THE ROLE OF COMPUTATIONAL COGNITIVE ARTIFACTS IN COLLABORATIVE LEARNING AND EDUCATION

PIs:	Gerry Stahl	Computer Science & Cognitive Science
	Bob Craig	Communication
	Timothy Koschmann	Medical Education
	Curt LeBaron	Communication
	Lesia Palen	Computer Science & Cognitive Science
	Tamara Sumner	Computer Science & Cognitive Science
Graduate Assistants:	Alena Sanusi	Communication
	Elizabeth Lenell	Education
	Leo Burd	Computer Science

PROJECT SUMMARY

This project builds on cognitive science theories of the role of artifacts in learning, understanding and working. It also adapts methods of human interaction analysis – based on detailed study of digitized video recordings – to the investigation of the use of computer-based simulations and communication media in collaborative learning settings. It thereby develops and tests a methodology for the field of CSCL (computer-supported collaborative learning).

This methodology allows researchers to investigate sessions of collaborative learning by describing interactions of participants with artifacts, expressed through discourse patterns and social practices. Specifically, computer support systems are also conceptualized as artifacts, so the methodology includes assessment of how particular software systems are adopted and whether their designs are effective in usage. In contrast to prevailing methodologies for educational technology that are based on psychological theories of individual learners, this methodology is grounded in social theories of human interaction and is therefore especially suited to support of collaborative learning.

The project studies how a small group of middle school students learns to use a computer simulation of rocket launches as a tool for scientific knowledge-building. As the project goes on, this simulation is incorporated into an on-line environment for knowledge-building. The research methodology is then adapted for virtual collaboration and provides formative evaluation for the computer simulation, the collaboration software and the classroom pedagogy. The goal is to have the students treat the simulation as more than a video game, the communication medium as more than a chat room for unreflective opinions and the curriculum as more than a series of isolated exercises. The project aims to understand in a detailed way how the artifacts participate in deeper collaborative knowledge-building processes.

The proposed project fits in ROLE's quadrant 2 because it builds bridges from the cognitive sciences and human interaction analysis to research on learning. It also fits in quadrant 3 because it extends an existing research base to support specific educational approaches within CSCL.

The interdisciplinary project team includes faculty and students from cognitive science, communication, computer science and education. They have conducted a number of pilot studies to explore various aspects of the project and they bring together the necessary mix of backgrounds. In particular, the team consists of researchers who have conducted pioneering work in human interaction analysis, CSCL theory and design of computational media. The project synthesizes this work to produce a much needed methodology for the design and development of computer support for education, grounded in an expanded theoretical understanding of the role of computational cognitive artifacts in collaborative learning.

PROJECT DESCRIPTION

Motivation

Much of the focal activity in school and work centers around physical and/or symbolic artifacts. Increasingly, these are "*computational cognitive artifacts*," that is, computer-based systems such as *simulations* or conferencing *media* that extend our ability to visualize, analyze, communicate and learn. Astrophysicists, for instance, model on mainframes phenomena that cannot otherwise be studied under controlled conditions; science students use computer simulations to observe idealized interactions. The Web was originally created for physicists to share the latest theories of subatomic matter; knowledge-building environments like CSILE (Scardamalia & Bereiter, 1996) are now being developed to let students collaborate on theories of everyday observable phenomena.

Recent trends in the cognitive sciences stress the central role that artifacts play in modern human cognition. The literature in CSCL (computer-supported collaborative learning) picks up on this view and relates it to learning in social settings. There are many suggestive remarks about the cognitive function of artifacts in writings from anthropology (Donald, 1991; Geertz, 1973; Hutchins, 1996; Hutchins, 1999; Hutchins & Palen, 1998; Suchman, 1987), cultural psychology (Bruner, 1990; Cole, 1996; Engeström, 1999; Norman, 1993; Vygotsky, 1930/1978), philosophy (Gadamer, 1960/1988; Hegel, 1807/1967; Heidegger, 1927/1996; Husserl, 1936/1989; Marx, 1867/1976; Wittgenstein, 1953), CSCL (Bereiter, 2000; Ehn, 1988; Keil-Slawik, 1992; Koschmann, 1999; Roschelle, 1996; Stahl, 2000b), cultural theory (Bakhtin, 1986; Benjamin, 1936/1969; Hall, 1996; Heidegger, 1935/1964; Wenger, 1998) and communication and social theory (Bourdieu, 1972/1995; Giddens, 1984; Habermas, 1981/1984; Lakoff, 1987; LeBaron & Streek, 2000; Streeck, 1996). However, there is no cohesive account of how people acquire understanding of the meaning of new artifacts or develop the skills required in using them effectively. We are therefore studying the texts referred to in the preceding citations as a preliminary to the proposed project. Based on these texts and empirical classroom evidence, the project will try to formulate the needed cohesive account.

Methodological extensions to conversational analysis developed in the past decade provide a promising access on a micro-ethnographic level to the processes involved in learning to use artifacts, including computational cognitive artifacts. The adoption and use of artifacts in collaborative settings takes place within complex interactions involving: (i) artifacts that have affordances, (ii) people who bring perspectives to bear, (iii) social practices reflecting various cultures and (iv) discourse patterns or mini-genres. The conversation analysis approach grounds its interpretation of these interactions in evidence of how the participants take each other's utterances (Heritage, 1990). It thereby provides access to actual phenomena of learning as they unfold (typically recorded on digitized video to allow for detailed study). A very different view of learning emerges from this approach than that provided by comparing results on pre- and post-tests to infer that specific facts or skills were somehow acquired by individuals. There have been scattered attempts by other researchers in CSCL and CSCW (e.g., Bødker, 1996; Roschelle, 1996; Suchman & Trigg, 1991) to use video analysis, and we will be incorporating and extending their work within our project.

The field of CSCL holds great promise for the future of education with its dual emphasis on collaboration and computational artifacts; both these potentially overcome the limitations of the unaided individual mind. But there is today no adequate methodology – grounded in theory and research – for the design of CSCL artifacts. Current assessment of educational technology relies on either pre/post testing of individuals or coding of isolated statements – both of which systematically exclude evidence of the interaction processes by which collaborative knowledge is socially constructed. The proposed project brings together experienced researchers in micro-ethnography, collaborative learning and computational support. Focused on empirical study of middle school science education, this project will develop, investigate and assess a much needed, theoretically grounded, socially-oriented methodology for observing the effects of computational artifacts in the classroom.

Pilot Studies

We have conducted three pilot studies to explore a methodology for studying the adoption and use of computational cognitive artifacts in settings of collaboration and education:

(a) A scientist mentors a small group of middle school students conducting a project using SIMROCKET, a computer simulation of rocket launches. Micro-ethnographic analysis of this three-hour interaction highlights successes and difficulties the students encounter in learning to use the simulation as an experimental tool, in negotiating goals for investigation, in coordinating data collection, in analyzing results and in drawing rigorous conclusions. One can

track the development of individuals' theories and the gradual adoption by the group of the scientist's systematic approach and of his comparatively precise formulations. At the same time, one can observe how various proposals by individuals are negotiated and taken up within the group. Artifacts (the simulation, instruction page and data sheet) became meaningful and cognitively effective through their integration within gradually adopted social practices (taking and sharing data; computing results; deducing conclusions) and discourse patterns (stating hypotheses; presenting evidence; arguing for theories; referencing artifacts).

(b) WEBGUIDE, a knowledge-building environment for discussing topics via the Web, is used in a middle school environmental science class and in college seminars on CSCL (Stahl, 1999b). This software is being revised and extended in response to the findings of its use in such settings. WEBGUIDE goes beyond similar discussion-based systems by supporting the representation and development of personal and group perspectives (Stahl, 1999a). Eventually, it could be used to facilitate and scaffold a group of students to use a simulation like that in (a) within an on-line, purely computer-supported interaction.

(c) JIME, a Web-based journal for interactive media in education, conducts group reviews of submitted articles on-line, and then includes an edited version of the review discourse with the published article (JIME, 1996-2000). We are currently analyzing the on-line review discussions to draw conclusions about how the journal software and practices might be improved. This study provides an example of how to analyze on-line discourse, extending the methods of conversation analysis.

Research Project

We propose to replicate our pilot study of SIMROCKET more rigorously and under varying conditions. We will improve the technical recording conditions to produce a higher quality record for transcription and analysis. We will use different teachers with different styles and different groups of students at somewhat different ages. The SIMROCKET simulation and its supports (e.g., a spreadsheet for data analysis) will be modified. For instance, students may be empowered to construct rockets with different selections of characteristics.

As is clear from our pilot studies, simply sitting students in front of a computational artifact will not automatically build knowledge. The teacher, curriculum and established social practices play essential roles, that will be investigated in the project. For instance, in the SIMROCKET pilot we observed the teacher repeatedly modeling patterns of behavior, analysis, questioning and articulating The students were observed gradually adopting some of these. The enormous complexity of the challenge to middle school students presented by a simple simulation becomes increasingly clear as one carefully studies their activities in transcribed video segments.

Later in the project we will move from face-to-face to virtual collaboration. Without the detailed study of the face-to-face interactions it would be impossible to design effective online scaffolding. We will adopt our methodology to observe the new interactions associated with new computational artifacts like WEBGUIDE. Out pilot studies of online collaboration indicate that much interpretation of interaction carries over from video transcripts to online logs, although with changes in the execution and meaning of turn-taking and other features.

This project will produce a methodology for observing the understanding, adoption and use of computational cognitive artifacts – that is, a methodology for studying collaborative learning and for studying the effectiveness of software artifacts. Specifically, the project will analyze at a micro-ethnographic level how middle school students acquire scientific practices in the use of computational cognitive artifacts. How does the understanding, adoption and use of such artifacts take place within the development and interplay of culturally regulated social practices and discourse patterns? And then how do these artifacts function within cognitive and collaborative activities as evidenced in behavior and speech? The project will also explore how Web-based media can support such learning in formal settings of collaboration. It will contribute a methodology that spans face-to-face synchronous and on-line asynchronous interaction. Such a methodology is desperately needed in order to make significant and systematic progress in CSCL as a research field.

Theoretical Framework

We start from three principles enunciated by Vygotsky (1930/1978; 1934/1986):

(1) *Mediated cognition*. Modern adult human cognition is thoroughly mediated by physical and symbolic artifacts such as tools and words. We extend this to the use of computer-based artifacts like simulations and discussion media.

(2) *Social cognition*. Meanings and practices are first established interpersonally and may then be internalized in individual minds. We take advantage of this by analyzing the interpersonal interactions, which are largely observable.

(3) *Zone of proximal development*. A student learns most productively when guided somewhat beyond his or her current skill level by peers or a mentor. We use this principle to design experimental situations in which a small group of students is challenged to engage in a scaffolded scientific task.

We conceptualize our subject matter as the process of "knowledge-building" (Bereiter, 2000). This is an active collaborative learning process in which a small community constructs *conceptual* meaning. For instance, in pilot study (a) the participants come to understand the effect of different variables upon future rocket launches; in study (b) students develop interpretations of texts; and in study (c) reviewers build a consensual critique of an article. The process of collaborative knowledge-building is interpersonal and observable – primarily through analysis of the discourse through which it takes place.

Collaborative knowledge-building involves an interplay between individuals and the group, with individuals contributing from their personal perspectives and the group accepting these contributions in its own way (Stahl & Herrmann, 1999). This perspective-taking and perspective-making unfolds in the observable world of signs and artifacts, such as spoken utterances and external memory devices (Boland & Tenkasi, 1995). The physical and symbolic artifacts mediate between personal and group understandings (see figure 1).

The social perspective of our theoretical framework provides conceptual unity to the project. We are interested in supporting collaborative knowledge-building, seen as a social process. Our methodology is designed to analyze that process as it displays itself intersubjectively. We view our computational artifacts – simulations and media – as components and facilitators of the social process underlying educational practices.

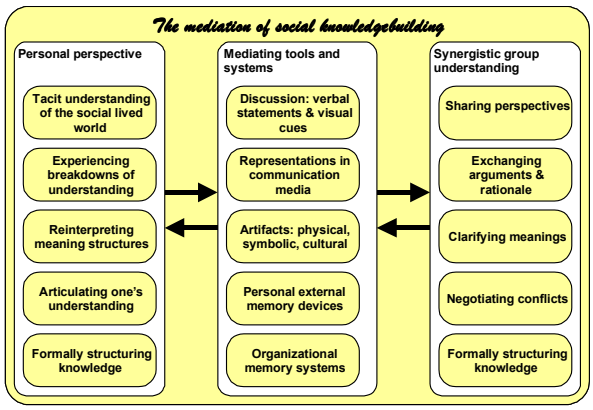

Figure 1. A theoretical framework for analyzing the mediation of social knowledge-building.

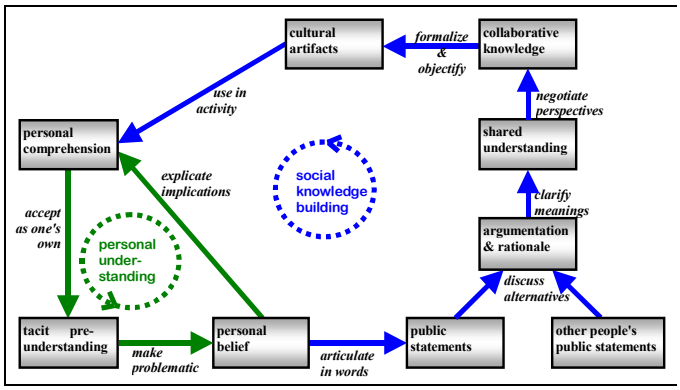

Figure 2. A paradigmatic cycle of social knowledge-building activities.

Educational Technologies Used and Developed

Computer and network technology allows us to design new mediating artifacts that can support collaboration and knowledge-building by extending cognitive powers (to imagine, analyze, express) and by facilitating collaboration (virtual, asynchronous, non-linear, persistent, perspectival, personalizable, creating complex and evolving communities) (Stahl, 1999a; Stahl, 2000a). But this potentially limitless transformation of knowledge-building requires an understanding of various activities and social processes in collaborative learning. Figure 2 provides a model of a paradigmatic process of knowledge-building that reflects our initial understanding (Stahl, 2000b).

Ideally, we would like to support each activity in this social knowledge-building cycle. To that end, we have developed a number of software prototypes that provide designed media for asynchronous discussion and knowledge-building. As indicated in the table, they support many of the activities identified in our models:

Knowledge-building activities	*Forms of computer support*	*Prototype systems*
articulate in words	discussion forum	DYNACLASS
discuss alternatives	personal & group perspectives	WEBGUIDE
argumentation & rationale	argumentation graph	INFOMAP
clarify meanings	interactive glossary	DYNAGLOSS
negotiate perspectives	negotiation support	WEBGUIDE
formalize and objectify	interactive bibliography	DYNASOURCE

During the life of our project we will integrate versions of SIMROCKET into WEBGUIDE. We will extend WEBGUIDE to include useful features of the other prototypes. We will also incorporate student scaffolding – such as that used in the KIE/WISE project (Cuthbert, 1999) – based on our analysis of the role of the mentor in our studies of students interacting face-to-face.

Project Team

The project team builds on three unique research strengths:

1. The Center for LifeLong Learning and Design (L^3D) at the University of Colorado at Boulder (CU) specializes in developing computer support for collaborative learning. The Center is part of the Department of Computer Science as well as the Institute of Cognitive Science. Stahl, Sumner, and Palen are faculty at L^3D with joint appointments in computer science and cognitive science. They have designed, implemented and studies the adoption of numerous computational artifacts and digital communication media.
2. The Communication Department at CU has brought together a group of researchers who specialize in micro-analysis of communicative interactions. Professors LeBaron and Craig are leaders of this group, which includes faculty and students from Education and Linguistics as well as Communication. The group has held collaborative data sessions for several years, usually every other Wednesday.
3. The Problem-Based Learning Institute (PBLI) at the Medical School of Southern Illinois University studies collaboration within the long-established PBL approach to medical education implemented there. This approach stresses collaborative learning in small groups. Koschmann is a researcher at PBLI and a leader in the field of Computer-Supported Collaborative Learning, having organized the first two international conferences on CSCL in North America (CSCL '95 and CSCL '97) and edited two major books on the field (Koschmann, 1996; Koschmann et al., in prep).

These three groups were brought together two years ago when Koschmann spent a year at L^3D and taught a seminar on CSCL. He was active in the data sessions organized by the Communication Department, and initiated a number of on-going collaborations among the three groups.

Stahl combines his backgrounds in cognitive science, philosophy and computer science to look at collaboration simultaneously from the perspective of social learning theory and from that of practical issues of technological support. He is developing a theory of collaborative knowledge-building that stresses the long-range potential of CSCL to open new cognitive possibilities, so that virtual groups can construct deeper knowledge structures than have been possible in the past. He has also designed, implemented, and field-tested Web-based systems for supporting collaborative online discussions from personal and group perspectives. He conducts seminars on CSCL, trying out the software to be used in the proposed project. He is the Program Chair of the next international CSCL conference.

Craig has developed a meta-theory of communication theory as a form of professional discourse. His research also focuses on student discussion in university-level critical thinking courses. Thus, he has looked at the collaborative knowledge-building process on the level of professional communities as well as that of groups of college students, using micro-ethnographic analysis of discourse and of social practices.

Koschmann has explored collaborative learning and CSCL at both theoretical and practical levels. He has written on the prominent theoretical frameworks for CSCL (from Dewey, Piaget, and Bakhtin to situated cognition and activity theory). He has also engaged in micro-ethnographic analysis of episodes of collaborative problem-based learning, in order to understand how best to conduct PBL sessions.

LeBaron is an authority on the use of interaction analysis and micro-ethnography to study language usage and social interaction. He uses video analysis to get at detailed social interactions that generally go unnoticed but may play important tacit roles. For instance, he has studied the use of bodily gesture and physical space – dimensions usually excluded from computer-mediated interaction. An innovator of the micro-ethnographic methodology, LeBaron organizes an annual national workshop on "Language and Social Interaction."

Palen currently studies the use of computational artifacts (like groupware calendar systems and wireless telephony) in collaborative settings. She has also used micro-ethnography methods to study the construction of shared meaning and collaborative knowledge through discourse and non-verbal interaction.

Sumner conducts research in scholarly discourse and how it can be supported with computer technology. A founder and co-editor of the on-line *Journal of Interactive Media in Education*, she is currently analyzing the discourse structure of on-line reviews of submitted articles. She previously developed distance education curriculum at the Open University in England.

An important part of the team will be **undergraduate and graduate students** and other colleagues. The project will hire several students. They will be recruited from the departments of Education, Communication and Computer Science. The following will likely be involved: Alena Sanusi, a communication student with strong background in linguistics and conversation analysis; Elizabeth Lenell, an education student specializing in CSCL, also with strong background in linguistics and conversation analysis; Leo Burd, a computer science student with experience in technology adoption in schools in impoverished areas. Other students will be involved through L^3D's Undergraduate Research Apprenticeship Program, related student projects in various classes, relevant dissertation topics, and participation in seminars that are studied within the project. It is anticipated that the proposed project will significantly increase interdisciplinary contact among researchers – both faculty and student – at CU.

Another important part of the team will be **teachers and middle school students**. The project will start by working with the teachers who were involved in the SimRocket pilot project at Platt Middle School in Boulder. Three teachers there work as a collaborative team to teach two classrooms in a very project-oriented way.

Method of Investigation and Assessment

We adopt a recent tradition of interaction analysis (Jordan & Henderson, 1995) that we refer to as "micro-ethnography." This methodology builds on a combination of conversation analysis (Sacks, 1992) and context analysis (Kendon, 1990). An integration of these methods has only recently become possible with the availability of videotaping and digitization that records interpersonal interactions and facilitates detailed analysis. It has been successfully applied to diverse concerns, such as police brutality (Goodwin & Goodwin, 1994), criminal recidivism (LeBaron & Hopper, 1997), medical education (LeBaron & Koschmann, 1999). Micro-ethnography as we use it can be described as one discernable area of emphasis within the field of language and social interaction. Presently, micro-ethnographic research involves (1) a specific setting, or research site; (2) a detailed analysis of both audible and visible micro-behaviors, which are to be understood in terms of their embeddedness within the particular social and material environment; (3) a recognition that culture is a product and a process of naturally-occurring communication, experienced by participants who at the same time make it available for empirical study and interpretation; (4) a displayed awareness of sociopolitical concerns that are in some way addressed, consistent with the notion that societal macro-structures are embodied and sustained through moment-to-moment, face-to-face interaction; and (5) a noteworthy use, perhaps dependence, upon recent technologies, whereby analysts may look and sometimes see anew the orderly performance of social life.

Faculty of the Communication Department who specialize in studies of human interaction regularly host a series of interdisciplinary micro-ethnographic data sessions. Over time, these meetings have involved faculty and students in Communication, Linguistics, Education, Speech Language & Hearing Sciences, Computer Science, and other fields. Participants meet informally to share recordings of human communication (video, audio, field notes, etc.) for group discussion. The recordings are drawn from ongoing research projects, and often are presented during exploratory or early phases of data collection and analysis. Short data segments, usually accompanied by written transcripts, are observed repeatedly and discussed. One important goal of data sessions is to generate insights, grounded in close observation from a variety of analytical viewpoints, that will be useful in the particular research project from which the data have been selected. A second, perhaps equally important goal is to cultivate observational and analytical skills among an interdisciplinary community of researchers involved in empirical studies of human interaction.

We will build on this approach and on the expertise and methodology which has evolved through these data sessions. We will conduct our own data sessions for project staff, working intensively with our data. We have already begun a series of sessions to collaboratively analyze our SIMROCKET pilot study data. After producing a log of the three hour student/teacher interaction, we selected 24 moments (segments averaging a minute) to digitize, transcribe, post on the Web and discuss. These moments cover many themes for analysis relevant to the proposed project.

The method of micro-ethnographic analysis provides a built-in evaluation process for the project. By videotaping our sessions of students working with artifacts, we will derive a formative evaluation of the learning facilitated by the artifact. By the end of the project, we will be able to compare in a detailed and documented way how well our revised versions of SIMROCKET and WEBGUIDE perform as compared to how they worked in the pilot studies and in earlier phases of the project. In addition, we will evaluate how successful we were in the course of the project in developing, formulating and applying this methodology for studying the educational role of cognitive artifacts and for assessing the ability of students to adopt the computational artifacts into their collaborative learning.

Contribution to NSF ROLE Goals and Potential Impact

Recent research on learning and on technology in education – as surveyed in the *Report to the President* (Panel on Educational Technology, 1997) and in *How People Learn* (Bransford et al., 1999) – stresses the potential of innovative constructivist educational approaches to foster deep understanding. The latter document, for instance, argues that key learning processes are "affected by the degree to which learning environments are student centered, knowledge centered, assessment centered, and community centered" (Executive Summary). It also concludes that computer technology "has great potential to enhance student achievement and teacher learning, but only if it is used appropriately" (Ch. 9).

Our project proposes to investigate at a detailed level the key learning processes in a student-centered, knowledge-building, problem-based, collaborative-community learning environment – whether computer-supported or not. We hypothesize that *collaborative learning* has a great potential to foster deep knowledge-building when it brings together the perspectives of multiple students in a productive way. However, this requires a more detailed understanding of how collaborative knowledge-building processes work. We further hypothesize that *computer support* has the potential to facilitate collaboration by removing communication limitations and by helping to manage the complexity of ideas and interactions. However, this requires carefully designed knowledge-management applications tuned to the needs of collaborative learning.

We believe that a collaborative approach to learning and computer support in education can have a transformative impact if adopted in a fundamental way rather than being merely integrated into schooling focused on individual learning. Collaborative learning should take advantage of the social origins of all knowledge and should foster integration of multiple perspectives. Computer support can facilitate the complex interactions needed for productive collaboration by providing appropriate external memories and communication media that allow participants to interact without, for instance, always going through a teacher. Our project will increase our understanding of the social origins of knowledge and develop a methodology for assessing the role of computational cognitive artifacts in supporting collaborative knowledge-building.

While ROLE projects related to neuroscience may focus quite literally inside the head of an individual learner, this project will look outside at the social interactions through which knowledge is constructed and shared – and at the same time evidenced – in educational settings. The project is situated in ROLE's quadrant 2 because it builds bridges from the cognitive sciences to research on learning and undertakes detailed micro-ethnographic studies of educational environments. It is also situated in quadrant 3 because it is building a stronger research base to support educational approaches (e.g., scaffolded collaborative small groups), curriculum materials (SIMROCKET experiments) and technological tools (WEBGUIDE) to mediate the learning process. In particular, the project builds on diverse cognitive theories of the role of artifacts and on methods of conversation analysis and micro-ethnography in order to develop and refine new education research and evaluation methods for analyzing the role of computational cognitive artifacts in collaborative learning and education.

Project Cost Summary

The major costs for this project are salary. We have budgeted for 6 months of the PI's (Stahl) time, 1 month for each of the other faculty, 3 graduate research assistants, 2 undergraduate research apprentices and release time for teachers. The total budget is about $250,000 per year for three years.

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