Section C: Project Description

1. Objectives and expected significance of the proposed work

People working collaboratively must establish and maintain awareness of one another's intentions, actions, and results. Understanding the role of awareness in computer-supported cooperative work (CSCW) and developing effective software tools to support awareness are keys to the future success of CSCW systems. We will investigate support and impacts of awareness in collaborative problem solving and learning activities. Our project has 5 objectives:

1. We will synthesize prior research in a taxonomy of types of collaborative activities, and types of awareness with respect to collaborative activities. This will guide our investigation of specific relationships among types of activities and types of awareness, and our development of new tools to support awareness.

2. We will develop a suite of awareness tools to support coordinated planning, action, and outcome analysis in an installed collaborative education system. We plan to examine the tradeoffs in effectiveness and practicality between lightweight mechanisms for awareness and more elaborate mechanisms. We hope to determine whether awareness mechanisms can provide low-cost information to such a level that an understanding of high-level goals and activities can be derived.

3. We will carry out a field study of awareness in a collaborative education system to assess and categorize critical issues, to empirically identify requirements for awareness tools, and to develop and evaluate the use of awareness tools. We will specifically address issues related to the following questions: What mechanisms and information in computer-supported learning assist student and teacher monitoring and assessment of collaborative activities? What are (and how does one gauge) the impacts of specific planning and awareness tools on processes of group work such as assimilating contributions from diverse members, organizing a plan, assigning roles, increasing interdependence, increasing content-related communication, and tracking outcomes.

4. We will carry out a series of laboratory studies to investigate specific awareness issues and tools with greater depth and focus, supplementing the field study. We will examine the perceptual and cognitive costs associated with maintaining an awareness of collaborators, their actions, and the groups' activities, and contrast these to the benefits of awareness in motivating, planning, executing, and evaluating collaborative work. At the same time we will extend the methodology of groupware evaluation, by designing and conducting laboratory studies that simulate the complex real world setting of collaborative activity—extended in time, with varied access to team members, and emphasizing the interleaving of synchronous and asynchronous interactions.

5. We will investigate a multivariate approach to laboratory and field studies, incorporating contextual observation, session logging and other performance and process measures, questionnaires and standard scales, and a Web-based critical incident forum. We will address issues relating to two questions: What are the most important factors involved in implementing a multifaceted evaluation approach to awareness, and what are the most effective levels of analysis that yield significant relationships across the different dimensions of awareness?

While we will articulate issues, tool support, and results as generally as possible, our study will bear most specifically on the domain of collaborative classroom-based science and systemic school reform.

Scientifically, we want to investigate and develop the notion of *activity awareness*, the awareness of project work that supports group performance in complex and long-term tasks. Activity awareness builds upon prior research on *social awareness* (of the presence of one's collaborators) and *action awareness* (of what collaborators are doing or what they have recently done) — see section 3.1. We believe that developing a concept of activity awareness can further integrate awareness research and tool support.

2. Relation to longer-term goals of the PIs

Our Center for Human-Computer Interaction integrates the construction of software and applications with the development of social and behavioral methods and analyses. We are committed to the interdisciplinary vision of mutually constraining and enhancing technology development and applied social science. For example, we developed a Java-based toolkit for collaborative component-based software [148] and a long-term approach to participatory design [38]. Each represents a technical innovation in its own area; each guided and leveraged the other.

This proposal is a case in point. It integrates tool development for awareness support, multifaceted evaluation methods for laboratory and field studies of collaborative software, and systemic school reforms in project-based science. The PIs bring formal disciplinary expertise in cognitive psychology, computer science, human factors, science and technology studies, and educational research, as well as extensive practical experience in collaborative software, participatory design, usability evaluation, and secondary school teaching.

3. Relation to the present state of knowledge

3.1 Awareness in collaborative work

In order to collaborate effectively one needs to know many things about one's collaborators: Who are they? What do they know? What do they expect? What do they want to do? What are they doing now? What tools are they using? To what other resources do they have access? What are they thinking about? What are they planning to do in the near future? What criteria will they use to evaluate joint outcomes?

In ordinary face-to-face communication, people work to establish and maintain a shared background of understanding called *common ground* [65,66]. Conversational interaction involves continual testing for evidence of common ground, and coordinated effort to enhance common ground. For example, if an interlocutor fails to respond to a request, one might restate presupposed information, point to a relevant object, request acknowledgement, or otherwise remediate. Common ground is unproblematic in face-to-face interactions because such a wide variety of situational elements contribute to it, and the work that people do to maintain common ground is so well integrated into habits and conventions of interaction.

When people work collaboratively, but *not* face-to-face, many interaction resources are disrupted [65,261]: field of view is reduced, the possibility to use gesture is limited, facial expressions are eliminated or constrained, auditory cues are diminished, tools and artifacts cannot be as easily shared, exchanged information is delayed or decoupled by seconds or even minutes, and collaborators may be in different time zones or different cultures. In remote collaboration it is difficult to convey or discern successful comprehension, current focus of attention, or concomitant attitudes and affect. It is difficult to repair or remediate miscommunications. This transforms the maintenance of common ground into a significant task, which is itself problematic: People are accustomed to taking common ground for granted, as a background task. They do not want to "spend" attention and effort on it.

These issues have made awareness an increasingly prominent issue in the design of user interfaces for computer-supported collaboration. Investigators have explored numerous user interface tools to help collaborators establish and maintain common ground by supporting their mutual awareness of one another.

3.1.1 Social awareness. Exciting early work focused on supporting social awareness of remote co-workers through various sorts of open video links. Systems were developed and studied in Bellcore, Sun, Xerox, and at several universities [1,18,77,80,98,103,131,170,212,227,262,266]. In these systems, information from collaborators' sites is periodically updated, providing incidental awareness of changes in their activity, group membership, social interactions, facial expressions, and so on (Figure 1- page 3). The systems make available the sort of background information obtained in face-to-face circumstances by merely looking and listening as one walks by offices and common rooms.

Video link systems do support the maintenance of common ground by encouraging ad hoc communication and collaboration, the sorts of unplanned and informal activity that are known to enhance a group's sense of community [158,280]. However, they raise many issues relating to decisions about what information about oneself is to be shared, and conversely what is really needed or desired from others [18,98,165]. And ironically, although people do complain about video quality [262], higher-quality video links can distract people from primary tasks and undermine their performance [172]. There was always a perception that video links did not provide enough benefit to justify their costs [3,86]. Video does not enhance human performance in design, decision making, instruction, and many other tasks [59,172,210,211,283]; though it can improve task outcomes in negotiation, bargaining, and conflict resolution [248,249,262]. All of the systems referred to above were abandoned [211].

Type of awareness	Information that can enhance this type of awareness
Social	Presence and identity of collaborators; facial expression or other indicators of motivational state or attitude; intensity or frequency of collaborators' activity; time, type and frequency of communication among collaborators
Action	Time, type and frequency of shared file modification; location and focus of collaborators' current activity; gesture, eye gaze, or other nonverbal communication cues; logged events from other collaborators' synchronous sessions
Activity	Group discussions or other records of goal decomposition and plan development; negotiation and assignment of roles and resources; representation and linkages among interdependent subtasks; plan modifications and rationale

Figure 1: Three types of awareness and examples of information that contribute to each.

Recent awareness research has emphasized that awareness is multifaceted [179], and has distinguished between social awareness and task-oriented awareness [24]. Social awareness, per se, is seen as a background condition [125], necessary but not sufficient for establishing effective common ground. Indeed, when collaborators can choose, they use video channels to share data and other work-related artifacts, rather than to exchange views of one another [90,195,281]. The focus of awareness research has moved to supporting awareness of planning, acting, and task status against a background of social awareness [8,20,52,53,54,79,107,108,112,114,115,116,117,118,119,120,121,122,123,124,129,147, 179,228,240,253,254].

3.1.2 Action awareness. When remote collaborators work in a common networked environment, their awareness of one another's actions can be supported by displaying information incidentally available (Figure 1). For example, basic file system services indicate whether and when a file has been changed. More elaborate version control systems build from this simple functionality, maintaining some number of previous versions, perhaps even facilities for visualizing what has changed [84,102,130,184,201,255]. Many of these techniques aggregate information into snap shots, compressed summaries, or abstractions that represent a set of changes across time, like tracking distributed interactions with various kinds of documents and data in a shared folder [14,147]. As another example, collaborative writing systems have explored techniques for extracting the gist from large change histories [200,201].

Most work on action awareness techniques has focused on displaying the current objects, views, and actions of one's collaborators (e.g., what set of things they are looking at, which document is currently active) [121,124,254]. One of the most successful and earliest examples is the radar view, a miniaturized workspace overview that uses rectangle outlines to indicate the part of the workspace in view for different collaborators [7,113,114,253]. Radar views provide information about collaborators' positions and movement within a workspace, and are also often used to navigate directly to a collaborator's view. Telepointers (individual pointers for each remote collaborator) can also be used to convey relative position, along with some degree of gesture (e.g., pointing at a document during discussion). Researchers have explored techniques for merging video information conveying work partners' gaze or facial expression with a shared workspace of task objects [149].

One of the great opportunities for collaborative software is to seamlessly support interactions spanning days and months that include a mixture of synchronous and asynchronous encounters. However, work on asynchronous and synchronous support for action awareness is not well integrated. For example consider the case of a collaborator who misses a synchronous work session. In her absence, other team members meet. Will it be enough for her to see a change log of shared documents? Will she want to see a replay of every mouse movement, or videotapes [193]? One approach to this explores the logging of communication that is normally ephemeral, for example, creating persistent chat logs in a MOO (multi-user domain) [52,53,54].

Ironically, task awareness has evolved, to a considerable extent, to constitute investigation of the *task of awareness* rather than facilitating awareness of cooperation in *some other task*. Some action awareness tools provide fine-grained information about collaborators' mouse movements and keystrokes, and consume significant amounts of display space. Studies assessing the benefits of such awareness tools often limit themselves to dyads of volunteers working together in controlled laboratory settings with well-defined collaborative awareness tasks [8,114,117,119].

3.1.3 Activity awareness. At a higher level than isolated tasks (e.g., "globally replacing a string"; "monitoring a collaborator's global replacement of a string") is the level of *activities* — longer term endeavors directed at meaningful goals like "explaining image positioning in Word 2000", "planning the layout of a town park", or "writing an NSF proposal" [17]. Longer term activity entails top-down goal decomposition [232], nonlinear development of partially-ordered plan fragments [233], interleaving of planning, acting, and evaluation [183,204], and opportunistic plan revision [128,258] (Figure 1). It involves coordinating and carrying out different types of task components, such as assigning roles, making decisions, negotiating, prioritizing, and so forth. These components must be understood and pursued in the context of the overall purpose of a shared activity, the goals and requirements for completing it, and how individual tasks fit into the group's overall plan [122]. The original motivation for work on awareness support was intended to support effective joint activity. The foundation of existing work on social awareness and task awareness makes it opportune to now refocus awareness research on the level of meaningful activities.

Studies of action awareness have tended to study simple awareness effects, such as noting that a telepointer has moved or that a file has been changed, and perhaps to store information about the properties of such events. In more complex and longer term activities, a greater range of group outcomes become important, such as representing discussion and decision processes, and associated results and decisions. High-level human performance considerations such as motivation become important. Collaborative systems often fail in real use because of an imbalance in who does the work to support effective interaction and who benefits from the work that is done [111]. Issues like motivation are often not visible when techniques are demonstrated in isolation, but they become first order issues when systems support real groups and real activities.

Activity awareness incorporates a greater awareness of *other people's plans* than social awareness or action awareness. Complex, long term, coordinated activity cannot succeed without on-going interpretation of current goals, accurate and continuing assessment of the current situation, and analysis and management of resources (including time) that constrain execution of possible plans. All members of a team must share a common understanding of the goal, currently developed plan fragments, and the problem state being addressed, as well as an understanding of how others on the team are perceiving the situation [89,90,95,142]. Descriptions of opportunistic planning show how goals regularly change during the execution of plans, forcing replanning [128].

Investigating activity awareness also entails a more ambitious empirical focus for studies of awareness. It is important to evaluate awareness support embedded in collaborative systems supporting real collaborative work, as opposed to stand-alone awareness demonstrations. There are studies of fielded collaborative systems, and awareness support is one facet of these systems, but overall system evaluations have often focused on target task performance, and not on awareness as a singular element of successful performance. For example, in our own work on remote mentoring interactions between community members and school children, we documented awareness problems pertaining to "late joiners" in synchronous sessions, but anecdotally [104,147]. It will also be important to carry out experiments to analyze particular activity awareness techniques and issues. However, to be relevant to the level of activities, such experiments will need to be far more elaborate than demonstrations with pairs of volunteers.

3.2 Education as a domain for awareness research

Schools contain particularly interesting and valuable settings in which to study awareness and planning. Collaborative and authentic learning represent two crucial and related trends in schooling, and respective pedagogies model on-the-job training in business and industry. Students develop a wide variety of social and cognitive skills in cooperative learning, indispensable skills that are demanded by the complexities of authentic work. Students, like trainees, learn to give and take initiative, to jointly develop and analyze plans into requisite actions, to assign roles and share responsibility among group members, to integrate results and synthesize final reports, and to remain focused on relevant work. Ideally, the roles and tasks that students perform mirror future expectations of employers. It is generally accepted that collaborative, project-oriented learning is a superior model to practice-and-test approaches [21,71]. When learners work together on authentic tasks, they engage highly valued work-related skills. They naturally describe, explain, listen, and interpret. They develop language skills, collaboration skills, self-monitoring, and meta-cognitive skills. Shared knowledge-building allows learners to regard themselves as people who solve problems.

Educators emphasize collaboration not only among learners but among teachers as well. Teachers manage student collaborations much like business supervisors manage their workforce, and teachers themselves are also being asked to collaborate in many of the same ways as business and industry managers. For example, the management of knowledge has become an imperative for many high-tech firms and has also been directed toward teachers [126]. The National Science Education Standards encourage innovations in teacher collaboration, suggesting that teachers need greater opportunities to interact, collaborate on curriculum and evaluation, and describe their own views about learning and teaching [196].

However, collaborations raise new challenges both for students and teachers. When students collaborate across different classrooms or with mentors outside the school, they experience a variety of problems maintaining attention (against the background cacophony of the classroom), and coordinating references to physical objects and events [104,213]. Classroom collaborative projects require continuing awareness of who is doing what; reduced awareness can encourage free-riding on the part of less motivated or capable students, and can undermine the motivation of other students, who may be reluctant to work harder than their colleagues [135]. Cooperative learning requires that students remain aware of the relevant tasks, actions, plans, and social situations at hand. Successful cooperation relies on students' abilities to depend on one another with respect to the *means* (roles, tasks, and resources) and *outcomes* (goals and rewards) of their learning activities [151]. Students need to be able to evaluate their own and their collaborators' contributions to the group [150,252]. Awareness requires devices for recounting, coordinating, and planning collaborative work which do not exist.

Teachers also encounter typical but acute awareness problems in their collaborations. Relative to other professions, teachers work in isolation from peers, and with understood responsibility for only their own classes [67,267]. Norms of individualism, differing pedagogical views, and the absence of shared professional identity or expectations all discourage teacher collaboration [229]. When teachers do try to coordinate with peers, they confront formidable problems. Curriculum planning and management, like management in general, depend on competencies, interests, and specific interactions, but teachers and managers cannot always readily control or anticipate these. Instead, they must become aware of these circumstances through the course of situated interactions, and adjust their plans based on these constraints. Teachers often are not afforded the luxury to meet and coordinate with colleagues to the same extent as other workers. As a result, they typically must meet after school in order to work together. In this context, coordinating a planning process across classrooms is a significant and continuing challenge.

Our experience with classroom research. Under prior NSF support (REC-9554206), we have worked closely with six science teachers over the past five years, to coordinate their development of collaborative teaching practices with our development of collaboration technology. We have addressed many of the aforementioned problems and issues in our own work with teacher collaborations [82]. The Learning in Networked Communities (LiNC) project has developed into one of the most long-lived participatory design projects yet attempted [38]. Our Virtual School (VS) software is intended to support interactions among teachers and students in different classrooms and schools. It incorporates a wide range of synchronous and asynchronous communication and authoring tools. It supports synchronous conferencing interactions (chat, video conferencing), but emphasizes integrated support for group projects extending over weeks, even months. For example, one project we studied during the 1998-99 school year involved the design of a robot in which a group of middle school students developed an arm while a group of high school students developed a mobile base for the arm. Some of the projects have involved more than two dispersed groups. The VS involves complex activities that exploit the full range of tools available, and thus users encounter a wide range of issues and problems related to awareness and planning. Projects have ranged widely from highly integrated and structured online materials about simple machines involving computer design, graphics, guided questions, as well as physical manipulatives, to open-ended student research and development about physical science principles such as aerodynamics, bridge structures, experimental design, and acoustics.

The VS is now a fairly substantial and stable testbed; the six LiNC teachers use it extensively, it regularly supports around 20 concurrent sessions. The current VS incorporates some planning and awareness support (see section 3.3), but we have identified crucial needs for new tools and mechanisms for planning and awareness. The current learning activities require extensive integration of physical and virtual artifacts across distributed and proximal groups. This demands extensive use of available CSCW tools and taxes the boundaries and scope of awareness. Unfortunately, teachers and students are currently left to the limited resources available and their own creativity and devices to struggle with immense awareness and planning problems. It is important to capture their tentative solutions and obstacles, and then to study and develop solutions and tools to address in the lab and in this rich field setting.

3.3 Computer support for awareness and planning

Support for awareness and planning in CSCW systems has traditionally focused either on concurrent activities or on activities taking place at different points in time. More recently, researchers have acknowledged that most collaborative relationships involve a combination of synchronous and asynchronous activities, making integration across the two collaboration modes a key concern [50,228]. In this section we briefly review progress made in supporting planning and awareness in synchronous and asynchronous collaboration, then describe more specifically the support that is and will be provided by the Virtual School, the collaboration environment forming the testbed for the proposed work.

3.3.1. Supporting synchronous awareness. WYSIWIS (What You See Is What I See) is a concept that grew out of early multi-user interfaces. In an attempt to create systems that modeled an abstraction of chalkboard use in face-to-face work, designers created interfaces that allowed users to see what everyone was writing and where they were pointing in the workspace. This design approach allowed users to maintain a strong sense of shared context. However, it quickly became apparent that users in collaborative systems needed support for individual work as well as group work. Thus Stefik et al. [257] proposed that WYSIWIS could be relaxed along four dimensions: display space (the display of objects), display time (the display synchronization), population (individual, subgroup, or full group), and view congruence.

Workspace awareness becomes more of a challenge as the strict synchronization of WYSIWIS is relaxed. Systems in which collaborators see the same objects at the same time and share identical capabilities and mechanisms for manipulating those objects most closely approximate collaboration in a physical space. Maintaining awareness of who is working on what and where they are working is significantly more challenging when users have different views of shared objects, can access shared objects at different times, and can manipulate those objects in different ways or with different capabilities.

Researchers have developed numerous techniques for maintaining collaborators' awareness of concurrent activities that are only loosely coupled to their own. Workspace overviews visualize the state of a remote collaborator's workspace [116]. The overview depicts a large 2D space (e.g., as in Kansas [254]) or a more specialized view of a structured space such as a miniaturized document [124]. Typically each user will be allowed a different viewport into these space; these systems are often augmented with radar views that display each individual user's viewport within the overview. A telepointer for each user may also be included [121].

Techniques such as these address awareness of location and task-focus of collaborators, and if telepointers are provided, enable an even more detailed monitoring of activities within a document. However there are many open issues about the level of activity that should be broadcast [8,9,116]. For example, if a user makes a menu selection, do collaborators need to know which menu and menu item was selected? For shared editing, do collaborators need to see the typing (and deleting) as it happens, or is it enough to get an update when the co-author moves on to another subtask? Decisions such as these clearly have an impact on awareness, but at the same have strong implications for the software architecture and system performance [8,9,73].

3.3.2. Supporting asynchronous awareness. Researchers supporting awareness of asynchronous activities have emphasized *implicit* collection and broadcasting of collaboration activities: the system captures and displays relevant information, rather than requiring *explicit* documentation by users [15,78,176]. For example, change bars indicate modified sections of text within a text editor, and can be augmented to also show who made the change, when it was made, even the previous version. The build-up of changes over time is addressed by the notion of edit-wear, where "ragged edges" appear next to frequently-revised portions of a document [136].

A large class of implicit awareness mechanisms is based on the capture and replay of event histories or screen snapshots [15,203]. Such records can be used to produce an exact replica of a previous system state [163], with user control over the speed with which events are replayed, or skipping past less interesting segments of past sessions. Extensions to the radar view include a slider that animates a collaborator's viewport movements over time [124]. Textual logs and audit trails provide an even more abstract form of asynchronous awareness information, as do graphical visualizations of document versions [184].

In contrast, explicit awareness mechanisms require collaborators to actively generate awareness information describing their actions. At a most basic level, email or other general-purpose communication tools might be used to describe or summarize activities. Here, the burden of selecting, capturing, aggregating, and presenting awareness information is shifted from the software to the user. However, embedding the explicit awareness mechanisms within a task context can simplify the task for the individual creating the documentation, by removing some of the overhead in describing the objects and changes of interest. For example, collaborative editors such as PREP [200] support annotations that are attached to shared content.

3.3.3 Supporting awareness in the Virtual School. The Virtual School software (VS; developed under NSF REC-9554206) supports a wide range of synchronous and asynchronous communication and collaborative authoring tasks, including note-taking, experimentation, data analysis, and report writing. The central tools are a session overview, an integrated set of communication channels (video conferencing, shared whiteboard, chat, and email), and a shared notebook that supports collaborative editing of a variety of page types [147,157]. As described in Section 3.2, this software has been used actively in several area classrooms, and will form the infrastructure for field studies of awareness tools.

The current VS implementation includes a number of features that can be used to support awareness, particularly social awareness (of the presence of collaborators) and action awareness (of what collaborators are doing and have done). User lists and avatars indicate presence and idle time. Icons and labels indicate pages of a collaborative notebook that are currently being edited. Asynchronous awareness information is provided in the form of an authorship coding feature that allows each author's contributions to be shown in a different color and a notice board that shows a log of past notebook modifications.

However, these features in our work, like many of those described previously, are intended to support a lightweight form of awareness. Prior evaluations of other awareness systems typically have considered whether users note presence, increase communication, and build community. We seek to support the more in-depth concept of activity awareness that can support users in maintaining an understanding of complex and long-term tasks. Currently, communication of plans and intentions must be done explicitly through tools such as email, chat, and notebook pages. Hence maintenance of activity awareness is a manual process that users often neglect. Beyond the awareness issues for students, teachers whose classes use the VS encounter activity awareness issues on a larger scale as they attempt to monitor and guide multiple distributed groups. The awareness tool enhancements undertaken in this project will seek to address activity awareness issues for direct participants in distributed collaborative work and for managers of distributed groups, the classes of users represented by students and teachers respectively. We will explore ways to facilitate communication of goals, plans, and tasks, as well as mechanisms to address the general problem of awareness information overload.

Leveraging planning artifacts for awareness. Development of a plan is typically a requirement for any successful, non-trivial project. In the case of class projects it is often an explicit requirement, with a document describing the project plan being a mandatory deliverable. To be useful for awareness, however, planning artifacts must be maintained over the course of a project and must be connected to interactions with other project artifacts.

We will study past and ongoing VS projects to design tools that facilitate collaborative documentation of goals, plans, and tasks. We will create extensions to the VS that support the nonlinear, dynamic nature of plan development over the course of a project. These planning artifacts will be integrated with awareness mechanisms, providing a source of easily specified context information for actions performed in the VS. Context information derived or manually selected from the planning artifacts can then be combined with passively gathered information on user actions and used to augment synchronous and asynchronous awareness tools.

This relationship between planning information and awareness information is bi-directional, so we will also explore the use of explicit awareness information as a source of data for plan maintenance. For example, the VS enhancements will support simplified transfer into the planning tools of information from annotations, chat messages, and other forms of communication.

Combating information overload. Currently the VS generates a large amount of information characterizing user actions, only a fraction of which is presented to students and teachers. Since the sheer amount of information makes direct access to it impractical, we are developing visualizations to reduce the apparent complexity yet still convey recent and ongoing activities. One goal is to ensure that the visualizations will be simple enough to understand with a quick glance in their typical state, with each capable of being expanded into a more detailed view when specified by a user. We are developing methods to identify interesting occurrences and patterns in the access of information, which then will be fed to the visualizations to help raise and maintain awareness of concurrent activities. For example, rather than simply indicating accesses to individual elements in VS as is done now, sets and lists of actions over time will be shown. We expect that this will help a viewer understand the longer-term goals of the user in performing the actions.

In addition, we plan to extend the role of the avatars in the session view to show more information about the actions of each user. Currently the avatars demonstrate only presence and idle time. We will extend the avatars capabilities to provide additional action indicators like those in [116] to illustrate otherwise invisible actions. Leveraging planning and task information, the avatars will also be able to suggest the context of and motivation for the user's actions. The additional information will be available in both the current textual form and in a reduced-size, easy-to-understand graphical form that integrates the avatar with symbols reflecting actions and purpose. As prior studies have shown that appropriate use of avatars can efficiently and effectively raise awareness and lower anxiety [106,223], we expect that students and teachers alike will benefit from a heightened sense of the actions of others.

Supporting inter-group awareness. Much of the prior work on awareness tools for collaborative systems has sought to enhance intra-group awareness, providing information about the presence and actions of collaborators that are part of a distinct group. In the case in the current usage of the VS these groups are formally established, with students being assigned to project groups. In other environments groups may be established informally, perhaps by users simply being co-located in a public chat room.

Within a collaborative environment such as the VS, distinct groups engaged in similar tasks are typically unaware of each others' activities. Hence the opportunity for knowledge-sharing across groups is lost. For example, a group of collaborators working together with a shared simulation tool would be aware of and could communicate with each other, but might also benefit from knowing about and interacting with others who are using the same kind of simulation. If collaborative environments are to support creation and maintenance of dynamic, long-lived virtual communities and organizations, tools that support intra-group awareness will need to be augmented by tools that support awareness of the activities of other groups (this is analogous to corporate knowledge management with tools like Xerox's DocuShare [73,168,278]).

We will explore enhancements to the VS that provide this type of inter-group awareness, with the goal of promoting opportunistic interaction and discovery of potential collaborators. We will specifically investigate techniques for linking awareness and communication tools across groups of users engaged in otherwise distinct interactions with similar kinds of collaborative objects.

Large screen information collage. In addition to exploring ways of improving the quality, efficiency, and task-appropriateness of the awareness mechanisms presented in the VS user interface, we will also investigate ways to provide awareness information in places other than the user's display. Specifically, we will develop tools that present awareness information on large-screen displays.

A significant issue for teachers is maintaining awareness of the presence and activities of the students. Since students are often scattered at workstations across a classroom and even at remote locations, it is difficult to keep up with the activities of every group. To help provide a unified overview of group activities, we plan to create a collage of information featuring collected and submitted information from the groups and their VS archives. Several systems create a collage of Web images used to track changes in a Web site or to view images seen by fellow Web surfers sharing a common proxy [22,132,154]. These information collages are designed to be used to passively maintain awareness of a collection of Web sites by displaying as a screensaver or on the screen background. In our system, the collage will include synchronously displayed information (images, video clips, real-time messages) as well as regularly updated asynchronous information (activity monitors, screenshots, project plans).

We plan to display the information collage on a large screen "liveboard". Recently, passive displays have been used on large screen systems as an aid in maintaining awareness of Web traffic [251] and group activities [109]. Instead of relying solely on automatically generated data (as in the Skog work) or on user submissions (as in Greenberg), we will combine the two to avoid a potentially unreliable dependence on user participation yet still encourage and leverage submissions. The automatically generated displays will include visualizations outlined previously as well as visualizations that show relationships between groups to enhance inter-group awareness. The contents of the collage will be controlled by a central administrator (presumably the teacher) who will provide high-level control over the shared contents depending on the desired degree of interaction between groups. The collage will show similarities between projects and project goals in situations where sharing of ideas is encouraged.

In addition, by using a liveboard as opposed to a static, non-interactive display, we will be able to provide interaction capabilities, allowing teachers to customize the view on the fly, point out errors, focus students toward goals, and expand the display to show details about items of interest. Each item in the collage will be interactive such that a teacher or student could click on it to obtain details about the image, text, or video. We plan to situate the liveboard at a location in the classroom that is clearly visible to the students and the teacher. We expect that this solution will help foster awareness among groups, between groups, and with teachers.

3.4 Multifaceted evaluation of groupware

Evaluation of single-user computer systems and applications has significantly advanced over the past two decades [202]. In particular, the value of using more than one method is well understood — it is common to see logging studies supplemented with user interviews, or thinking aloud protocol studies supplemented with summative performance tests. Different methods are differentially susceptible to problems of internal validity, statistical conclusion validity, construct validity, and external validity [68,181]. Integrating methods offers a strategy for minimizing central threats to validity and makes it possible to triangulate [25] or mediate [243] evaluation interpretations. However, the evaluation of single user systems typically uses multiple data for supplementary rather than integrative purposes.

Studying groupware systems of significant social scope, such as classroom education projects [96], requires that multiple methods be used and fully integrated in order to accurately characterize system use. Real-time data collection from a single perspective (conceptual, method, location, investigator, or in time) becomes unrealistic because events both physical and electronic transpire that are distributed in time and space. Also, when groups of users work together, the volume of potentially interesting data and data relations increases more than linearly with the number of participants. It is often necessary to capture and collate event streams that are physically dispersed but transparently synchronized, for example, actions various users take via keyboards, the echoing and consequences of these actions, comments uttered aloud, and manipulation of physical objects in the work context. Causal factors appear at every level — the individual user, the proximal group, and the dispersed, computer-mediated group — and they interact fluidly. Contextual factors, work practices, and organizational dependencies are seen to dominate the usability and usefulness of groupware, mandating field studies of fully implemented systems instead of laboratory exercises that are limited in scope [110,111]. Although the factors involved in evaluating multi-user systems are more complex, in practice multifaceted evaluation of groupware is less common.

3.4.1 Studying awareness in the field. We have made significant progress in developing a multifaceted approach to evaluating computer-supported cooperative tools [197]. The proposed work continues this methodological development specifically directed at awareness mechanisms. Our current evaluation work incorporates new tools and procedures for mechanically and analytically bridging methods and data. Through direct observation and contextual inquiry, field notes, and video records, synchronous interactions are combined with computer logs, constructed artifacts, interviews, and surveys. At the heart of integrating these approaches, are the *integrated activity scripts* created from tools we have developed to combine multiple data types with records created from our multi-user computer logging tools. The scripts reconstruct distributed group activity and make accessible and explicit the phenomenon relevant to groupware awareness and usability.

One of the more salient outcomes of our prior evaluation work has been the critical incident reports describing communication and planning problems including misinterpretations, conflicting directions, and halting interaction among teachers and students arising from group awareness problems [43,82,198]. In the proposed work we will develop a multifaceted evaluation framework that will extend our overall strategy of method and data integration with the use collaborative “breakdowns” and “critical incidents”. We will build on the work of Winograd and Flores [284] who studied breakdowns in the context of single-user systems and Easterbrook [84], who identified collaborative breakdowns as “a mismatch between the expectations of one participant and the actions of another”. We will also draw on Flanagan's [99] notion of a critical incident, defined as an episode of behavior and experience in which things go surprisingly poorly or well. The two concepts have many similarities in use [6,**Error! Reference source not found.**,230,244,247,268].

The evaluation approach described above is designed specifically to be used with field investigations that afford the opportunity to study more realistic and longstanding awareness issues when complex tasks are performed in authentic contexts. Significant outcomes resulting from technological innovations often emerge slowly [214], and studying long-term system use becomes essential for uncovering phenomenon that develops over time, such as learning, adaptation, and group process evolution [26,153,272]. However, this approach can be optimized by interleaving a set of laboratory experiments to more specifically test and verify hypothesis derived from the field studies, and in turn used to construct new relationships that can then be validated in the field [270]. By interleaving research settings, realism, generalizability, and precision are maximized. The more comprehensive laboratory studies will be experimental simulations. With this form of experimentation, generalizability and precision are maintain by simulating a naturally occurring system, while the precision of measurements are greatly enhanced through the control of extraneous variables.

3.4.2 Studying awareness in the laboratory. The methodology used in the experiments will draw heavily from research in human factors that investigates the “situation awareness” of pilots in highly dynamic environments [89,91,93,217]. These methods are appropriate for laboratory studies of groupware awareness because of the similarity in the underlying constructs studied and because the methods were designed to be used for controlled experimental simulations. Four broad classes of measures will be considered: performance-based, knowledge-based, verbalizations, and subjective measures. Performance-based measures directly capture participants' responses to experimental situations. Developed from observable actions, these methods indirectly infer the participants' level of awareness. Through the careful development of scenarios, experiments can be manipulated by introducing subtle system state changes, disruptions, and anomalies that produce measurable responses in participants reflecting their level of awareness [236]. Pseudo-agents or "wizard-of-oz" techniques can be used to produce these conditions and allow for the measure of specific and testable responses. Controlling for testable responses reduces the ambiguity between performance and inferred awareness [219].

Knowledge-based measure will include queries and probes to elicit levels of awareness. We will adapt the situation awareness technique of suspending or freezing the experiment and asking a series of questions about the state of the tasks, environment, and other collaborators. We will borrow heavily from the Situation Awareness Global Assessment Technique (SAGAT), a method shown to have a high degree of validity, sensitivity, and reliability [92]. This method produces an objective assessment of users' awareness by halting activities at specific points and querying participants about their perceptions. These snapshots can then be used to produce an overall index of awareness. Under certain conditions we will also employ confederates in the studies acting as collaborators. The confederates will be used to 1) shape the direction of collaboration, (2) request certain information to assess the participants' level of awareness, and (3) to evoke higher levels of verbalization by participants [152].

Lastly, we will collect verbal protocols and subjective measures. Participants will be asked to think aloud during portions of the experiments. These verbalizations will provide specific information regarding problem-solving strategies to maintain awareness [219]. Developed for traditional psychological research [94], the thinking-aloud method is one of the most useful usability engineering techniques practiced by evaluation specialist [202]. Our subjective awareness scale development will include elements of the Situational Awareness Rating Technique (SART) [91,264]. These scales will be multidimensional and will be combined with the scales used by Monk and Watts [190,275] to measure awareness in collaborative systems. The use of the scales may include self-assessments, expert judgments, and collaborator ratings. It is often useful to correlate ratings from different groups to assess levels of agreement [12].

Few studies have investigated awareness empirically under controlled conditions, and even less work has been done in realistic working contexts. The development of a multifaceted evaluation framework for awareness will greatly advance the current approaches to designing and developing state-of-the-art collaborative systems. Our prior work in developing methodologies to evaluate collaborative technologies in authentic contexts uniquely positions us for furthering this work through the integration of field and laboratory approaches. Combining different measures of awareness allows researchers to pinpoint awareness breakdowns throughout the different stages of activities leading to overall performance goals and objectives [271]. This framework will provide a methodological foundation, useful to researchers and practitioners alike, that can be used as a standard for evaluating and comparing collaborative computing systems.

4. Plan of work

We have planned a set of coordinated field and laboratory studies. Findings from both types of studies will provide feedback and direction for the development and refinement of planning and awareness support in the Virtual School. Each set of activities will take place in overlapping cycles as diagrammed in Figure 2. Initial work will rely on the awareness tools currently implemented in the Virtual School; as lab and field data become available, the results will be interpreted and used to guide refinement and re-design of the awareness support. This in turn will raise opportunities and constraints for a more focused and extended field study. This iterative cycle will be repeated in the second year; the third phase will combine a follow-up field study with work aimed and generalizing and disseminating the results of both the empirical and software development work.

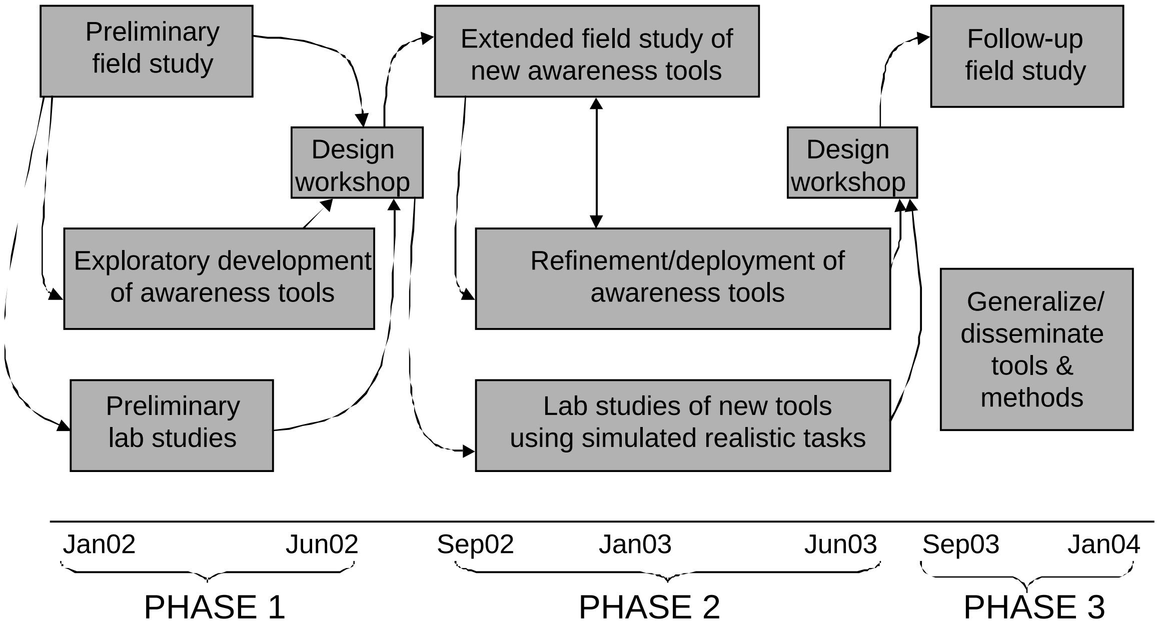

Figure 2: Proposed research activities and their interactions

A major external constraint on the plan of work is the school system schedule—classes begin in late August and continue through early June; teachers are available for planning and development during the summer months. Thus in the following, we decompose and discuss the work plan into segments that coordinate with the standard school system schedule.

4.1 Phase 1: Initial planning and development (January 2002 – August 2002)

The Virtual School is already installed and in use in a number of classrooms in Montgomery County, Virginia (the result of work funded by REC-9554206). As a result, we plan to begin field work in two classrooms immediately, investigating the system's current support for awareness in collaborative science activities. For example, one well-developed and popular activity involves eighth grade students mentoring sixth grade students in physical science experiments with a Lego construction kit. Students in this activity collaborate both asynchronously (e.g., developing or answering thought questions) and synchronously (e.g., creating the Lego constructions). In carrying out such tasks, the students and teachers rely on awareness information such as the presence of identity information (i.e., avatars), chat labels, videoconferencing windows, email or notebook logs, and so on. We will enumerate all such information and examine whether and how students and teachers use it to facilitate collaborative work.

We will use field methods developed in our previous research [197]: We will regularly perform synchronized contextual evaluations of the two classrooms, making field notes and video records. Several researchers will meet weekly to review these records and jointly interpret and classify them, focusing on the awareness categories and needs summarized in Figure 1. We will also gather interaction logs from the machines active in our network. We will create integrated activity scripts incorporating time-stamped, transcribed video and field notes, as well as data logs of Virtual School interactions; segments of this master record will then be classified in an evolving type system. Each type of data will be used to identify breakdowns and critical incidents; the aggregated data will be used to identify sets of causally-related but distributed factors that make up major awareness themes. Finally, we will use our Collaborative Critical Incident Tool [43,198]—developed for shared reporting of salient episodes—to engage the teacher-participants in further discussions and interpretations of collaboration episodes. The field study will be carried out by Carroll and Dunlap with the assistance of one research assistant.

In parallel with this initial field work, exploratory development of new awareness techniques will begin. For example, we will investigate techniques for aggregating and displaying group activities on large displays in the classroom, as well as workstation-specific tools that enhance awareness of group plans and of the activities of individual collaborators. This work will be inspired both by the literature and technology of awareness, and by the findings and interpretations of the concurrent field work. The software development will be carried out by McCrickard and Isenhour and two research assistants, one working primarily with the large screen display technology, the other refining and extending tools within the current Virtual School environment.

The preliminary field study will also help us to specify a preliminary series of laboratory studies. For example, if the field data show that students have difficulty appreciating what their remote partners have done since the last joint session, we might design and conduct an experiment contrasting several different techniques for conveying project history information.

A more general contribution of the field work will be to development and refinement of awareness evaluation methods. For example, we will need to model of the awareness needs that students and teachers have when engaged in different kinds of tasks. We will begin to create these models from the field data, perhaps using the method of "rich pictures" to capture the many interacting factors within a classroom situation [189]. More detailed analysis of awareness variables may be supported by computer technology usage diagrams [275]. We will also develop methods for measuring the cognitive and social impacts of awareness, for example assessing the degree of common ground evident in a collaborative exchange, and measuring levels of perceived interpersonal awareness.

The lab studies themselves will adapt classic methods from social psychology, in which participants are given communication tasks, sometimes interacting with confederates [4, 27, 140]. However in our studies group members will communicate only via networked software. We will begin with a set of brief pilot studies to operationalize and refine the independent variables (e.g., types of awareness information and tasks, number of participants) and dependent variables (e.g., task performance time and errors, frequency and length of turn-taking, memory, interpersonal awareness and engagement). The pilot studies will be followed by a formal experiment. We will recruit undergraduates as volunteer participants in the laboratory studies. The laboratory studies will be planned, conducted, and analyzed by Rosson and Neale and one graduate assistant.

During the summer months, all research participants will work together to merge our findings thus far, and to design and develop collaborative science projects that will be used by the two teacher-researchers in their classrooms. Early in the summer, the results of the empirical and software development work thus far will be shared and discussed in an all-hands analysis and design workshop. The product of this one-week workshop will be the specification of a long term collaborative science activity that will exploit the new awareness capabilities of the Virtual School, and that we expect to benefit from all three levels of awareness (i.e., social, action, and activity). We will also use this workshop to plan a series of laboratory studies that will complement the field work. The remainder of the summer will be spent preparing for the classroom activities, the corresponding field study, and the laboratory studies.

Although the primary aims of Phase 1 are to refine our understanding and support of awareness in collaborative activities, the work will also contribute to the research on groupware development and evaluation methods. We will draft a report describing the interrelations between the field, laboratory, and software activities (this report will be refined and extended in the subsequent phases). This report will summarize each set of activities and document how the concepts and findings from one type of activity have contributed to those in a parallel effort. For example, it will ground the variables and measures of awareness used in the laboratory studies with the observations from the field work.

4.2 Phase 2: Extended field study (September 2002 – May 2003)

The major focus of Phase 2 will be a field study conducted over the entire school year. Depending on the outcome of the summer design work, the study may investigate a set of independent activities (e.g., multiple 2-4 week collaborative projects) or a single 6-9 month project. In either case, we anticipate that synchronous remote collaboration sessions will take place once every week or two. As in Phase 1, we will document these sessions with the field methods established in our earlier work—direct observation and field notes, video recordings, computer logs, computer-generated artifacts, questionnaires, interviews, critical incidents, and contextual inquiry [197, 198]. The field work will be carried out by Dunlap and Neale and two graduate students, with assistance from Carroll, Isenhour, McCrickard, Monk, and Rosson.

In contrast to the activities observed in Phase 1, the classroom activities in this phase will have been specially designed to examine the impacts of awareness. As a result, our analysis will be more extensive, incorporating both quantitative and qualitative methods. Quasi-experimental interrupted-time series designs will be used to compare pretest and posttest measures collected at multiple intervals. Although all students will use the same Virtual School functionality, some independent variables naturally differentiate: Group composition is likely to vary with respect to gender-balance, number of members, and distribution of grade levels. Different groups tend to develop different practices (for example, using annotations vs. email to share content updates). Analysis of variance will be used to compare the number and type of features used across a number of awareness dependent variables. For example, increased use of awareness features (e.g., viewing an information collage) may be associated with reduced text discussion in the chat, or with reduced email traffic. We will also use the subjective scales of awareness created during Phase 1 (these will combine the work on situation awareness with the more specific awareness measures developed by Watts and Monk [275]), to determine if availability and reference to awareness tools increases perceptions of awareness.

To create a complementary qualitative view of students' use of awareness information, breakdown analysis will be combined with critical incident analysis to identify, classify, and analyze awareness problems (e.g., lack of cooperation in turn-taking, failure to understand collaborators' contributions). We will also apply activity set methodology [275], a state-based approach that characterizes sequences of behavior as events. Behaviors are categorized and represented on timelines that show state changes. A state might be time spent using the activity-planning tool, or amount of time spent viewing an information collage. Contingencies among group members can be measured as time spent in a state, number of times a state occurs, or the synchronization of states across distributed group members.

As in Phase 1, the second phase will include laboratory studies of specific awareness techniques. However we will build from our experiences in Phase 1 to design and conduct a more ambitious series of experiments. Specifically, we will simulate semi-realistic collaboration tasks, for example tasks that are extended in time, and that involve some of the complex coordination typical of real world collaboration. As an example, two or more volunteers might participate in a sequence of tasks, some carried out synchronously (perhaps including one or more confederates), some carried out asynchronously. These tasks will allow us to investigate activity awareness in a controlled setting, in addition to the simpler constructs of social and action awareness. A key methodological challenge in this will be developing a cover story that motivates and coordinates simulated collaborations of this sort. Again, our intent is to contribute to the methodology of groupware development and evaluation at the same time as we learn more about the impacts of specific awareness features. The laboratory studies will be designed, conducted, and analyzed by Neale and one research assistant, with the assistance of Rosson.

The awareness features of the Virtual School will continue to be refined and extended. Some of this work will be in direct response to the field study as it takes place; for example, refining or modifying features that prove to be either very useful or problematic as the students carry out their project. Other aspects of the work will be more substantial, such as the implementation and deployment of the large screen display techniques. Our general approach will be one of constant iteration and re-deployment. In our earlier VS work, we developed simple and robust methods for rapid prototyping "in-situ"; we often made small changes to the system in one week that were used by students during the next week. Indeed the underlying architecture is specifically designed to support this style of development [148]. McCrickard and Isenhour and one research assistant will carry out this work.

Phase 2 will conclude with the analysis, design, and implementation of a refined set of classroom activities. This will again be initiated during an all-hands workshop held at the beginning of the summer, followed by the development of materials in support of the activities and the final field study. A constraint operating at this point will be that the implementation and evaluation of the revised classroom activities can take place before the end of the year.

4.3 Phase 3: Iteration and generalization (June 2003 – December 2003)

The final phase will be one of consolidation, generalization, and dissemination. A follow-up field study will provide feedback on the new awareness techniques supported by the Virtual School and the impact of this support on cross-classroom collaborations. The findings of the field and laboratory studies will be integrated and published within the growing literature on awareness techniques. The awareness techniques themselves will be generalized and deployed within other collaborative systems (e.g., the MOOsburg community network [52]), and will be packaged for dissemination to other research groups. The methodological analysis of the interrelations among the three parallel strands of research activity will be finalized and published.

4.4 Project management and dissemination plan

Carroll will serve as Project Director, responsible for overall management. Technical roles of all investigators and graduate research assistants are detailed above and in the Budget Explanation.

Our dissemination effort focuses on (1) HCI researchers interested in user interface techniques for supporting collaborative planning through enhance mutual awareness in the context of realistic work activity, and (2) HCI researchers interested in multifaceted evaluation methods (including the synthesis of field and laboratory methods). The fact that this project integrates research on interface techniques, realistic applications, and laboratory studies provides an excellent opportunity to speak to both communities, and to pull together their approaches and interests. We will submit reports to the annual conferences of the Human Factors and Ergonomics Society and the ACM Special Interest Group on Computer-Human Interaction, and the ACM Conference on Computer-Supported Cooperative Work.

5. Results from Prior NSF Support

Leveraging Networks for Collaborative Education in the Blacksburg Electronic Village
REC-9554206, (1/1/96 - 12/31/99; $1,117,128, plus $173,770 in supplements (CISE Postdoctoral Research Associate in Experimental Computer Science, POWRE, & REU)
Principal Investigators: J.M. Carroll, M.B. Rosson, J.K. Burton, L. Arrington, C. Shaffer
URL: http://linc.cs.vt.edu

The project (LiNC: Learning in Networked Communities) designed, implemented, and evaluated a networking infrastructure for collaborative science activities. The key results were: (1) a long-term participatory design technique that spans the entire system development lifecycle; (2) development and assessment of a Java-based networked learning environment emphasizing support for the coordination of synchronous and asynchronous collaboration, including planning, note taking, experimentation, data analysis, and report writing; (3) development of a component software architecture for the learning environment; (4) development of collaborative science activities that integrate synchronous and asynchronous interactions, are multi-faceted and extended in time, and in which collaborative episodes are diverse and often ad hoc; and (5) development of a comprehensive set of evaluation instruments and procedures for distributed collaborative software, including attitude scales, contextual interviews, classifications for critical and routine classroom episodes, and programmatic creation of master logs that include ethnographic field notes, categorized and annotated video transcripts, and interaction logs.

The Montgomery County Public School system is continuing to use the software and content developed in this project, and has recently won a grant for further content development.

The project supported two post docs (R.T. Eales, now teaching at University of Luton, in England, and J. Koenemann, now a researcher the German National Research Center for Information Technology) and 18 graduate students (one of these was African-American). There were 22 undergraduate researchers; 9 were supported by REU Supplements. The project produced 2 undergraduate honors theses [100,185], 1 Masters thesis [144], and 2 PhD dissertations [7,61]; 5 PhD dissertations are currently underway (Dunlap, Ganoe, Neale, Schafer, Seals). There were 40 technical publications and presentations [8,9,10,11,34,35, 36,38,39,40,41,42,43,44,45,46,47,49,50,52,53,54,55,56,57,62,63,64,82,83,100,104,133,145,146,147,148, 157,197,198,221,222,239,246].

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