of the full population had this response compared to 47% of the subset). In turn, while 61.3% of the full sample was unclear about this issue, only 53% of the subset was unclear. In response to questions about what changes they had made in the project over the last three months (April), students in the subset were proportionally more likely to report that they had narrowed their topic (39.1% compared to 32.4% of the full sample) or altered their equations or code (28.1% compared to 22.8% of the full sample), and less likely to report that there had been no changes (9.4% compared to 14% of the full sample) or that they had generally made progress in a positive direction (14.1% compared to 18.4% of the full sample).

Procedures for Data Collection

To make the videotaping of students' project presentations an authentic and meaningful record of student learning two important steps were taken: i. students and teachers were informed about what would be expected of them; ii. questioners and videographers were trained.

Preparing students and teachers for the videotaped presentations. Preparation for the videotaping of students' projects began during the fall workshops, when the videotape-based assessment method was introduced to all AiS teachers.[8] During each state's workshop, staff from the Center for Children and Technology of Education Development Center (CCT of EDC) discussed the goals and objectives of the evaluation, introduced teachers to performance-based assessment techniques, and reviewed the criteria that would be used to evaluate student performances. Teachers were given a copy of the assessment criteria.

By mid-February the schools where the videotaping would take place had been identified and teachers and students at those sites were prepared in more detail. Teachers at these schools were contacted by e-mail, and notified that videotaping would take place in their classrooms. The goals of this process were reviewed, and the format for the videotaping was outlined. A list of questions that students were expected to address in their presentations was also distributed. Teachers were encouraged to share the list with their students, and to help their students prepare for their presentations through rehearsals, mock videotaping, or discussions.

Training questioners and videographers. On March 1, representatives from each state who were participating in the videotaping process attended a training workshop at EDC offices in New York. The purpose of the workshop was to communicate a consistent structure to all participants which would make it possible for the videotaped performances to be consistent technically, structurally, and in content. Drawing on other research with videotaped assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Rochelle & Frederiksen, 1992), technical procedures, questioning strategies, and expected content of student presentations were reviewed. Questioners and videographers were provided with materials to support them in the taping process.

All taping and questioning was conducted by staff of the three Department of Energy laboratories. Finished tapes were sent to EDC offices.

Procedures for Analysis

Selecting and training coders. Performance-based assessments that are designed to authentically reflect the goals and objectives of a program require that judgments of students' performances be made by those who are most familiar with the program (McDaid & Davis, 1991; Rudner, 1992). In school-based projects those individuals are almost always teachers currently using the relevant curriculum. In accordance with this process, a decision was made to use AiS teachers to score students' project presentations.

Scorers were solicited from each state via e-mail sent by the state coordinators. Interested candidates were asked to notify EDC staff and to briefly describe their experience in the AiS program. Six scorers were selected out of approximately twelve applicants. Scorers were chosen based on geographic distribution (all three states needed to be represented by the coders); whether the applicant had primary responsibility for teaching an AiS class; and recommendations provided by state coordinators.

Scorers participated in an intensive three-day training workshop at the EDC offices on June 25-27, 1994. Training focused on hands-on experience in using the coding scheme, and on discussion of teachers' developing understanding of the goals and structure of the coding scheme. Teachers worked in pairs, viewing tapes, discussing their responses to them, and determining together how to code them appropriately. Group discussions after each coding session focused on proper coding techniques, and the importance of citing concrete evidence for judgments. Group consensus was reached on codes for each of the tapes used in training.

Criteria for coding. The coding scheme is based on criteria developed for videotaped, performance-based assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Frederiksen & Collins, 1989; Hawkins, Bennett, & Collins, unpublished manuscript) developed at CCT. Over a period of several years CCT researchers have worked in collaboration with teams of teachers to develop and refine criteria that reflect students' capacities to understand content, think critically and analytically about it, communicate it well to others, and work collaboratively with their peers.

Based on our knowledge of the AiS program, and preliminary viewings of a sample of project tapes, this scheme was modified to reflect the aspects of student work most relevant to the goals of the AiS program. The scoring criteria were pilot-tested with researchers at the Center and the scheme was revised.

The coding scheme includes five dimensions, each of which are coded on a scale of 1 to 5, with 1 representing poor work and 5 representing outstanding work. The five dimensions are:

- Understanding: to what extent do students demonstrate knowledge of their area of inquiry?

- Critical thinking: To what extent are students able to be reflective about the challenges and problems they encountered in their project and the larger implications of their work?

- Clarity and coherence of presentation: To what extent are students able to effectively communicate their ideas to others?

- Teamwork: To what extent do the students work collaboratively on substantive aspects of the project?

- Technical competence: To what extent are students able to apply programming skills to analyze or investigate their area of interest?

Procedures for coding. An identical coding scheme was used by all coders, for all project tapes (with the exception of teamwork codes, which were not applied to individual projects). Codes assigned to project groups were assigned to all individual students in that project group. All tapes were coded by two independent coders. Tapes were assigned to coders randomly.

One point discrepancies were resolved by averaging the codes (i.e., a score of 4 and a score of 5 became a 4.5), and 2 and 3 point discrepancies (i.e. scores of 2 and 4 or 2 and 5) were resolved by researchers, who examined coders' evidence statements, re-viewed the project tape in question, and arbitrated a resolution (Frederiksen, 1994a).

Reliability. The overall reliability of the scores was 80%. This was calculated based on the number of pairs of scores, out of a total 670 pairs,[9] that matched, or were off by one degree. Of the remaining pairs of scores, 19% were off by two degrees, and 1% were off by three. Relative to other research projects using similar assessment techniques, these scorers achieved a high level of reliability (Frederiksen, 1994a).

Results

Students' scores on their videotaped performances were subjected to a cluster analysis. The goal of this analysis was to determine how students' scores could be grouped into clusters which would describe different types of performances, and then to determine what factors from the demographic and process learning data were significantly related to the distinctions among clusters of student performances.

Cluster analysis resulted in a three-cluster distribution of the 137 students. Clusters were defined by determining those groupings which had maximally distinct means across the five dimensions of scoring. See Table 3 for an overview of cluster means.

Table 3

	Understand	Crit Think	Clarity	Teamwork	Technical
Integrated knowledge (N=70)	4.62	4.21	4.04	4.30	4.23
Procedural knowledge (N=47)	3.24	3.35	3.39	3.52	2.76
Fragmented knowledge (N=20)	2.18	2.88	2.45	2.72	1.30

51% of the sample fell into the *Integrated Knowledge* cluster. Their scores reflected high marks across the five dimensions, and they scored particularly well in understanding. 34% of the sample fell into the *Procedural Knowledge* cluster. Their scores across the five dimensions ranged from a 3.52 on teamwork to a 2.76 on technical ability. 15% of the sample was in the *Fragmented Knowledge* cluster. Their scores were below average across the dimensions, and were particularly low in technical (1.30) and understanding (2.18).

Discussion

Mean scores across the five scoring dimensions produced distinctive profiles for each of the three clusters (see Figure 22). The following descriptions elaborate on the types of performances that corresponded to these mean scores.

Integrated knowledge. 51% of students fell into this cluster (N=70). The *Integrated Knowledge* cluster was relatively consistent in their scores across four of the five dimensions. Mean scores for critical thinking, clarity, teamwork, and technical were all within a 0.26 range (a low of 4.04 on clarity, and a high of 4.30 on teamwork). Their mean understanding score was distinctly higher, at 4.62.

These mean scores reflect students' success at applying computational techniques to a well-defined set of questions. These students were generally highly knowledgeable about the content area they worked with, and had a coherent understanding of the structure and function of the algorithm they used in their inquiry. For example, a project included in this group might be an investigation of reforestation, in which a student proposed to model the resurgence of plant life in an area cleared by fire. The student developed a program which created a series of elements representing rocks, water, and indigenous grasses and trees. The student carried out library research and interviewed local experts to learn about the varying growth rates and survival requirements of the plants included in the simulation. The elements were then defined in the program according to these parameters. The completed program simulated the reforestation process.

Projects in this cluster had a very high mean score on understanding (4.62). This score suggests that these students had taken on a *well-defined* and *original* problem, and were able to explain the relationship between the conceptual issue at hand and the techniques of inquiry they employed. They also demonstrated an understanding of the interaction of all the variables they were working with, and were able to explain their visual displays in terms of the relevant conceptual issues.

Critical thinking means for this cluster (4.27) were slightly lower than the understanding mean score, but still reflect substantial mastery of the topic at hand. This mean indicates that these students were able to be reflective about their work, in relation to both the meaning of their findings and the process they went through in carrying out their inquiry. These students consistently attempted to explain their choice of strategies, and identified shifts in strategy and obstacles they encountered in the course of their work. Students in this group were able to explain in depth the problems they encountered and the solutions they devised to address such problems.

These students also have high scores on the clarity of their presentation (4.04), indicating that they outlined their project structure, and consistently attempted to explain relationships between the premises and conclusions of their work. These students' presentations incorporated explanations of all or most of the project components - such as programs and formulas used - and visual aids - such as graphs and illustrations. Teamwork scores were also quite high, indicating that in group presentations most or all of the team members participated substantively in the presentation and in responding to questions, and most or all team members were identified as having made substantial (non-clerical) contributions to the project.

The mean technical score for this cluster was above average as well. The students in this cluster created programs that took into account interactions of multiple variables; they were able to explain the specific function their program performed in their inquiry. They also explained, or attempted to explain, the structure of the program, and how the program executed the formula or algorithm in question.

Understanding is a critical category for this cluster. The high mean score on this dimension reflects a substantive grasp of the content matter being examined by the students in this cluster. The high level of these students' mean technical score is also important to note, as it reflects a consistent capacity to explain the function of the program the students used - they were able to articulate the conceptual connections between subject matter of their project and the technical procedures which drove their inquiry.

Procedural knowledge. 34% of students fell into this cluster (N=47). With the exception of the mean technical score, the mean scores for this cluster were all within a 0.28 range (a low of 3.24 on understanding, and a high of 3.52 on teamwork). The outlying score for this group was their technical score, which was distinctly lower, at 2.76.

The central issue reflected in these scores is that students' work was judged to be *procedural* - that is, they generally fulfilled project requirements, but displayed little ability to reflect upon, elaborate on, or explain the implications of their project work. Understanding, critical thinking, clarity and teamwork were all judged to be adequate, but to be lacking the substantive reflectiveness, and the understanding of the subject matter and the process of developing the project, that was present in the *Integrated Knowledge* cluster. A student in this cluster might have set out to determine whether ozone levels are decreasing over the United States, and to determine how this might affect sun screen requirements. In a final presentation, data might be presented reporting ozone levels for three different locations in the U.S. as recorded on a single date over a number of years. The student might create a program which averaged these values, and generated a line graph describing a downward trend. However, the student could not explain why these particular readings were judged to be adequately representative, would not hypothesize about why readings differed across the selected locations, and would not use this information to predict or determine sun screen requirements.

The just-above-average mean score on understanding for this group (3.24) describes students who were able to identify and investigate a problem, but who did not express any understanding of a relationship between the conceptual issues poised by their choice of problem and the methods of inquiry they employed. The understanding they demonstrated tended to be isolated - different elements of the project structure were not drawn together as a coherent whole, but were each described on their own terms, with little reference to other aspects of the project. Knowledge was not integrated across the various dimensions of the project.

Critical thinking mean scores (3.35) for this cluster were consistent with the procedural focus of their presentations. These students identified the procedures they went through, but were not able to reflect on their hypotheses, their choice of strategies, their outcomes, or any relationships among these elements. They consistently missed opportunities to explain why they pursued an issue, why they used the techniques they did, or why their project outcome was what it was.

The mean clarity score (3.39) was also consistent with the procedural quality of these students' work. Because they did identify project elements, but did not explain relationships among project elements or larger implications of their work, their presentations were somewhat lacking in clarity. Premises and conclusions were identified, but causalities were not represented or explained.

Teamwork for this group was somewhat above the other mean scores (3.52). In this cluster it was common for one group member to dominate the presentation; group members were acknowledged as having all made contributions to the project, but individual roles were not clear, and one group member answered most or all questions.

The technical mean score for this cluster (2.76) is distinctly lower than scores on the other dimensions. Students in this group were generally below average in their technical ability. This indicates most prominently that they were unable to explain the function and structure of the program they used in their project. It also indicates that the programs written for these projects performed a single function, and took into account only one of the variables relevant to the topic. While the students were able to fulfill the baseline expectations of the program, they were not fully successful in producing a study of their content area that took full advantage of the computational tools available to them. Additionally, they were not able to explain the relationship, or establish conceptual links, between their program and their area of inquiry.

Fragmented knowledge. 15% of students fall into this cluster (N=20). The *Fragmented Knowledge* cluster had a more diverse set of mean scores than the *integrated* or *procedural* clusters. Mean scores ranged from a low of 1.30 on technical, to 2.88 on critical thinking. There was a particularly wide gap between the *procedural* and the *fragmented* mean scores on understanding (3.24 and 2.18, a difference of 1.06) and technical (2.76 and 1.30, a difference of 1.46) scores.

The below average mean scores for this cluster reflect students' inability to make connections between a well-defined conceptual problem and the computational resources available to support investigation. A project in this cluster might be a study of a degenerative disease. The student might want to show how particular body tissues deteriorate over time as different stages of the disease develop. The student would collect information on the topic, expecting to find a formula that would describe the phenomena under study. The topic, however, would remain broad and poorly defined, and the student would be unable to find or devise an appropriate algorithm. Consequently, the student would not carry out an analysis of the degenerative process, and might decide instead to present an overview of the information collected about the disease. In the final presentation the student might describe the symptoms of the disease and display textbook illustrations of degenerating tissue.

The below average mean scores for understanding in this cluster (2.18) reflect an inability to demonstrate a coherent grasp of the project content. Knowledge was fragmented, and gaps in understanding were prominent. These students identified a topic, but they were unable to define an area of inquiry or state a specific hypothesis. Students had a limited grasp of the relevant terminology, and did not demonstrate any clear understanding of the variables relevant to the system they were studying.

Critical thinking mean scores (2.88) were somewhat higher for this group than mean scores on other dimensions. One possible explanation for this is that some students were able to identify and describe their own shortcomings, an ability which was included as a positive accomplishment under the critical thinking dimension of the scoring rubric. Additionally, students in this cluster were typically questioned more extensively by observers than other students. These questions may have arisen out of questioners' confusion over the presentation, or as an attempt to give students a second chance to explain themselves. A consequence of this extended questioning was that these students spent more presentation time than most in answering questions, which gave them an expanded opportunity to explain gaps in their comprehension or project design.

Low mean scores for clarity (2.45) reflect the students' inability to present a coherent and cohesive outline of the program of work taken on; understanding the basic project goals required a significant amount of inference or questioning by observers. Low technical mean scores (1.30) reflect either an inability to demonstrate an understanding of the technical components of the project, or an absence of any use of programming or computational tools in the project.

The profile of mean scores suggests that in this category, students were typically hindered by some combination of two factors. First, they had not mastered the subject area they had taken on in any substantial way and had not defined a clear line of inquiry in relation to that subject area. Second, they were unable to make use of the computational tools they were exposed to in the course of the AiS curriculum.

Summary. An extremely high proportion—51%—of students included in this analysis fell into the *Integrated Knowledge* cluster. The profiles of mean scores, which distinguish the clusters, diverged most prominently on the understanding and technical dimensions, suggesting that students in the *Procedural Knowledge* and *Fragmented Knowledge* cluster were struggling to form conceptual connections between these two central dimensions of computational research. The *integrated* cluster performed particularly well in understanding, and maintained a mean technical score on a par with other dimensions. The *procedural* cluster performed weakly in the technical dimension, while all other scores, including understanding, were close to constant. The *fragmented* cluster performed poorly on both the understanding and technical dimensions, while continuing the pattern of relative consistency across critical thinking, clarity, and teamwork.

Factors Influencing Student Performance

In order to determine those factors which were significantly related to students being represented in a particular cluster, demographic and process learning data were analyzed to determine which variables were significantly correlated with each cluster.

Method

After reviewing crosstabs of all variables in relation to the cluster groupings, ANOVAs were run to isolate those variables which were significant in relation to the clusters. Correlation coefficients were run to determine exactly which values of the variables correlated with the clusters. Significance levels ($p<.05$) for Pearson's correlation coefficients are reported here.

Results

A particular group of variables was determined to be significantly related to the cluster groupings. These variables were size of the project group the student worked with; sex of students in the project group; sex of teacher, teacher's years of experience with computers, teacher's years of teaching experience, teacher's primary teaching assignment, whether the teacher had a modem at home, and the questions the student was concentrating on around mid-year, according to journal reports.

Integrated knowledge cluster. Members of the *Integrated Knowledge* cluster were most likely to belong to *mixed sex groups of three students* (p=.003) or *mixed sex pairs of students* (p=.014). When group size and sex of group members were examined independently, *two* or *three* person groups (p=.044 and p=.016, respectively), and *all female* groups were significant to this cluster.

Having a *female* teacher correlated positively (p=.021), as did having a teacher with *ten or more years of computer experience* (p=.006), having a teacher with *twenty or* *more years of teaching experience* (p=.006), and having a teacher with *a modem at home* (p=.040).[10] Having a teacher with *nine or less years teaching experience* was negatively correlated with this cluster (p=.006).

Students in this cluster were most likely to report that, in February, they were focused on *questions about programming* (as opposed to questions about their content area, or logistical questions) (p=.033). Having questions about content was negatively correlated with this cluster (p=.041).

Procedural knowledge. Being a *single female* working alone on a project (p=.012) was significantly correlated with membership in this cluster. Working alone was also significant for both male and female students (p=.011). Being in a mixed-sex group of three was negatively correlated with being in this cluster (p=.001). When group size was investigated independent of group members' sex, working in a group of three remained negatively correlated with being in this cluster, regardless of the sex of group members (although at a lower level of significance, p=.018).

Students were least likely to be in this cluster if they worked with teachers who were primarily science teachers - this was negatively correlated with cluster membership (p=.009).

Fragmented knowledge cluster . *Mixed groups of four or five students* were most likely to be in this cluster (p<.0005). If size of group was disregarded, *mixed sex groups* were, overall, also likely to be in this cluster (p<.0005), while all male groups were least likely to appear here (p=.026). If sex of group members was disregarded, two person groups were the least likely size of group to appear in this cluster (negatively correlated, p=.022). Students who were focused on questions about the *content area* of their project according to February journal reports were likely to be in this cluster (p=.006).

Having a teacher with *nine or less years of teaching experience* was correlated with falling into this cluster (p=.006), as was having a teacher who was primarily a *science teacher* (p<.0005).[11] Students whose teachers had ten or more years of computer experience were not likely to be in this cluster (negative correlation, p<.0005), nor were those whose teachers had twenty or more years of teaching experience (negative correlation, p=.006) or whose teachers were primarily computer science teachers (negative correlation, p=.009).[12]

Discussion

The contextual data collected through site visits and teacher interviews provides a basis for informed conjecture about connections between the variables found to be significantly correlated with membership in the various clusters, and the type of work associated with that cluster.

Group size and composition by sex. This analysis indicates that the size of the group a student worked in, and the sex of the students in that group, are important factors in the type of project work a student is able to accomplish in AiS. Groups of two or three students, and particularly all-female or mixed-sex groups, were most likely to achieve the integration of content understanding and mastery of computational strategies that characterize the *Integrated Knowledge* cluster. Students working alone, whether male or female, were most likely to produce work lacking in reflectiveness and conceptual mastery, which characterizes the *Procedural Knowledge* cluster. Being in a group of four or five students was correlated with being in the *Fragmented Knowledge* cluster - these students unable to create a coherent or well-defined project or to use any computational techniques in their project.

These variations strongly suggest that students were confronting the challenges of group work which are typical of collaborative efforts among students (Cohen & Benton, 1988; Harvard Education Letter, 1989; Rennie & Parker, 1987). Students working in twos and threes were most likely to be able to establish an effective distribution of labor. They brought different strengths to their project work, and were working in a small enough unit that every student had an opportunity to contribute their ideas and suggestions. Consider, for instance, a pair of students who presented their study of a particular number set which generated fractal patterns. When they discussed their teamwork during the year, they acknowledged that one student was a strong programmer and had taught the other student most of the programming he knew. Meanwhile, they explained, the other student was an artist, who was interested in fractals because of the role they play in naturally-occurring patterns, and had explained the mathematics associated with fractals to the programmer.

In contrast, groups of four or five students were most likely too large to allow for substantive contribution from all group members. On a day to day basis, there may not have been adequate time for substantial conversation among so many students, and on a long-term basis, there may not have been enough coherent and substantive tasks to break up among that many individuals. There is evidence from site visits that suggests that large groups were formed when students who had entered the course at mid-year, or who were not performing well with another group, were combined into an existing group by a teacher.

Single students tended to perform procedurally. Because they developed and researched their projects largely on their own, these students are likely to have had fewer opportunities for discussion about the material they were working with than students who worked in groups. The lack of opportunity to question, explain, and discuss may have limited these students' in their abilities to think reflectively about their topic, to think through the implications of their assumptions, or to establish connections between the conceptual and content-specific parts of their project (Cohen & Benton, 1988; Johnson & Johnson, 1979; Webb, 1982).

Our findings indicated that both all-female and mixed-sex groups were significantly correlated with being in the *Integrated Knowledge* cluster. The literature on the impact of student sex on group work suggests that boys tend to use more aggressive strategies to make themselves heard in group discussions, while girls are more likely to seek consensus and to remain silent when necessary to avoid conflict (Linn, 1992; Agogino & Linn, 1992). Although outcomes were strong for girls whether they were in mixed- or single-sex group, it is likely that girls fare better in all-female groups, in that they are likely to experience more direct and substantive participation than in mixed-sex groups (Bennett, in press).

Teacher variables. Five variables associated with teacher's characteristics—teacher's years of experience as an educator, teacher's years of experience with educational technology, teacher's primary teaching assignment, teacher's sex, and whether or not their teacher has a modem at home - were significant in relation to the clusters. It is reasonable to infer that the sex of the teacher is not a determining, but rather a descriptive, variable. The raw data reinforced this inference, confirming that, for this group of students, teachers' sex was simply correlated with degree of experience with educational technology, and with whether or not the teacher has a modem at home. Previous research with teachers who are working with innovative technologies and new curricula suggest that teachers' years experience with technology, teacher's years of experience as an educator, and whether the teacher has a modem at home, are characteristics which tend to play a particularly significant role in the implementation of the new curriculum in question (Hadley & Sheingold, 1993; Honey & Henriquez, 1993; Sheingold & Hadley, 1990).

Students in the *Integrated Knowledge* cluster were more likely than students in other clusters to have teachers who were experienced teachers, experienced users of educational technology, and who had modems (and presumably computers) at home. These students were working with teachers who had had a significant amount of time to adjust to the impact of new technologies on the classroom. According to Sheingold and Hadley's study of teachers who were accomplished users of educational technology, teachers with five or more years of experience with interactive technologies were most likely to be engaging in innovative teaching practices (Hadley & Sheingold, 1993, and Sheingold & Hadley, 1990). These teachers, then, are most likely to have already had their students working on groups, or working on sustained projects, before beginning their participation in the AiS program. Innovative educational practices, as well as their greater fluency with the technology, are likely to have made these teachers better prepared to lead their students through AiS project work. These teachers also had significant amounts of time to explore new resources and to build up their own expertise because they had access to the technology at home.

This profile of the teachers associated with the *Integrated Knowledge* cluster is consistent with the interpretation of the cluster's mean scores (see discussion of cluster analysis, above). Students in this cluster were most successful at applying computational techniques to the analysis or investigation of a well-defined content area. The data suggest that teachers who are fluent with the technologies students are using in their work are most able to support their students in applying those technologies in a productive and appropriate way to the questions the students are trying to answer.

Students in the *Procedural Knowledge* cluster were least affected by teacher variables, showing only a negative significance for having a science teacher as an AiS teacher.

Students in the *Fragmented Knowledge* cluster were most likely to be working with teachers with less teaching experience, less experience with educational technologies, and who did not have a modem at home. Their teachers are likely to be less acclimated to the changes brought about by using technology in the classroom. Because they do not have access to the technology at home, these teachers have less time to learn and explore on their own. The negative correlation for having a computer science teacher as an AiS teacher also suggests that there is a strong correlation between being a computer science teacher and having extensive experience with educational technology.

Journal variable. When students reported what questions were most prominent in their project work as of February, their responses correlated with their membership in cluster groups. Students in the *Integrated Knowledge* cluster were most likely to have questions about programming—they were focused on refining their code and debugging their program. Students in the *Fragmented Knowledge* cluster were focused on content questions—they were struggling to understand and make sense of the topic they had chosen for their project. This finding suggests that students who had been able to establish a well-defined topic by the middle of the year were able to spend several months (from February on) developing and refining the program that would support their investigation. For students in this phase of project development, questions about the relationship between the program and the content area are to be expected. Other students who had not defined a topic by mid-year were spending their class time looking for content information, and trying to understand the basic issues relevant to their inquiry. Some students also abandoned their original topics when they were unable to collect enough information to allow them to carry out a project. These students were beginning a new investigation at mid-year.

Looking across the clusters, then, the significant variables describe a set of circumstances which are particularly important to the quality of student outcomes. In summary:

- Students in the *Integrated Knowledge* cluster were working in groups of two or three. They were likely to be working in mixed sex groups, although some were in all female groups. It is reasonable to infer that the group size was adequate to allow for efficient distribution of work, and that students succeeded in coordinating their strengths to develop a well-integrated project that exhibited both a depth of knowledge about the topic, and a successful and well-reasoned application of computational techniques. These students were supported in their work by a teacher who was an experienced educator, who was experienced with educational technologies and who had the opportunity to continue to develop technological skills outside of the classroom. By February, these students were far enough along in understanding the content of their project that they were able to focus on the writing of a program.

- Students in the *Procedural Knowledge* cluster were likely to be working alone. These students had relatively fewer opportunities for critical discussion with peers than students who were working in groups, giving them less of a chance to develop a reflective and cohesive grasp of content and computational issues. It is very likely unmanageable for one student to accomplish all the work that is necessary for a successful computational science project - doing a thorough job of researching and developing a topic, testing and developing techniques and tools for inquiry, and then synthesizing findings and presenting them may be more than most students can accomplish alone during a single school year.

- Students in the *Fragmented Knowledge* cluster were likely to be working in large, mixed sex groups. This configuration very probably made efficient distribution of responsibilities difficult, and may have impeded constructive communication of ideas and suggestions among group members. Their teachers were likely to be less experienced educators and less experienced users of educational technology, and they were likely to still be focused on content questions by mid-year. This group struggled with the challenge of defining a workable project topic, and was unsuccessful at generating a meaningful method of computational inquiry into that topic. Both the size of these groups and their teacher's inexperience with technology are likely to have contributed to their difficulties.

Student race and student sex. Because the AiS program targets girls, students of color and economically disadvantaged students, to draw them into forms of scientific inquiry usually reserved for students in advanced science and mathematics courses (in which gender and race gaps are most prominent), it is particularly important to note the role sex and race play in student achievement. Sex was not a significant variable in relation to any of the clusters. Student race was also not a significant variable in relation to any of the clusters.[13]

These findings on student race and sex in relation to achievement are encouraging. In reference to the gender gap in mathematics and science achievement, these findings are consistent with research that suggests that such gender gaps decreases when students are asked to solve novel problems of their own devising, rather than asked to engage in traditional forms of learning and assessment such as multiple choice tests (Linn, 1992). Additionally, when these findings are compared with NCES data reporting proficiency levels based on National Assessment of Educational Progress (NAEP) tests, differences are dramatic (National Science Board, 1993).[14] In both comparisons of boys and girls, and of Hispanic, African American, Caucasian and Asian students, gaps on the NAEP tests are significant, with boys' scores well above girls', and Caucasian and Asian students' scores well above Hispanic and African-American students' scores. The high level of achievement among females and among Hispanic and African American students in AiS suggests that the program's commitment to matching substantial technological resources with innovative learning and teaching techniques is highly successful (OERI, 1994). The group-based, project-driven structure of the AiS program is central to the continued success of female students and students of color in the program.

Conclusions

The goal of this evaluation was to determine what types of learning experiences were typical of students participating in the AiS program. In order to answer this question three types of data were collected and analyzed: demographic data describing the participating students, teachers and schools; contextual data describing the particular circumstances in which the AiS curriculum is implemented; and student learning data documenting the process and the outcomes of students' work. The data documenting student learning outcomes - videotapes of student groups presenting their projects and being questioned about them - was analyzed according to performance criteria. Students were then clustered according to the scores they received on their presentations. There were found to be three resulting clusters which had distinctive profiles according to the quality of student performance on the five dimensions of the performance criteria: understanding, critical thinking, clarity, teamwork, and technical competence. Clusters were then analyzed in relation to the demographic data and learning process data to isolate the variables that significantly correlated with membership in each of the clusters. Contextual data was used to aid in the interpretation of the significant variables. See Table 4 for a summary of cluster characteristics.

Overall, the findings from this evaluation are extremely promising. Of the 137 students included in the performance assessment, a very high proportion - just over half (51%) - were able to demonstrate an integrated understanding of the content area they were investigating and the computational techniques they employed. This capacity to bring together an understanding of content and computational methods of inquiry indicates that students are achieving the objectives of the AiS program. Additionally, findings indicate that the target population for this program - female students and students of color - are achieving on a par with other students in the program. The findings also indicate that the AiS program is succeeding at offering students opportunities to use authentic computational techniques to engage in substantive and complex scientific inquiry.

The following conclusions can be drawn from this analysis:

- *The diversity of programming skills among students in the Integrated Knowledge cluster is a convincing demonstration of the capacity of computational science to support students in addressing complex problems and dynamic systems without requiring sophisticated or elaborate knowledge of programming techniques*. The *Integrated Knowledge* cluster includes both students whose projects were based on highly sophisticated programming, and students who used programs consisting of a single do-loop. However, the strength of projects in this cluster was that students succeeded in building a conceptual link between their content area and the mathematical or algorithmic analysis or transformation being executed by their program. They were able to explain the form and function of their program, regardless of their level of programming expertise or the level of complexity of their program.

- *Students who completed projects which were substantive in their use of computational tools and examined a well-defined question were investigating topics about which they had acquired a substantial body of knowledge and understanding*. The particularly high mean score for understanding exhibited by the *Integrated Knowledge* cluster is a strong indicator of the importance of this factor. This finding is reinforced by the correlation between membership in the *Integrated Knowledge* cluster and reporting in journals that by mid-year the student was primarily focused on programming. They had reached a point in the development of their projects at which they understood the content sufficiently well to be able to think about the effective use of programming techniques. In contrast, students in the *Fragmented Knowledge* cluster were more likely to focus on content in the later months. This suggests that students were most successful at carrying out substantial inquiry when they understood the content relevant to their topic well enough to be able to define computational techniques appropriate to solving the problem.

- *AiS is effectively supporting girls and students of color in undertaking complex computational inquiries*. Enrollment for both girls and students of color is comparable to national averages for advanced placement science courses. However, performance gaps remain wide in advanced placement courses, both for girls (in comparison to boys), and for African American and Hispanic students (in comparison to Caucasian and Asian students). In contrast, performance variables in the AiS program indicate that girls and students of color are achieving on a par with boys, and with Caucasian students, respectively.

- *Teachers with substantial previous experience with educational technologies are likely to be most successful at supporting their students in carrying out computational science projects*. Teachers' years of experience with educational technology was found to be a particularly significant variable in relation to student achievement. Technologically experienced teachers are most likely to be already using inquiry-based methods of teaching in their classrooms (Sheingold & Hadley, 1990). AiS teachers who are new to these tools are acquiring a whole new set of technical skills, and in addition, are likely to be facing a whole set of pedagogical and managerial challenges. These hurdles complicate the effective implementation of the AiS curriculum for teachers for whom AiS is a first introduction to educational technology.

Recommendations

Based on the evaluation findings, the following recommendations can be made:

- *Students need to be provided with maximal opportunities to understand the conceptual links between the problem-solving applications of computational techniques and the problems they define based on content areas of their own interest.* Providing teachers with, or helping them to generate for themselves, examples of meaningful problems, and the computational investigations that shed light on them, that they can introduce in their classrooms early on in the school year, will help students to conceptualize the relationships between content and computational technique. Examples do not need to be presented in full technical detail; well designed heuristic models (illustrating processes such as modeling, representing, simulating, or transforming data or systems) would be equally valuable in introducing students to the roles computational techniques can play in problem solving.

- *Achievement in the AiS program is not necessarily dependent on previous computer experience or programming ability.* Process learning data and contextual data indicate that students participating in AiS vary widely in their readiness to use sophisticated programming in their work. Some students are already accomplished programmers when they begin the course, while others have no programming experience and little academic experience which would prepare them for the logic and analytic thinking required for programming. Similarly, some AiS students have teachers who are experienced teachers of programming languages, while others have teachers who are only able to write the most basic commands themselves. At this point, AiS is committed to supporting students who do not come to the program well prepared to become accomplished programmers. Our findings reinforce the wisdom of this choice, and suggest that further development of the course should continue to build on the premise that with adequate support students can create successful computational science projects using only basic programming skills.

- *This analysis indicates that the content and structure of the course may be effectively supporting girls' learning, but their perceptions of the course must be addressed if larger numbers of girls are to be invited into the course.* Teachers need support in continuing to promote the course to girls in their schools. Girls who have taken AiS have done well, but they are still underrepresented in the total pool of students taking the course. Obstacles to girls' enrollment, such as the perception that AiS is a computer science course, need to be specifically identified on both a programmatic and a school-by-school level, and dismantled aggressively.

- *Students' mastery of content areas needs to be stressed early in the school year*. Our analysis suggests that successful projects are the partly the result of substantial knowledge of a content area and an extended period of inquiry and analysis based on a well-defined question or hypothesis. In order for students to have time to carry out this work, teachers and mentors need to focus on helping students refine their topics and their central questions or hypotheses during the first half of the school year. Site visits and student journal reports suggest that this process is often not substantially addressed until well into the second semester. First semester work needs to be structured so that students become substantially engaged with the content area relevant to their project *while* they are learning FORTRAN in the first months of the school year.

- *Teachers who enter the AiS program with little or no experience with educational technology need to be teamed with teachers who are experienced users of educational technology*. Consistent support from someone who is both an experienced user of these technologies and a fellow teacher will allow technologically inexperienced teachers to put their strengths to good use, rather than having their time and energy consumed by trying to overcome newly acquired obstacles. Additionally, the strong technical support provided by the national laboratories to the AiS schools should continue to be a strong component of the on-going teacher support the program provides.

Endnotes

[1] For example, 76% of twelfth graders reported that their science teachers lectured during classtime at least several times a week (NCES, 1991, in NSB, 1993).

[2] For purposes of comparison, all demographic surveys were designed to be consistent with demographic surveys conducted by the National Center for Education Statistics.

[3] One AiS school is not teaching any classes in which students are completing year-long projects. Consequently, student data was not collected from that school. Additionally, the total number of AiS students included in the evaluation dropped to 334 in the second semester. This is due to a number of students from a very large AiS class dropping the course.

[4] No national data is available on students who have modems at home.

[5] Two of the AiS classes had class mentors. These were community residents who regularly visited the schools and interacted with all the students in those particular classes.

[6] December and May journal sets were excluded from the analysis due to low response rates.

[7] The 65 tapes were selected by eliminating a small number of tapes with below-average sound quality and randomly eliminating tapes from over-represented schools.

[8] Because the evaluation continues into the 1994-95 school year, a decision was made to introduce both first and second year AiS teachers to the assessment procedures. In this way, teachers who are part of the 1994-95 evaluation will be familiar with the procedures early on in the process.

[9] 67 projects and 10 scores/project – each scored on five dimensions by two scorers.

[10] Since teacher sex and having or not having a modem at home are dichotomous variables, of course the reciprocal of these correlations holds true as well. Having a male teacher is negatively correlated with being in this cluster, as is having a teacher who does not have a modem at home.

[11] The science teachers included in this sample were also among the least experienced teachers, so these variables can be understood as confounded.

[12] Having a female teacher was negatively correlated with this cluster, as was having a teacher who had a modem at home.

[13] This does not include findings for Asian and Native American students, as Ns were too low for reliable reporting.

[14] NAEP administers standardized tests in all disciplines to a randomly chosen national sample of students at ages 9, 13, and 17. These tests are the federal government's primary indicator of student achievement. Student performance is measured through three types of questions: multiple choice, short answer, and extended response. These tests are "low stakes," as students are selected randomly for participation, and their scores are not individually reported.

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Table of Contents

Executive Summary

The goal of the Adventures in Supercomputing program is to cultivate the interests of diverse populations of high school students in mathematics, science, and computing. The AiS curriculum introduces students to the field of computational science, in which supercomputers are used to run simulations based on mathematical or physical models. Students engage in long term projects that require them to pose hypotheses, devise methods and procedures for solving problems, and draw on a wide array of resources including text and electronic sources, computer simulations, and human experts, to undertake their inquires. With its emphasis on independent and original student research, the AiS curriculum dovetails effectively with current education reform efforts.[1]

The evaluation of the AiS program was designed to assess student learning as evidenced in final project presentations, and to systematically examine variations in learning based on a range of demographic and contextual data. Using performance-based assessment measures, students' project presentations were videotaped according to a standardized format. A subset (n=137) of these students were selected to present their final projects to an audience of Department of Energy program staff, state site coordinators, and their teachers. Videotapes were scored using established performance assessment criteria.

Given key implementation conditions, two central findings emerge:

- A substantial number (51%) of AiS students demonstrated mastery of their computational areas of inquiry. These students effectively *integrated knowledge* across the conceptual and technical dimensions of their work by successfully applying computational techniques to a well-defined set of questions.

- There was no evidence of a gap in achievement based either on student sex or race, suggesting that the AiS approach to learning is effectively overcoming sex- and race-based performance gaps that remain evident in numerous indicators of math and science performance.[2]

1 National Center for Improving Science Education, 1991; NCTM Commission on Standards, 1989; Task Force on Educational Network Technology, 1993; U.S. Department of Education, 1994

2 National Center for Education Statistics, 1993a, 1993b.

The following key conditions were found to play a critical role in influencing student achievement in AiS:

- Mastery of content knowledge is critical to the effective application and execution of computational techniques. Students performed best when they had a substantive understanding of the content area they were investigating. Substantial engagement with a well-defined topic and hypothesis during the entire school year is optimal for student achievement.

- Working in groups of two or three was best suited to students' developing an integrated understanding of the technical and conceptual aspects of their project. Groups of this size allow for effective communication, which encourages the discussion and questioning that is necessary for the development of students' critical, reflective understanding of their project work, and also facilitates effective distribution of tasks according to students' varying strengths.

- Students benefit from the guidance of teachers who have extensive prior experience with technology. Teachers who are comfortable with the technological components of the program are generally able to respond quickly to the technical challenges of students' work, and can focus on supporting students in pursuing conceptual issues.

- The AiS teachers who had the most experience as educators (those with 20+ years of experience) were most successful at supporting their students in carrying out well-integrated computational work. In addition to their expressed willingness to adopt innovative new classroom practices, these teachers bring experience and confidence to their participation in AiS.