THE JOURNAL OF THE LEARNING SCIENCES, 5(4), 297–327

Exploring Learning Opportunities in Coordinated Network-Enhanced Classrooms: A Case of Kids as Global Scientists

Nancy Butler Songer
School of Education
University of Colorado, Boulder

With the careful examination of one Internet-infused learning environment, this article begins a dialogue on the new potentials for learning that exist when students use the best features of the Internet telecommunications network to conduct genuine questioning and investigation in middle school science classrooms. Learning features explored include communication and the value of quick access to a wide range of information and resources. To best utilize these features, new instructional models are developed including the design of a coordinated, distributed-learning approach to guide the development of cohesive and relevant understandings. Learning potentials are explored and continued challenges, primarily in facilitating the learning, are discussed. Potential changes discussed include role changes for project participants, including the addition of new participants and the shift in roles for continued participants; the potential for more personal, intermediate-level explanations of science phenomena; and new opportunities for increased motivation to learn.

To keep the next generation of students abreast of the changes inherent in the Information Age, current reforms and political platforms call for the telecommunications industry and others to wire every classroom in the nation by the year 2000. Although a formidable goal, most politicians and experts recognize that connecting all the nation's classrooms to each other via telecommunications networks is a substantially simpler task than both understanding how to use the tools effectively

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Requests for reprints should be sent to Nancy Butler Songer, School of Education, Institute of Cognitive Science, The University of Colorado, Campus Box 249, Boulder, CO 80309. E-mail: songer@stripe.colorado.edu

and implementing quality learning experiences in these classrooms. These tasks require a deep understanding of the educational goals and the limitations associated with the use of the tools in classrooms, as well as the skills and support structures to develop materials, train teachers, and implement these ideals.

The work described here begins a discussion of the opportunities for student learning in an environment infused with previously unexplored telecommunications-based learning tools and resources. The project profiled was designed to explore the learning potential of organized, Internet-enhanced, middle school classrooms. Through the design and careful examination of one possible learning environment, this article begins a conversation about the conceivable learning with the Internet telecommunications network and its resources for middle school students and teachers. Topics discussed include the design of a learning environment that takes advantage of particular features of Internet-based classroom learning, the necessary conditions for facilitating learning, the challenges encountered in facilitating the learning, and the changes in schooling, including the addition of new participants and the shifts in roles for continued project participants.

The Kids as Global Scientists (KGS) project brings an understanding of what works well for middle school science to the design of innovative learning communities (Linn, diSessa, Pea, & Songer, 1994; Songer, 1993). Although the use of telecommunications networks by school populations grows exponentially, the potential for student learning with this tool, particularly learning focusing on genuine questioning and investigation, remains largely untapped and virtually unstudied. Project work is timely in that the need for greater understanding of network use in schools appears essential if quality widespread implementation is to occur.

A major goal of this work is the exploration of learning potential. What does *exploring learning potential* refer to? We define this phrase as the study of students' knowledge development as it progresses from less articulate and less integrated understandings to increasingly complex and explanatory forms. The exploration of learning potential includes the analysis of knowledge that is larger than content alone. The learning we refer to includes content understandings, motivations and knowledge about self-regulated learning, and other not-yet-defined learning that emerges. We discuss learning potentials, as opposed to defined learning outcomes, because we recognize that we are introducing resources of information and representations of knowledge that are not well understood. We also recognize that we are developing activities that encourage students to combine and work with these resources and representations in potentially new ways. We refer to learning potentials as increasing when it appears that students' understandings, motivations, or abilities to guide their own or others' learning result in richer or more interesting learning outcomes than is the case under more traditional learning situations.

We focus on learning potential for several reasons. Although many earlier projects developed important guidelines for the effective establishment of telecommunications-rich classrooms, a majority of groups focused on overcoming the barriers associated with the physical setup of hardware and access within classrooms, rather than investigating the cognitive and epistemological changes that can result.

Although early research results helped to characterize important obstacles to effective use, such as curriculum integration, teacher preparation, and the adaptation of tools to classrooms (Edelson, in press; Office of Technology Assessment, 1995), much work is still needed to further characterize what learning potentials exist and to develop successful strategies for implementing a learning-focused approach.

Recently, several projects, including TERC's Global Lab, the Learning Through Collaborative Visualization (CoVis) project, the Knowledge Integration Environment (KIE) project, AT&T/I*EARN Learning Circles, the Computer-Supported Intentional Learning Environments (CSILE) project, and others began to address the challenging and complex questions that focus on student learning with telecommunications technologies such as the Internet (Bell & Tien, 1995; Berenfeld, 1993; Hunter, 1992; Newman, Bernstein, & Reese, 1992; Pea, 1994; Riel, 1992; Scardamalia & Bereiter, 1993–1994; Schofield, Futoran, & Eurich-Fulcer, 1994; Songer, 1993). Building on the work of others, the KGS project recognizes that a focus on either infrastructure, access, teacher training, or curriculum development alone seldom results in quality educational learning opportunities (Software Publishers Association, 1995). What is needed is also the goal most difficult to achieve: a program that successfully integrates all these areas and focuses research on the characterization of student learning. This result appears to be the only way to facilitate a high-quality learning experience that provides added learning value not available with previous learning approaches or resources.

In order to identify and explore learning potentials, several factors are essential. First, work must be done to examine the new features the technology might provide and how they can be utilized to foster challenging learning goals, such as the development of more complex forms of thinking. Second, the new features must be tested for learning potential through the development and implementation of a curriculum that attempts to foster these learning goals. Third, research needs to be conducted that explores the learning potentials that develop, as well as the cognitive and logistical challenges that emerge in the new environment. Once preliminary results are obtained, the curriculum and learning approach, as well as features of the technology, must be adapted and refined to continue the characterization of learning outcomes.

This article discusses one project's work to address the first three of these goals. Subsequent article sections outline the learning approach that was developed and refined, the design and refinement of technological tools, and the preliminary research conducted on student learning potentials. Other features discussed briefly here, and in more detail in other articles, include access to technology, interface design, and teacher training and support (see Black, Klingenstein, & Songer, 1995; Hester & Songer, in press).

Therefore, the specific goals of the KGS project were to develop, enact, and study the impact of a 6-week weather curriculum utilizing telecommunications resources. One of our major hypotheses was that the combination of our learning approach and the use of networks in middle school classrooms would influence the type of knowledge developed by students. But we were unsure in what ways influence might be noticed. The project wanted to investigate whether an innovation, such as the Internet and its resources, might hold promise for introducing more authenticity, collaborative learning, and opportunities to effectively use peers in other locations to expand students' understandings of complex phenomena in science.

To conduct our investigation, the KGS designers recognized three major priorities. First, the curriculum and technological design decisions needed to be coordinated so that, in particular, major technological decisions were driven by learning perspectives, as opposed to being either independent of educational priorities or driven by new technological developments. Second, the KGS curriculum needed to utilize telecommunications resources effectively to encourage greater dialogue and authentic practice within classroom science. To reach these goals, the project explored the network features of communication with individuals located worldwide and rapid access to individuals and information. Finally, the curriculum needed to organize students so that individual learning could benefit the learning of others. The result was 6 weeks of activities that helped students elaborate and examine their expertise on a selected topic in Atmospheric Science (Songer, 1993).

GLOBAL EXCHANGE: THE KGS LEARNING APPROACH

This section justifies and explains the design of our learning approach as well as the project goals for student learning. Building on previous work with middle school science students' learning and new technologies (Linn & Songer, 1993), the project team looked toward relevant practices and theories of learning, including the social construction of knowledge. We recognized the emerging need for school-based activities that encourage a wider population of students to develop more complex forms of thinking, including critical thinking, question formulation and refinement, the development of sophisticated explanations, and communication skills (Brown, Ellery, & Campione, in press). Like many others, we recognized the importance of helping students foster these skills in the elementary years, as well as the challenges such visions put onto learning community participants, particularly teachers.

We envisioned an instructional approach that could capitalize on the Internet's ability to provide information relatively quickly. We also desired an instructional approach that would help students to build on the communication features of the

Internet so that knowledge development was supported through a relatively new type of socially constructed knowledge community: that available through interactive electronic mail (e-mail) dialogue with peers and scientists located worldwide.

Working to capitalize on the power of the social construction of knowledge to implement rich, two-way interactions (Newman, Griffin, & Cole, 1989), the project team looked first at learning approaches utilized by other groups, particularly other distributed-expertise approaches. Some early design decisions were influenced by Brown et al. (1992) and Aronson (1978), who showed that distributed expertise is a powerful method of empowering knowledge development in classrooms of varied learners. In Brown's classrooms, seventh-grade students were empowered to be an expert in some area that others needed. This encouraged all children, even those who did not normally see themselves as classroom leaders, to be viewed as individuals with important knowledge to share.

In the KGS work, we wished to test if distributed-expertise learning might provide a vehicle for two-way interaction among sites located worldwide. Sharing information among student experts might allow the development of commonalties among strangers because it empowers a wide range of children to be viewed as important contributors to others' understandings. The KGS project hoped that our students would come to recognize the power of their own explanations as they shared them with others who would otherwise not have access to this information. The project speculated that the anonymity that the Internet provides might allow some students who were compromised in normal classroom social structures to be empowered to share and learn with and from others.

In addition, we recognized the importance of encouraging students to pursue authentic questions on current topics in science (Edelson, in press; Linn & Songer, 1993). We desired curricular activities that would focus student knowledge development around the formulation of rich questions and the subsequent development of rich, content-based explanations.

To meet these goals, we developed and organized a set of activities that were choreographed to occur in two phases. We planned the two-phase approach so that individual learning could be fostered and distributed information could be utilized for further knowledge expansion. We hoped that rich content understandings might develop if students first learned to compose detailed understandings of a local and familiar phenomenon, then were encouraged to utilize the organization of resources we had coordinated to expand their own understandings and the understandings of others.

Previous work with the design of middle school curricula (Linn & Songer, 1993) informed us of the importance of appropriately scaffolded learning activities to help students build from familiar representations to increasingly complex and abstract views. One of the goals of the KGS curriculum was to develop curricular activities that could help students bridge from the data they were collecting on, for example, precipitation patterns in their own region, to that collected by others in different locations. In addition, we wanted to explore the types of representations and understandings that developed when students worked with complex and varied real-time imagery, such as that demonstrating local and global precipitation patterns. We wanted to find out what new information might be available when students capitalized on the resources we made available to them in different geographic locations. We also wanted to know if it was possible to help students develop an understanding of their topic that would enable them to make reasonable short-term predictions about weather patterns, primarily in local regions.

When we combined these desires, the resulting Global Exchange curriculum focused on an opportunity to provide students with the inquiry tools and resources needed to develop rich understandings and questions focused on a specific content area of science. These central features of the Global Exchange curriculum are presented in Table 1. In particular, students utilized many sources to gather information, including online and print media current conditions and forecasts, imagery, and personal resources. The activities were problem based and included

TABLE 1
Global Exchange Learning Approach

Curriculum Features	*How Global Exchange Addresses This Feature*
Nature of problems studied	Real and complex problems associated with weather phenomena.
Information sources	Numerous; distributed among many sources including real-time data, peers, and mentors in many locations, and online and offline resources.
Nature of activities	Problem-based research. Emphasis on reflective questioning, data collection, analysis, comparisons and predictions, and inquiry-based activities.
Nature of questions and responses	Tailored to individual requests. Contain many firsthand, personal narratives and explainations. First questions are seeded; subsequent questions are students' own, answers provided by mentors and, later, by knowledgeable peers.
Focus of knowledge development	Begins with local phenomenon then bridges to the same phenomenon in different geographic locations through firsthand communication and data sharing.
Data collected and analyzed	Begins with firsthand and local data. Extends to comparison with data collected by others; multiple views including real-time data and real- and near-time dialogue with mentors and peers.
Role of students	Reporters, participants, and providers of information and data.
Role of teachers	Facilitator of student research. Less emphasis on lecture, without compromising content learning.
Role of learning community	Utilize communication, interest from others, and data comparison as the hook to motivate deeper science learning.

student data collection and organization, experimentation, and questioning. Knowledge development encouraged students to focus on the topic area and the distinguishing features of this phenomenon in their geographic region. Once a local understanding was developed, students were encouraged to expand their ideas and questions through dialogue with students who had studied the same phenomenon in different locations. Student roles included that of data collector, reporter, and dialogue participant. Teachers' roles included being a facilitator of student research activities and a monitor of the quality and quantity of information students received from other sources. The community, including online mentors and peer experts, served new roles as knowledge resources for individuals. In summary, the project team looked to current research in the design of new learning environments to guide the development of the Global Exchange curriculum and distributed-learning classrooms. The next section outlines the Global Exchange curriculum in more detail.

Global Exchange Curriculum

This section outlines the two phases of the Global Exchange curriculum. All teachers were instructed to enact the curriculum simultaneously in their different locations so that coordinated activities could most easily take place.

Research phase. The focus of the research phase was to support students in the development of a local understanding of a given topic. Throughout this phase, the goal was for students to gather a great deal of information from many sources to help them develop a general explanation of the patterns and parameters influencing their topic.

For the first 3 weeks, students worked in groups of two or three to become experts in one particular area of local weather, either winds, precipitation, severe weather, clouds and humidity, or environmental issues. All students were given focused curriculum questions related to their topic area. These questions served both to seed initial knowledge development and as an organizational mechanism for the range of student information that students gathered throughout the exchange.

A majority of the research phase activities were designed around the topic-specific curriculum questions. From the outset, students were instructed to perform a variety of activities and collect a variety of information from sources including hands-on data collection, experiments, and questioning of local experts or resources. Students were to organize the information learned from these activities into explanations for the topic-area curricular questions. Sample curriculum questions included "How does your local geography affect environmental conditions?" and "What are the effects of severe weather on health, business, nature, architecture, etc.?" All students used local sources of information to develop their explanations to curriculum questions. At the conclusion of this phase, all student teams sent to the research team short descriptions of what they had learned.

Although many students' research methods were similar, some variations occurred. Some students used a great deal of dialogue with online scientists to develop explanations to these questions. Others primarily utilized library resources. All students collected and recorded 2 weeks of daily observations related to their topic, such as wind speed and direction, cloud type and coverage, and relative humidity. After data collection, students were guided in the organization and interpretation of their data, looking for generalized patterns and other characterizations. Students then used generalized summaries of the data to answer curriculum questions such as "What are the types of precipitation in your area?" Additional activities that helped students understand local phenomena included at least one hands-on experiment, activities that had students look for patterns within real-time imagery, book research, and computer searches using tools such as Gopher and other Internet resources.

Exchange phase. Exchange phase activities were developed to explore the learning opportunities made available through the exchange of information between knowledgeable peers in different locations. For the remaining 3 weeks of the curriculum, students at each site were guided to expand on what they knew of local science by sending questions to peers studying the same topic in different places. They were also instructed to respond within 24 hr to all notes they received. We hoped that if we encouraged all students to send several questions and respond to all questions received, a rich dialogue might develop. We wanted to see if this activity would encourage students to compare similarities and differences in their understandings of local phenomena with that from other locations.

During the exchange phase, students were encouraged to generate inquiry questions on their topic specialty. Students used the resource list to locate teams investigating similar topics and then sent their questions to these students. Although initial questions were given to students in the form of curricular questions, these questions were quickly adapted to students' own interests and expanded by the students themselves in subsequent questions and dialogue. Sample student-generated questions included "Why is it so windy in the Four Corners area of Arizona in the spring?" and "Why don't we have tornadoes?"

As a result of the development of expertise and question-and-answer exchange, each student group collected, from a variety of teams, a range of materials that enhanced their understanding of their own topic and local conditions. The unit culminated in a final group portfolio that summarized the activities performed and knowledge developed by group members.

In summary, the KGS project established a rich set of activities that we hoped would encourage students to develop and expand on their own observations of local science. We also wanted to explore whether a rich dialogue could be established that might help students use and refine their own understandings to facilitate others' learning. This design built on the project's recognition of the importance of student participation in social knowledge building and becoming knowledgeable in an area that has value for others.

Early Concerns and How Global Exchange Addressed These Concerns

We believe the first systematic development of our learning approach, Global Exchange, addressed many of our early needs and concerns. First, the Global Exchange approach addressed a concern that students might only use the Internet for the passive downloading of information. In work with students prior to this project, we observed that most students were using the Internet to go to particular locations, such as the National Aeronautics and Space Administration (NASA) or Unidata, to download relevant information or attractive images. Based on our understanding of the active and socially influenced nature of learning—that students construct understandings through the contribution and interaction of ideas from many sources (e.g., see Cobb, 1994; von Glaserfeld, 1987)—the KGS project desired a learning approach in which all students were active contributors as well as consumers (Songer, 1993). Therefore, we established geographically distributed nodes of expertise, developed by and for students, to help facilitate rich, two-way interactions among and between students.

The Global Exchange curriculum also helped address an initial concern related to students' inability to integrate knowledge from varied and complex sources. Curricular activities encouraged students to work with multiple views of the same data, including data they collected themselves, data collected by others during the same time period but in a different location, real-time weather and satellite imagery, experiments and simulations of weather phenomena, and dialogue on weather with peers and mentors. Activities were designed to help students make sense of these complicated and varied data forms, thereby providing opportunities for students to develop explanations for phenomena in Atmospheric Science that were applicable to both familiar and new real-world situations.

Although we had not yet explored an information exchange of this kind, we believed students might be motivated to conduct these activities for several reasons. First, students appeared motivated to interact socially, through e-mail, with both peers and professional scientists matched to their classroom. Second, some students were interested in the opportunity to explore in depth a local phenomenon for which they had a great many firsthand observations (such as unusual or sensational local wind patterns). Finally, one of the strongest motivations appeared to be students' desire to understand something about their topic of expertise prior to the exchange phase, when students from other locations would send them questions about their topic. Some students were worried that if they did not understand their topic well, they would not be a useful resource for other students' questions.

METHOD

The study reported here expands the early work conducted by the KGS research group on student and teacher learning. Our very active collaborative group included learning science researchers, scientists, curriculum developers, teacher trainers, full-time classroom teachers, and technology experts. This section discusses project participants, support systems for learning, collaborative approaches explored, and assessment tools developed and implemented.

Participants

For the first research cycle, Internet classrooms were established in six locations: the Denver, Colorado area; a mountainous area of Colorado; a Navajo reservation school near the Four Corners area of Arizona; New York City; Tallahassee, Florida; and the Melbourne, Australia area. Locations were chosen for their ethnic, cultural, geographic, and economic diversity. KGS project participants included 230 middle school students in the six locations (seven classrooms) and approximately 40 adults, including teachers, mentors, advisors, and facilitators. Although data were collected from all locations, this article reports on the comparison between the two classrooms in the Denver, Colorado area. Both Denver-area classrooms were taught by the same classroom teacher.

To increase our ability to compare learning from more traditional resources with learning from our Internet-enhanced resources, we examined in depth the experiences of students in two classrooms in the Denver-area school: an Internet classroom and a comparison classroom. The Internet classroom performed research as described previously, using and exchanging information via telecommunications networks. The comparison classroom followed the same learning approach and curricular sequence, but they used only traditional, offline resources (e.g., books, phone inquiries). In addition, the Internet classroom exchanged information with middle school students in all the other locations, but the comparison class exchanged information only with students within their own school.

Support Systems for Learning

In addition to our focus on the design of our learning environment and learning approach, the project recognized a need to establish expertise in many other areas, including access to the technology; appropriate computer interfaces; adequate teacher training in content, pedagogy, and use of technology; and online content resources for students and teachers. Each of these are discussed briefly in subsequent sections.

Access: Bringing the Internet to the schools. The project recognized early on that several features of Internet access, including school connectivity, the establishment and maintenance of student accounts, management of host computers, and available interfaces, were not developed with school communities in mind. Working with a National Science Foundation and Annenberg-funded project called the Boulder Valley Internet Project (BVIP), the KGS project addressed and overcame basic access issues. A host computer was dedicated exclusively to school district use, but it was housed and managed at the local university's Computer and Network Services. Student Internet accounts were readily available, provided students and parents or guardians read and signed a contract developed with assistance from school district attorneys. During this time, local KGS schools had direct connectivity (Integrated Services Digital Network lines).

What early Internet-available materials were appropriate for student access and use? Guided by the exploration of Internet resources, the project chose to focus on real- and near-time National Weather Service–Unidata-available weather maps and satellite imagery. Through assistance from the Unidata Program Center, our middle school classrooms learned to obtain weather maps of many continents, satellite images of North America, and other rich imagery such as temperature contour maps, radar data, and forecasting maps. The maps and satellite images were obtained largely through FTP (File Transfer Protocol). Images were very current; being updated hourly for North America and every 6 hr for international locations. A new role taken on by KGS project personnel was to assist in the modification of images so that they were easy to read and useful for middle school audiences. These modifications included superimposing continent and state outlines on North American satellite pictures so that students could more easily locate weather in particular geographic regions. Finally, the project began to archive a set of sensational images, such as satellite pictures that chronicled the paths of Hurricane Andrew and Hurricane Emily. Sample weather maps and satellite images that were available to our classrooms are provided in Figure 1.

Interface design. The role of software development was to transform existing software into powerful learning tools. Because no uniform World Wide Web browsers were developed yet and most middle schools did not have appropriate access to these tools anyway, two Hypercard front-ends were developed to facilitate student and teacher use of Internet resources. The first, called Internet Trek, was a Hypercard front-end that allowed students and teachers to locate weather information and imagery and to send and receive mail. The second piece, Trekker Database,

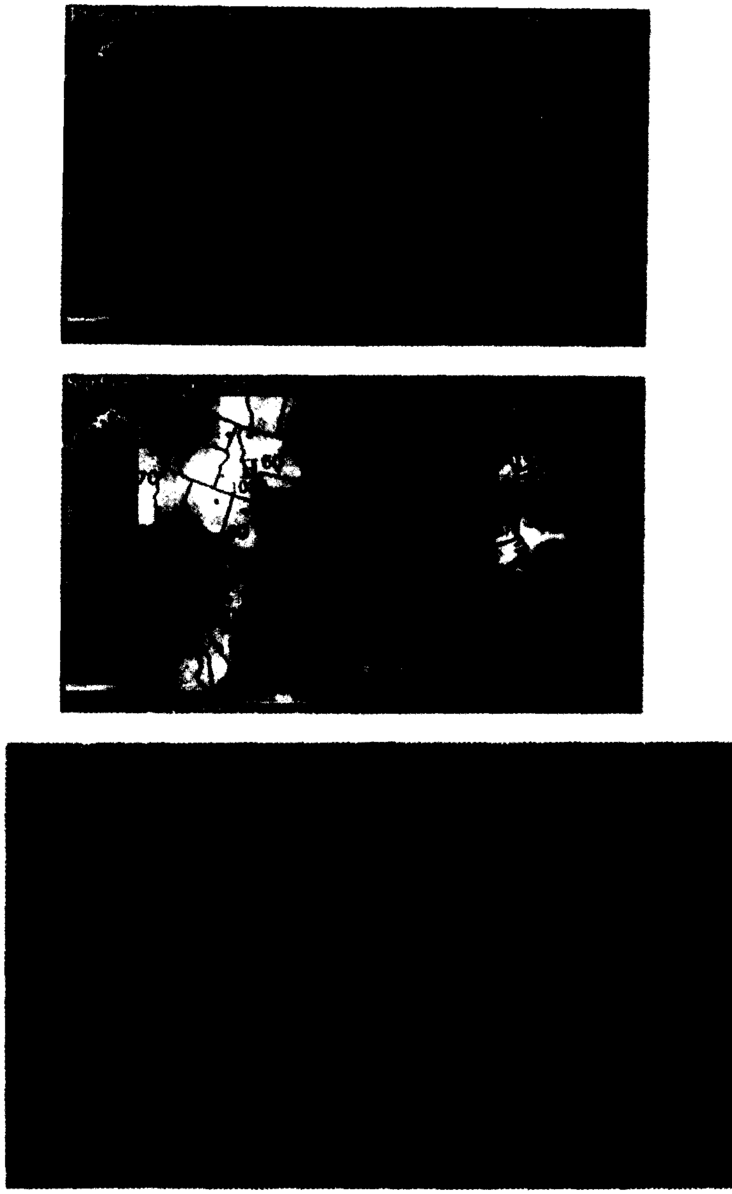

FIGURE 1 Three-screen composite of Internet-available, real-time weather imagery: (a) weather map of North America, including precipitation, pressure, and front data; (b) North American surface temperature data; and (c) visible satellite image of Australia. (Image obtained from the GMS-5 satellite of the Japan Meteorological Agency and processed by the Commonwealth of Australia, Bureau of Meteorology.)

served as an online, searchable index of available student groups and scientists who were participating in each organized information exchange. Sample software screens are illustrated in Figure 2.

Teacher training and support. Locally, all KGS teachers were members of the BVIP Teacher Core Group. This group participated in intensive summer workshops and monthly update meetings focusing on general Internet use. At the time of the work discussed in this article, all local KGS teachers had participated in 9 months of Core Group activities.

Teachers in distant KGS locations were given training and support from a variety of resources, including sharing the training materials from BVIP Core Group teachers; ongoing telephone and e-mail discussions with technical and research staff; written support materials addressing common content, technological, and pedagogical questions; and extensive utilization of local technology resources.

Classroom support and mentors. Capitalizing on the rich possibilities for collaboration available through the Internet, the KGS project looked for opportunities to test a variety of collaborative approaches. Those investigated included mentor–student, student–student, teacher–student, and teacher–teacher collaborations. As a result of these 1st-year investigations, several sets of support materials were developed to help new collaborators more rapidly understand the dynamics of productive dialogue in each type of relationship (see Devaul & Songer, 1995; Songer, Devaul, & Hester, 1995).

Atmospheric Science mentors were located in each geographic location and were matched to each classroom site. In most cases, these mentors were graduate students in Atmospheric Science at a 4-year college close to the site. In addition, one graduate student in Computer Science was matched to each location to serve as a technical resource. At all locations, but especially the distant locations, local resources were established to serve as on-site aids in the implementation of the distributed-expertise learning approach and to provide help with cooperative group strategies.

In summary, the KGS project recognized that a focus on student learning was not possible without the establishment of baseline supports within our middle school classroom communities. Overcoming basic issues of access, interfaces, teacher training, and online mentors provided teachers and students with the necessary components for active project participation.

Measuring Weather Knowledge

A variety of data was collected in both classrooms: pre- and postunit written assessments, videotaping of all classroom activities, group portfolios, and detailed pre- and postunit interviews of representative students in each class.

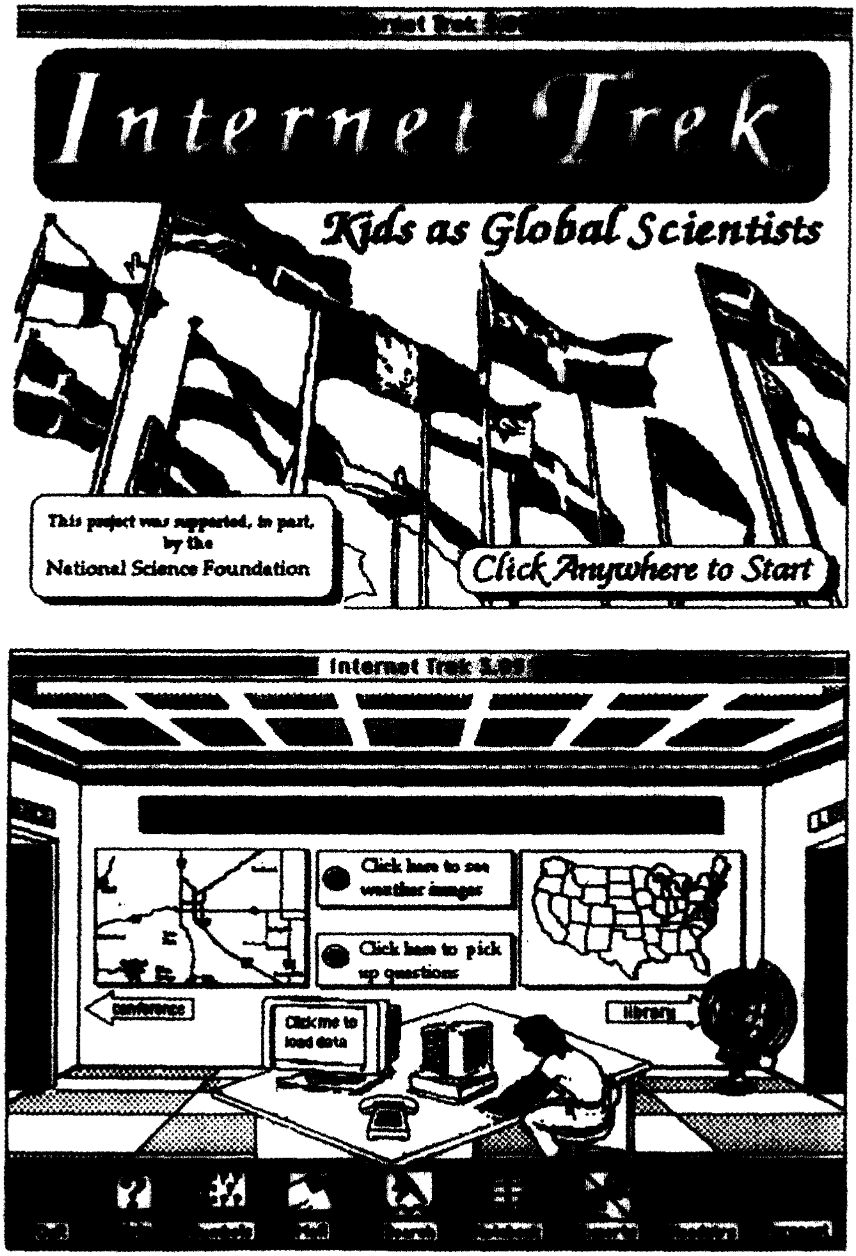

FIGURE 2 Sample Internet Trek interface screen: (a) Internet Trek introduction screen, and (b) Internet Trek weather station screen.

Written assessments. To assess understanding of weather knowledge, 20 open-ended questions were presented to all students both prior to and after the curricular unit. The questions asked students to explain in writing or through illustration what types of weather they have in their area. All students were also asked to elaborate on what the weather was like in the six locations participating in the telecommunications portion of the study. Another set of 7 assessment items probed student understanding of questioning skills. These items asked students to evaluate two hypothetical questions sent to them from another student and to generate a new question about their topic. Students were also asked to describe and evaluate the resources they used for information gathering.

The description and explanation questions on the written assessments were designed to resemble classroom activities performed by students. For example, the early-seeded questions, which were given to the clouds and humidity specialists by the curriculum developers, included "How do clouds form?" and "How does the local geography affect clouds and humidity?" Parallel evaluation questions asked all students to explain or draw a picture or model that illustrated what the clouds were like that time of year in their area.

All Denver-area written assessments were evaluated according to a detailed coding key for pre- and postunit assessments established by the research team. Responses coded in the highest category provided an accurate explanation or description, utilized scientific language correctly, and provided a response that expressed some depth of explanation or an example. All assessments were coded anonymously by the same individual for greatest reliability.

Clarifying Interviews. A total of 16 students, 8 each from the Internet and comparison classrooms, were chosen for detailed interviews. These students were selected by the classroom teacher to represent the range of general science performance abilities represented in the larger class population.

The interviews were designed to clarify understanding of responses on the written pre- and postunit tests. They lasted about 15 min each. Students were asked to elaborate on their answers on the written tests. Based on student responses, the interviewer asked follow-up or clarification questions. All interviews were tape-recorded and transcribed.

Group portfolios. Final group portfolios were collected from all Denver-area student groups, and sample portfolios were collected from all KGS classrooms. These portfolios represented group work on all the unit activities including hands-on experiments, their own real-time data represented in charts or graphs, e-mail dialogues (when appropriate), and summaries of student data. Portfolios from Internet classrooms contained information from groups in many geographic locations; portfolios from comparison groups contained information from several groups all within the same school. The classroom teacher and researchers evaluated all portfolios on a point scale with a maximum of 40 points.

E-mail dialogues. Researchers collected copies of all of the mail sent and received by the Denver-area Internet classroom, and sample e-mail notes were collected from many other KGS classrooms. E-mail served as an excellent trace of student questions, explanations, and guidance from content experts and peers. Notes were largely used to demonstrate the ongoing dialogues between groups.

Classroom videotapes. All KGS classroom activities of the Denver-area classrooms were recorded on videotape. Tapes were not formally coded, but they were used to help document classroom events.

RESULTS AND DISCUSSION

Research data consisted of written pre- and postunit tests, clarifying interviews, group portfolios, e-mail dialogues, and classroom videotapes. Because many assessment pieces were developed and utilized for the first time for this study, we were careful to evaluate our data looking for signs of learning potential rather than significant learning results. In addition, whenever possible, we checked multiple data sources on the same dimension in order to strengthen our conclusions.

Our data analysis focused on five questions related to emergent learning in the KGS environment: (a) Did roles for participants change within an expanded learning community? (b) did students gain understanding in the content area of weather? (c) did real-time resources impact students' developing understandings? (d) did gathering information from firsthand resources impact students' developing understandings? and (e) did motivational differences exist? The following sections outline the results we collected and our discussion of the presence or absence of emergent learning.

Did Roles for Participants Change Within an Expanded Learning Community?

With the addition of distributed peers and online scientists, the learning community expanded its members to include many outside the classroom building. We were not sure whether or how the encouragement of several forms of two-way information exchange might shift or alter the responsibilities of traditional learning community participants, such as the teacher. We speculated it was possible that when the teacher was no longer seen as the sole knowledge resource, other community members, such as students, would take on greater responsibilities. We looked to our e-mail dialogues and other assessments to examine these issues.

In general, e-mail dialogues consisted mostly of peer-to-peer notes (48%) and peer-to-scientists notes (42%). The remaining notes were primarily Phase 1 summary notes sent to project researchers.

Particularly during the exchange phase, students' roles as content resources for each other increased as their content knowledge development included both sending generated questions to peers and answering all questions sent to them. During severe weather events, students' roles increased even more because they were responsible to report on the science of the event for all participating sites. The following example illustrates a dialogue between peers in Colorado and Alberta, Canada.

> To: Wild Winds, Alberta, Canada From: Winds Group, Denver, Colorado
> Hello. This is the winds group from Denver, Colorado. Are you getting a lot of wind over there? We are getting a medium amount of wind today, mostly downslope winds called Chinooks. Do you know about Chinooks? They are winds that sweep down from the Rockies. They can be strong or soft winds. We see you on the map and you are right next to the Rockies, too. Are you getting a Chinook wind? Sometimes we get winds up to about 100 miles per hour but we don't get them often. We would like to know about the winds in your area. What kind of damage do they do? Sincerely, Winds group

> Hi winds group,
> We don't get Chinooks here because we are too far north. Well, every now and then we get one, but not very often. We are not having one today. Calgary, to the south of us, and other cities like Lethbridge get them all the time. We are lucky. Our winds almost never do damage, well not big damage. Once we had a tornado that killed a few people in a trailer park. Most of the time tornadoes around here don't actually touch down on the ground. Sometimes in the winter we get high winds in a snow storm, and then it's a blizzard. They hardly ever even cancel school for them, though. Wild Winds, Alberta, Canada

As mentioned earlier, peer-to-peer dialogues were the largest category of notes classified. Although the large number of peer notes indicated the beginning of a role shift in which peers relied on each other for explanations and increased information, only 20% of the peer-to-peer notes were like this sample, which contains a direct response to another students' question. The remaining peer notes, which were not direct responses to students' questions, provided either comments on their own phenomena or questions that remained unanswered. We imagine that unanswered questions were a source of frustration for many students as they learned to shift their own responsibilities and expectations. We continue to investigate ways to improve the inquiry-focused activities and time line so that a greater percentage of student notes contain answers tailored to another students' questions.

Not all students agreed that learning through peer dialogue was a favorable approach for them. On the written assessment, about 10% of students gave responses that indicated their recognition of a new role that was not always a comfortable one.

> Assessment Question: Do you like it when other kids ask you for answers to their questions, or not?
>
> Student 4: No, not really, because sometimes I do not know the answers and that's really hard to answer.
>
> Student 5: I don't like it. It's cheating.

However, many students, through written assessment responses, described the importance of peers as resources. We speculate that being uncomfortable with their new roles was not necessarily contradictory to understanding the value of peers as resources. Following are some responses to the question "How is learning via peer interactions different from learning from traditional sources, such as books?"

> Student 1: Because in a book you're just reading a book, but when you talk to kids about weather there, they can describe it the way we would describe, and we could see it better in our minds.
>
> Student 2: Because it would be from a kid's (like me) perspective.
>
> Student 3: I like it when kids ask me questions because it lets me learn more about what I already know, and it's helping them.

Teachers' roles also began to shift in important ways. The classroom teacher was very supportive of the new resources available to her, including the quality dialogues she saw developing between her students and their online mentors. She alluded to this in her comment:

> Teacher 2: I really think the [Internet] kids were far more specific to the [local] area. They were talking to meteorologists who were here in Colorado. They were getting specific things that they couldn't have gotten from library books. The closest thing [the other classrooms who did not use Internet] got was an almanac where we could look up some data for Colorado, but nothing like talking to a meteorologist who's right here.

Interestingly enough, however, the interaction was also uncomfortable for the teacher in that the learning approach dramatically reduced her role as a content resource for her students. In final interview conversations, the teacher commented that not having the students turn as often to her for content information led to a reduced ability to keep an ongoing evaluation of students' developing understandings in science. In subsequent years, teacher support materials were developed to assist teachers in the transition to their changing roles (see Songer, 1996).

Although the Internet students utilized the classroom teacher and peers for questions and responses, they also relied heavily on the electronic resources, especially the graduate student science mentors from their local region, for content information. The following examples illustrate the range of questions and information one group, the Cyclones, sent to local meteorologists.

Message 2: Hi Larry. How are you? We are working with severe weather and we will be asking you lots of jolly old questions. Bye so long for now.

Message 4: Our question is, how does hail form? We have another question for you, What other severe weather do we have here?

Message 5: Hi Zander. Can you answer this question? Why are there tornadoes?

Message 6: We thought you answered our question well so we have another question for you: Why does the weather change dramatically, like when it is 60 degrees one day and the next day 2 below zero?

Message 7: Hi, Larry. We think we have the answer to your question, which is: why does warm air always end up on top: because warm air rises. We are The Cyclones.

Message 9: Hi, we are the Cyclones and our names are Alan, Maria and Laura. We are studying severe weather. We've found info on how hail forms, severe weather, tornadoes, temperature. BYE-BYE.

In addition to a rich set of questions sent by students, the online scientists were also active correspondents. The following note illustrates Larry's response to Message 7.

> Hi Cyclones, You're right warm air rises. Now take that one step further, why does warm air rise? I'll give you a few hints: it only rises relative to cooler air, and it rises for the same reason things float in water. Bye, Larry

This response was chosen because it illustrates Larry's ability to seed ideas for students, such as presenting students with thinking questions, analogies, or experiments for students to perform as a part of their ongoing research investigations. Although this mentor response was a cleaner illustration of good mentoring by Larry than were some other examples, we encouraged this type of communication, rather than providing direct answers to student questions. Linn, Songer, and Eylon (in press) discussed students' ability to be "cognitive economists" in which case, if given the option, students choose to use the simplest response, such as a formula or definition, rather than struggle for a more complete understanding. We wanted to avoid such economy of learning; therefore, we provided ongoing suggestions and examples of appropriate responses for the mentors during this 1st year. These dialogues continued to serve as important training materials for future mentors.

In summary, our efforts to provide opportunities for students to ask questions of others and contribute to each others' learning did result in the beginning of new shifts in responsibilities for students, mentors, and teachers. Global Exchange was a learning approach that students were not familiar with; however, a majority embraced this approach, sending many introduction notes, questions, and some responses to peers and mentors. In the most successful cases, students were able to incorporate the information they had gathered into a direct response to another students' question.

Although the teacher was also positive, the shifts in her role also provided her with new challenges, such as how to remain abreast of the development of students' understandings when she was no longer their primary resource for scientific information. Subsequent project work investigated the other collaborative relationships and how they impacted the changing roles for members of the learning community.

Did Students Gain Understanding in the Content Area of Weather?

A large portion of our research focused on the characterization of students' understandings in Atmospheric Science. A primary focus was whether students' developing understandings represented knowledge that they might not otherwise have been familiar with if restricted to more traditional science resources or learning approaches. We were particularly interested in how students' experiences with real- and near-time data affected their developing understandings.

Our results demonstrate that students in both the Internet and comparison classes showed improved understandings of weather concepts, both locally and in distant sites. We estimate that a total of 37% of our students achieved a good level of understanding, as measured by the written assessments, of weather concepts. This percentage varied by topic, with the following combined (Internet and comparison) class averages: winds, 44.0%; precipitation, 32.5%; clouds and humidity, 40.5%; environmental, 28.0%; and severe weather, 40.0%. A good understanding implied that students could explain what the scientific phenomenon was in general terms and, in many cases, could also give one example of its use. Sample good responses from the written assessment follow:

Question: What kind of environmental issues do you have this time of year in your area?
[Answer:] We have a lot of air pollution problems. In the morning the air tends to be cold so the pollution settles at a low elevation.
Question: What are the winds like this time of year in your area?
[Answer:] We have cold gusty winds that come in waves down the mountains.

Within both Internet and comparison classes, students who were experts in a particular topic outperformed their peers on that topic. For example, the clouds and humidity students performed significantly better than did their peers on clouds and humidity questions, $F(1, 38) = 3.18$, $p < .024$. Although the experts always performed better than peers studying different topics, these results were not always significant.

One noticeable difference between the Internet and comparison students was students' ability to explain weather patterns in distant sites. As might be expected, students in the Internet classroom, who participated in dialogue with distributed peers, demonstrated significantly greater understanding of weather in distant locations than did students in the comparison class, whose research focused primarily on local resources, $F(1, 48) = 6.55$, $p < .014$.

In general, the written assessments showed general progress in understanding weather phenomena, particularly local phenomena, among both Internet and comparison students. We believe the similar progress of students in both classes was due to many factors, including the similar set of activities and curricula of the two classrooms. We speculated at this point that the learning impact was made primarily by the curriculum rather than the medium of exchange or resources used. We also recognized, however, the difficulty in designing a written assessment that would illustrate differences between the groups, such as differences in content understandings, which might result from learning from real- or near-time imagery or learning from questioning peers and local scientists online. For these reasons, we chose to look more carefully at the other data we had available for signs of new learning. The next section outlines some results that we observed through analysis of our additional assessment tools, including student interviews, project portfolios, and videotapes of classroom activities.

Did Real-Time Resources Impact Students' Developing Understandings?

Our classroom observations helped us notice that at several points throughout the curriculum, students experienced a learning opportunity that appeared quite different from one that might be available under more traditional classroom situations.

In these instances, students had the opportunity to observe several images of an interesting or sensational scientific event as it was occurring. These images included satellite pictures, current weather maps, and movies showing imagery over a 24-hr period. We decided to look carefully at our data on these events so that we could begin a more detailed characterization of both how learning from these events might impact students' developing understandings of science concepts, and what activities we could design to best take advantage of the events.

The first major example of this phenomenon was the development of a very large storm in the eastern United States; it was called the Storm of the Century. As the Storm of the Century hit, Colorado Internet students were extremely motivated to pull down weather maps that displayed sensational aspects of the storm. Wanting to know more about the storm, particularly from their peers who were experiencing it directly, many Colorado students sent a series of e-mail questions to our middle school Internet students in Florida and New York City to investigate how and why the storm developed.

In a few cases, East Coast Internet students were able to respond quickly enough to these questions to provide important answers in real or near time. However, most of the questions remained unanswered. In this particular case, because the storm hit late in the exchange and resulted in a temporary loss of technology, it was impossible to exchange a large number of responses within the time period.

At first we believed we had missed out on an important learning opportunity. Subsequently, we recognized that this event was a great illustration of the potential power of such instances for meaningful and highly motivated learning about scientific events, both for those who were the local reporters and those who were developing questions about the phenomenon. Most important, we used this experience to help us prepare for similar events in future exchanges. For example, in subsequent years, students or teachers were chosen to watch for interesting storms and to contact peers near the storms' path to serve as correspondents for all other groups.

In addition, although the data provide only anecdotal evidence at this point, the Storm of the Century illustrates important potential differences between Internet and comparison classroom students. In final interviews, many Internet students spontaneously described scientific events and explanations of this storm as illustrations of the kinds of scientific knowledge they had learned during the project. In contrast, no comparison class students spontaneously mentioned this storm. Even more important, when the interviewer probed students from the comparison class to tell us what they knew of the Storm of the Century, a majority of interviewees were not aware of its occurrence, despite their simultaneous study of current weather.

Did Gathering Information From Firsthand Resources Impact Students' Developing Understandings?

Our initial work also helped us to explore the learning possible when students learn directly from interactive, firsthand resources (Songer, 1993). Once again, we recognized that firsthand resources and dialogues might affect student learning in unusual ways, but we were unsure what changes might be noticed. We speculated that firsthand information is unlike some of the most popular sources of information found in middle school science classrooms in that the information provided by books or teacher lectures is generalized information geared to one wide audience. We also recognized that the combination of real-time imagery and firsthand information from peers or resources close to a current event might make the real-time event an even more interactive way of learning about current events than would imagery alone. For example, if students were able to view real-time imagery of an event, then dialogue with and receive personal descriptions or explanations from peers or scientists who were close to the event, students could benefit from both the professional imagery and narrative descriptions of a scientific phenomenon, including the ability to ask and receive customized responses within the narrative description. We looked to our data on firsthand resources to help us evaluate how personal information and the combination of a powerful scientific image and a customized textual description might help students come to understand the science in new or different ways. We looked at student portfolios, interviews, and classroom videotapes to help us explore learning in this area.

One example of real-time dialogue and real-time data occurred when a student downloaded a weather map showing current weather information for Australia. The individual noticed an unfamiliar wavy line weather symbol in the Melbourne area. After consulting the weather symbol chart, this student discovered that the symbol represented smoke. While wondering why the symbol for smoke was present, a student from another group downloaded a message from students in the Melbourne area:

Message 11: Hi Envios

> We live in a farming area. The farmers burn the stubble from their wheat crops to prepare the pasture for ploughing and planting. That makes smoke and that causes air pollution. They do it in Autumn which is now. Today, the air is full of smoke. But the rest of the time it is clean.
>
> From the Ozone Layers in Ballarat, Australia

When the students across the classroom presented this e-mail explanation to explain the wavy line symbol, several students seemed to understand some of the motivational benefits of this connection of scientific imagery and real people. Although anecdotal, the dramatic enthusiasm seen in several students to the match of an interesting image with a current personal message indicated to us that this was a learning opportunity worth further exploration.

General project results demonstrated that the most popular source of information for Internet classroom students was the array of personal contacts available over e-mail. Student questions were individually generated, and, when responses were possible, students received customized responses. For example, responses from the scientists were not a generalized or canned set of responses but were geared to the individual inquiry, allowing a potentially unique response for each instance. The following questions from students in the mountainous area of Colorado to students in Florida illustrate the personal tailoring of questions.

Message 1: Hello! We're the Severe Weather Dudes. We're from Mountain Elementary and in charge of investigating Severe Weather. Our last big storm was about two weeks ago. We got about one foot of snow. How many tornadoes have you had in the last year? Where were you when Hurricane Andrew struck? If you were in it, what was it like? Where do hurricanes usually strike in Florida? Do they strike in your area?

Careful comparison of Internet student portfolios versus comparison student portfolios also led to interesting observations. In both the following portfolio excerpts, student groups were asked to respond to the question "What are the effects of wind in your area?" The first response is from the wind experts in the comparison class, who used traditional sources, such as the school library, to research their question. The second response is from the wind experts in the Internet class, who researched their question primarily through electronic dialogue with a local graduate student. The teacher, the same for both classes, awarded both responses an identical grade of 4 of 5 points.

Question: What are the effects of wind in your area?

Comparison group response: Winds usually get only up to 47–54 m.p.h. When it gets up to that, there is usually some damage done. Colorado is not like Florida or California that experiences winds that get up to 75+ mph. When winds get to that high its technically a hurricane speed. Hurricanes cause a lot of severe wind speed damage. Winds here is the main factor in weather damage in the mid-to-late fall.

> Internet group response: The effects of wind in our area are like how the wind mostly blows from the west to the east, which causes less rain and snow which is nice.... Most trees you see have a little bend towards the east because of wind. Another affect is that we got Chinook winds. Chinook winds are when the strong warm winds come over the mountains. The air drops very, very suddenly from above. It is a lot like when water spills over a dam or a waterfall—the water at the bottom is churned up and splashes around a lot. The Chinook winds is one of the reasons why we sometimes get big gusts of wind. Wind can also be dangerous and they have to close Highway 93. They close Highway 93 because the winds are so strong along the Front Range from Boulder to Golden. The winds can blow cars right off the highway.

Although many portfolio responses contained information specific to the local area, our analysis of student answers reflected a major qualitative difference between Internet-based responses and those based on other resources: Internet-based responses focused on a mixture of scientific and personal information, such as personal anecdotes or familiar occurrences in the local weather patterns. The comparison students discussed similar scientific phenomena, but their responses were more general and less likely to include personal experiences or rich local analogies such as the bend in the trees or the cars blowing off the freeway. Both sets of responses provided good explanations of weather phenomena, as demonstrated by identical evaluations by the classroom teacher in this instance and the similar performances by students in the two classrooms on the written postunit evaluations. However, the character of student answers from these groups were not the same. Clearly, each response reflected its source, and the Internet students had access to a wider range of personal resources that provided this opportunity for an understanding with a deeper mix of scientific knowledge and personal experiences.

Why might it be important for students to develop understandings that are a rich mix of scientific information and personal experiences? We believe the ability to relate complex generalities to familiar situations is a type of qualitative knowledge development important for middle school students in that it helps them to develop a rich explanatory base for the application of future abstractions (Linn et al., 1994; Songer & Linn, 1991). Our previous work demonstrated the importance of selecting a rich set of accessible explanatory tools, such as pragmatic principles, that explicitly help students to integrate personal experiences with complex formal understandings so that they can begin to make sense of the formal science. Although our results here demonstrate that Internet students and comparison students performed similarly on our fact-based, written assessment, we speculate that later the development of these rich explanatory bases might help students bridge to more complex science. Because these results illustrate qualitative differences that are difficult to characterize, we continue to work to discover in what manner the personal narratives and examples can serve important bridging roles from familiar to abstract ideas. Current work is expanding our set of personal narratives and examples into a set of explanatory models that are grounded in local experience and that serve as bridges to abstract scientific principles.

One student interview also captured some of what we believe is the potential for learning from peers and current data when she stated:

> Student 6: It's different because they [the students in the other locations] give you their point of view of the weather, not what other books give you. ... Every day is the same to books.

In summary, although every day is the same to books, we speculate that every day can be potentially different when investigating topics with the Internet or other tools that allow firsthand, real-time or time-series information. We believe the learning effects are powerful when students can learn from individuals and data that capture a snapshot of the event as it occurs. We also believe this learning is quite unlike learning from most traditional and static middle school science resources, such as books or filmstrips. Perhaps learning science in this manner allows students to understand and question the science in a manner more similar to the process and motivation scientists experience when they work with questions for which the answers are uncertain, ambiguous, or dependent on the next experiment. With the Storm of the Century, the answers were unknown. Students could ask questions, make predictions, and gather information from knowledgeable others. Their teachers and online scientists could not provide the answers. Only the storm itself, as it evolved through another day, could resolve their inquiries.

Did Motivational Differences Exist?

Although preliminary classroom observations revealed interesting anecdotes about students' interest in learning from firsthand sources and about current events, we were unsure if motivational differences existed between students learning in our learning environment and those learning under more traditional situations. We also hypothesized that it was possible the anonymity that the Internet provides might enable a greater number of students to be willing to contribute their information toward others' learning. An interesting question we also raised was whether providing learning opportunities in which students are accountable for both their own knowledge development and that of others might also change the value of learning as perceived by the students (Songer, 1993). We explored our teacher interviews, student interviews, and videotapes for help in addressing these questions.

One of our first major observations was the large increase in the number of students who wished to use their own free time to work on this project, particularly extra time to dialogue with peers and, for some, to explore more images. Complementing this observation, our teacher interviews showed an unanticipated early result: Every participating teacher mentioned some indication of increased student interest in this project over other projects, and most attributed student dialogue with peers as the important motivator. The Colorado teacher commented:

> I think there were ... major differences between the learning in the Internet classroom and the learning in the control [comparison] classrooms. The first one deals with motivation level. I could see that the kids in the Internet classroom were more motivated to learn the material because they knew that they would be sharing it with other kids their own age, and I think that the idea of sharing it with their peers was a very high, very good motivator for them.

Similarly, the Florida teacher commented:

> If I had said to them just, "We're gonna start studying the weather," I think they would have kind of been, "Oh, big deal." But when I told them we're gonna be communicating with, you know, other schools around the country and the world, that was, "Oh well, gee, that's neat." So it did make them more interested. Definitely.

Although these comments did not provide concrete evidence of changes in motivation, we believed our preliminary data indicated a strong potential for increased motivation among students. We were curious as to how the dialogue with distributed peers, for example, might increase student motivation.

One hypothesis we generated concerned the ability of students to transform what they had learned of local phenomena into anonymous, but customized, information that was needed by others for completion of their portfolios. We believed that the Internet students were becoming experts so that they would be prepared to answer peers' questions, but that the comparison students were more preoccupied with learning and its relation to their class grades (L. Silfven, personal communication, April 1, 1993). We also believed it was possible that a lower level of intrinsic motivation existed for the comparison students. Lave and Wenger (1991) and others (Burbules & Linn, 1991; Newman, Griffin, & Cole, 1989) discussed similar distinctions in their comparisons of learning under different situations. For example, Lave and Wenger discussed legitimate peripheral participation, in which knowledge is developed with social goals in mind; that is, it is learned to be applied and used in context. In contrast, knowledge that is developed within more traditional learning situations, such as schools, is often devoid of this social goal. Other goals may be emphasized, such as a reporting goal, in which the knowledge is developed to be exchanged for an external reward, such as a grade.

Our project speculated that Internet students, through the responsibility of translating their expertise into explanations for others in distant locations, developed understandings that took into account the social goals that were also a part of the KGS exchange. Riel (1985) reported a similar finding in her work with the AT&T Learning Networks. She found that when students wrote telecommunications material to a designated audience, as opposed to writing just for schoolwork purposes, the quality of writing improved.

In the Colorado location, we also noticed a change in the population of computer users. In the school computer lab, the computer teacher gathered statistics of numbers and characteristics of students who used his lab during free times before and after school and during lunch. After direct Internet connectivity was established in this lab, the population of users changed from a 2:1 ratio of boys to girls to a 2:1 ratio of girls to boys (S. Dixon, personal communication, April 1, 1993). Intrigued, the teacher asked students what activities they were performing. The middle school girls had begun to use the Internet as a new form of social communication, much like note passing. As a result, the population of computer users in the lab had changed dramatically. Clearly, this finding does not guarantee new benefits in terms of student learning; however, it raises the possibility that if learning activities could more successfully capitalize on some of the social uses of telecommunications, perhaps the tools could be more attractive to a wider population of users.

In summary, although we do not yet have concrete results concerning changes in motivation, we believe several comments from teachers and students indicate that motivation and the influence of social goals on learning are important areas of future research. Our analysis continues to investigate whether motivational differences exist and, if so, their potential influence on knowledge development and the social components of learning.

CONCLUSIONS

Our research results indicate that use of real-time resources and firsthand information has the potential to influence the character of student understandings. They also suggest that the changes in types of resources used, the degree of communication and its relation to knowledge development, and potential motivational differences might hold promise for introducing new opportunities for student learning. We speculate that although our factual, written assessments display only small differences in knowledge development between Internet and comparison students, the qualitative differences observed in the nature of understandings developed between the groups are important. Opportunities for students to build understandings from their own personalized questions and to develop understandings that can serve as a rich explanatory base for the application of future abstractions are important tools for knowledge development and worthy of further exploration.

We also recognize the challenge of developing high-quality assessment instruments that can successfully illustrate the nature of the potential differences discussed here. We continue to develop and refine assessment instruments so that we and others can more successfully illustrate the nature and value of any potential learning differences.

This work describes a first attempt to go beyond the substantial technological, scientific, and pedagogical challenges that the new learning environment presents. In an active, classroom-based curriculum, this proved to be no simple task. As many other studies demonstrated (Black, Klingenstein, & Songer, 1995; Office of Technology Assessment, 1995), most teachers find the new technologies, the new reform pedagogies, and the new content challenges intimidating. In addition, the volatile nature of these emerging technologies is almost incompatible with the labor-intensive work of developing and implementing high-quality curricular products. As one recent report stated: "Curriculum integration is central if technology is to become a truly effective educational resource, yet integration is a difficult, time-consuming, and resource-intensive endeavor" (Office of Technology Assessment, 1995, chap. 1, p. 2).

We believe the value of raising new questions about learning potentials is very high. In particular, we continue to ask the following questions: When new roles are developed for project participants, such as teachers, how can these new roles best be understood and built upon? What types of assessment instruments can be developed that more carefully document the character of student understandings being developed? How can explanatory models or rich qualitative explanations be used as successful intermediaries between students' observations and intuitive ideas and more formal, abstract understandings? What is the learning benefit of current information and firsthand, interactive dialogue? How does introducing social goals into classroom science change the character and motivation for student learning?

Although specific answers on cognitive gains, student achievement, or motivational changes are not yet available, the careful reexamination of learning goals, instructional approaches, and resources for student learning made possible through the thoughtful infusion of the technology into classrooms can begin the development of greater understandings of student learning and its potential.

ACKNOWLEDGMENTS

This article is based on research supported by National Science Foundation Grant MDR–9253464. I thank the Kids as Global Scientists research team, including John Supra, Holly Devaul, Karen Tonso, Zhihua Long, Laurie Silfven, and Peter Hester, as well as Marcia Linn, Hilda Borko, and three anonymous reviewers for their thoughtful comments on this article. I also thank University Corporation for Atmospheric Research's Unidata Program Center for their support and assistance in the access and manipulation of weather data and Tina Mueh for her excellent teaching and insight. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the author and do not necessarily reflect the views of the National Science Foundation.

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