INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.B. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Gerry Stahl

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 01-2	FOR NSF USE ONLY
NSF 00-126 **01/22/01**	**NSF PROPOSAL NUMBER**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **IIS - ITR SMALL GRANTS**	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				007431505	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYMS(S)
846000555	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Colorado at Boulder	**Admin. & Res. Center - East Campus** **3100 Marine Street, Room 481, 572 UCB** **Boulder, CO. 80309**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0013706000**	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **ITR/PE (EHR): Information Technology for Distributed Collaborative Learning in a Virtual Biology Lab**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ **472,610**	**36** months	**09/01/01**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
☐ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.C.9)
☐ HISTORIC PLACES (GPG II.C.9)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date ______
☐ HUMAN SUBJECTS (GPG II.C.11) Exemption Subsection ______ or IRB App. Date ______
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED ______
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
ICS/Computer Science, Campus Box 430	**University of Colorado at Boulder** **Boulder, CO 803090430** **United States**
PI/PD FAX NUMBER **303-492-2844**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Gerry Stahl**	**Ph.D.**	**1993**	**303-492-3912**	**gerry.stahl@colorado.edu**
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this proposal.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Social Security No.*	Date
PI/PD **Gerry Stahl**		SSNs are confidential and are not displayed *ON FASTLANE SUBMISSIONS*	
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 01-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debarment Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure Form to Report Lobbying,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) **Laurence D. Nelson, Director, OCG**		**01/16/01**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
303-492-6221	**Larry.Nelson@colorado.edu**	**303-492-6421**

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

PROJECT SUMMARY

This project develops, deploys, and assesses innovative information technology to support distributed and collective learning. The technology, called WEBPERSPECTIVES, is integrated into VIRTUALBIOLAB, an on-line high school biology lab environment, to allow geographically distributed students to work in collaborative groups. WEBPERSPECTIVES is a server technology that organizes displays of information from a shared knowledge repository according to personal and group perspectives. The approach of computational perspectives is motivated by a theory of learning as collaborative knowledge-building, in which the interaction of perspectives is seen as central to collaboration. The design and assessment of this technology within the virtual lab context takes advantage of micro-ethnographic video analysis of small groups of students using the software.

This research responds to the perceived potentials of distance education and collaborative learning. Distance education is increasingly seen as an attractive solution to several problems in contemporary schooling, including that of broader access to educational resources. At the same time, educational research emphasizes the importance of social interaction, communication, and collaboration for learning – something that is often overlooked in distance education environments. The WEBPERSPECTIVES technology is explicitly designed to support collaborative learning in distance education by representing the essential interaction among personal and group perspectives in collaborative knowledge-building. The methodology of micro-ethnography analyzes this interaction in order to inform the design and assessment of such technology being used in naturalistic learning settings.

To students using VIRTUALBIOLAB, this Web-based system appears as a coherent educational environment consisting of a number of features. The centerpiece of each lab curriculum is a series of exercises that students must work through, simulating the steps taken in conducting a specific biology experiment in a physical wet lab. Associated with these exercises are computer simulations, questions to be answered, background information pages, and related websites. In addition, there is a collaboration window consisting of a threaded discussion and various knowledge management tools. The threaded discussion displays all notes in a selected perspective. The perspective can be that of an individual student (the user or a colleague), that of a group of students who are working through the experiment together, that of the entire class which shares common tasks, or that of a particular knowledge management function like negotiation.

This will be the first attempt to use perspectives in distance education. The concept of computational perspectives derives from Vanevar Bush's "trails" and Ted Nelson's "transduction"; it was further developed in `Hermes`, the PI's design-support hypertext system, and in `WebGuide`, his Web-based collaborative knowledge-building system. However, it has never before been integrated with a science learning environment or used in a distance education setting. While most of the components of this system have been developed in previous work by the PI and his colleagues, they will have to be integrated in the present project. This requires the development of a flexible architecture, modification of components to be compatible with the architecture, and development of new components to fill in missing functionality. Through iterative design and testing, computational perspectives will become capable of supporting collaboration in distance education.

Collaboration is always difficult and tricky. There are complex and subtle interactions and relationships to keep track of. A central question for research in this area is whether computational support of collaboration can be made intuitive enough that people using it will be able to work fluidly, enjoy it, and be motivated to participate fully. In order to investigate this, the project will videotape small groups of students using the system and analyze their experience at a very detailed interactional level using micro-ethnography. This is a rigorous qualitative method that can make collaborative learning visible to researchers. It can reveal: (a) how well students are understanding each other and successfully building knowledge collaboratively, (b) what and how the students are learning, (c) where the software design is producing problems.

This three-year research project will be closely associated with complementary research and development, including the iterative design of the virtual biology labs and the micro-ethnographic assessment of their use by college freshman at the University of Colorado. In its third year, the project will deploy the software (VIRTUALBIOLAB with WEBPERSPECTIVES) to Advanced Placement high school biology students in the Boulder Valley School District. The project will involve the PI – who has conducted computer science and interdisciplinary cognitive science research in many successful projects – and graduate students from Computer Science, Communication, and Education. There will also be a ten-person Advisory Board of people experienced in human-computer interaction, education research, interaction analysis, and virtual environment assessment.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

PROJECT DESCRIPTION

Overview of Project Description

1. The Potential of IT Collaboration Support in Distance Science Education
2. Theory of Learning as Collaborative Knowledge-Building
3. IT Artifacts for Supporting Collaboration in a Virtual Biology Lab
4. Methodology for Assessing IT Artifacts
5. Results from Previous Research
6. Plan for Proposed Research
7. Expected Impact of Proposed Research

1. The Potential of IT Collaboration Support in Distance Science Education

The Potential of Computer Support

Based on our own experiences with software in classrooms, we have found that computer-supported collaborative learning (CSCL) has a vast – and largely untapped – potential (Kintsch et al., 2000; Stahl, 2000c). Access to global sources of information is just one facet. In addition, computer simulations can transform conceptual representations into interactive worlds for inquiry. They can transcend real-world barriers of time, expense, geography, scale, expertise, etc. to allow students to engage with and experience phenomena that have until now been unapproachable – such as Nobel prize-winning biology experiments. Hypertext systems of information can personalize presentations to meet individual learning needs, providing links to both remedial and supplemental information. Communication media can promote collaboration in ways never before possible, as well as among people who could not hitherto interact, allowing students to work with other students with similar interests far away. Structured curricular databases and shared knowledge-building environments can support student learning processes by providing access to ideas of scientists and fellow students in persistent forms that can be thought about and inter-related. However, we have seen that students always use computer artifacts in ways not envisioned by the designers. So, careful study of the artifacts in naturalistic settings is critical to the development of effective educational technology. This project will develop and integrate a VIRTUALBIOLAB Web-based system that embodies these potentials, and will assess the degree to which these potentials are achieved.

The Potential of Distance Learning

The general problems of computer-mediated education multiply substantially under the pressure to rush to distance learning. Universities and dot.com's around the country have jumped on the distance education bandwagon, without necessarily thinking through the complex educational issues involved. It is true that distance education has the potential to address various pressing educational, social, geographic, and economic issues (Keegan, 1986). It is also true that the technical infrastructure that will enable this revolution in education to proceed is being quickly set in place. However, the design and development of the necessary tools, curriculum, and content lags far behind. In the dash to market, providers of distance education are likely to settle on software technologies that were developed for other uses and are inappropriate for educational applications, curricula that implement outmoded approaches like drill-and-practice, and content that has not been tested for its learning effects. We need to develop more new models of computer support for learning that are effective in distance learning. This is particularly true of support for collaboration in distance education approaches: they too often try to get by with generic conferencing technologies like chat windows. We have seen from extensive studies of experimental knowledge-building environments like CSILE/KNOWLEDGEFORUM (Scardamalia & Bereiter, 1996), KIE/WISE (Cuthbert, 1999), and COVIS (Pea, 1993) that collaboration support for learning can be powerful. Environments like these transcend rote learning of isolated facts by engaging groups of students in discussions and explorations of challenging and meaningful scientific issues. Our WEBPERSPECTIVES software is designed to be such an environment.

The Potential of Collaborative Learning

Our theory of learning (see next section) stresses the social nature of learning and recommends support for collaborative approaches to education. But we need more than generic chat windows to encourage students to engage in scientific inquiry through discussion with other students. To begin to achieve the potential of collaborative learning, we need specialized communication media that provide specific functionality and that can scaffold the exploration of leading scientific themes. Like anyone developing scientific understanding, students should have knowledge management tools to organize, categorize, revise, summarize, question, and propose. If they are to learn how to approach a topic using scientific modes of thought that are new to them, then their interactions with other students should be scaffolded and guided through the computer interface. The integration of the WEBPERSPECTIVES collaboration medium with VIRTUALBIOLAB is designed to provide such support.

The Potential of Perspectives Support

Our theory claims that collaboration centrally involves interaction among multiple personal and group perspectives. Most communication, conferencing, and collaboration media provide no support for organizing contributions according to who made them, or for building group perspectives from selections out of personal perspectives. Some systems provide two fixed levels: personal and group – either by limiting access to various pieces of information or by defining personal and group workspaces. WEBPERSPECTIVES will be the first system that enables multiple levels of groups and subgroups, and allows new subgroups to be added interactively. Moreover, WEBPERSPECTIVES automatically includes information from certain perspectives in other perspectives (according to a user-defined "content inheritance" lattice of perspectives), so that all information accepted by a group is incorporated in the perspectives of that group's subgroups and members. This provides a computationally supported knowledge management and knowledge-building approach appropriate to the structure of interpersonal collaboration.

2. Theory of Learning as Collaborative Knowledge-Building

Learning as Knowledge-Building

The term "learning" can refer to a wide range of phenomena, from the accumulation of facts to the development of deep understanding; from the experience of anything new to the mastery of specific complex skills. Attempts to assess learning range from assumptions that people are always learning to frustration that people cannot transfer what they have learned to new circumstances (Russell, 1999). For the assessment of learning in the sciences, we prefer the term "knowledge-building" (Bereiter, 2000). This refers to the progressive construction of knowledge about a specific topic of inquiry. For instance, a group of students may gradually propose tentative answers to a scientific question, accumulate relevant data, debate alternative arguments, and converge toward a deeper understanding of the phenomenon (Donald, 1991). This process of knowledge-building takes place within a community of inquiry, in which experiments can be replicated, assumptions questioned, and insights discussed (Scardamalia & Bereiter, 1996). Knowledge-building is an interpersonal process that can be observed and documented, unlike learning, which is generally taken to be a psychological phenomenon that can at best be inferred indirectly through tests or other outcomes (Lave, 1991).

The Collaborative Nature of Learning

Knowledge-building is inherently collaborative. By "collaborate" we simply mean "to work together" (from the Latin *com laborare*). To build knowledge is to formulate theories and similar bodies of knowledge that are (or at least could, in principle be) shared by a group of people and that meet accepted criteria for contributions to knowledge (Latour & Woolgar, 1979). A high school biology class, for instance, must develop knowledge of biological phenomena and theories that meet criteria that gradually approach the standards of the field of biology. Although it may reside in the minds of individuals, knowledge is generally the result of interactions with other people, with cultural artifacts, and with shared language (Vygotsky, 1930/1978). It is often useful to conceptualize and analyze learning within "units of analysis" that include small groups, their tools, and their language (Engeström, 1999; Hutchins, 1996).

This project is guided by a theory of collaborative Knowledge-Building Environments (KBEs) that we are developing (Stahl, 2000b). This theory proposes the following principles:

- Collaborative knowledge-building is a particular view of group learning that focuses on a range of activities that take place within communities, as opposed to focusing on learning as the transmission of bits of information to individual learners.
- Collaborative knowledge-building takes place largely through the interaction among people with different understandings from multiple personal and group perspectives.
- Such knowledge-building within groups can be helped by appropriately designed information technology (IT) that supports various knowledge-building activities and supports interaction among alternative perspectives.

In the following subsections, we discuss the model of knowledge-building, the role of perspectives, and the potential of computer support.

A Model of Collaborative Knowledge-Building

One approach to better understanding how to design computer support for collaborative knowledge-building in social settings is to conceptualize the various constituent activities involved in individual and social knowledge-building. Figure 1 from (Stahl, 2000b) provides a starting point for this, combining aspects of activity theory, situated learning, hermeneutic philosophy, and distributed cognition theory (Chaiklin & Lave, 1993; Cole, 1996; Engeström et al., 1999; Gadamer, 1960/1988; Hutchins, 1996; Lave & Wenger, 1991; Nardi, 1996).

The idea of this diagram is that knowledge-building can proceed through many different activities. The sequential structure of the model is only illustrative of a paradigmatic conceptualization. We understand that these activities complexly overlap in practice. The possible relationships among the individual activities – and particularly the interactions between the personal and social – can be complex and varied. The purpose of the diagram is to suggest a number of distinct activities that could be supported by a KBE with multiple functionality; the sequential flow is not intended to imply a necessary order to the activities.

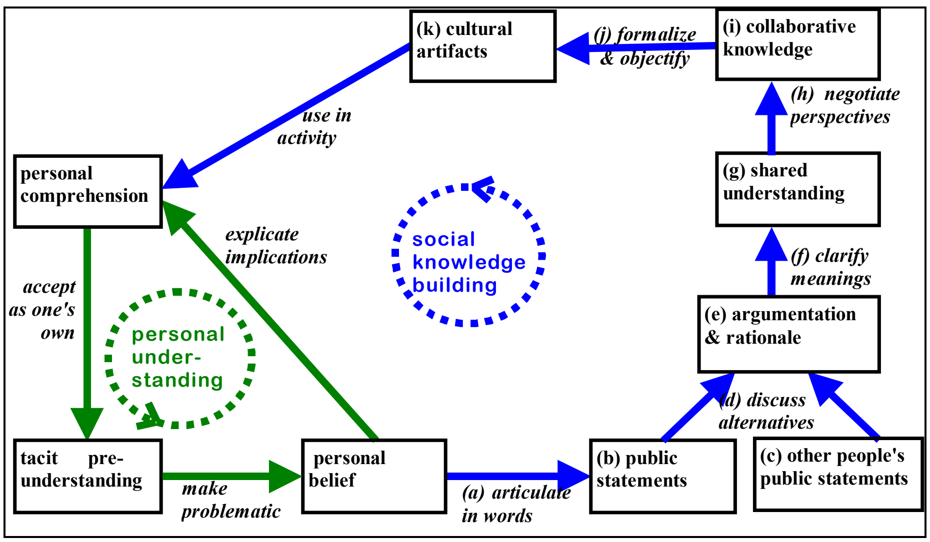

Figure 1. *A model of personal understanding and social knowledge-building*.

A set of seminal books and articles in Computer-Supported Collaborative Learning (CSCL) has formulated a view of learning as a social process of collaborative knowledge-building within communities of practice (Brown & Campione, 1994; Brown & Duguid, 1991; Koschmann, 1996; Lave, 1991; Lave & Wenger, 1991; Pea, 1993; Scardamalia & Bereiter, 1996; Wenger, 1998). However, these texts do not make the set of cognitive and social activities that underlie such a view explicit in the manner attempted in our KBE theory.

Starting in the lower left corner, Figure 1 shows a cycle of personal understanding. The rest of the diagram depicts how personal beliefs can be articulated in language and become part of social interaction. Note that the results of social knowledge-building eventually feed into personal understanding, providing the evolving toolkit of culturally-based individual cognitive capabilities. The collaborative knowledge-building process begins with (a) the articulation in language and the confrontation of these statements (b) with alternatives from other perspectives (c). The interplay of perspectives proceeds through various interactional mechanisms, potentially culminating in the reduction of shared knowledge to a text or other persistent artifact (d-k).

Perspectives in Knowledge-Building

According to the philosophy of interpretation (hermeneutics) human understanding is fundamentally perspectival. We construct knowledge from our situated perspective in the world: our historical position, cultural tools, and practical interests (Gadamer, 1960/1988; Habermas, 1981/1984; Heidegger, 1927/1996; Stahl, 1975). Computational support for knowledge-building can represent our interpretive perspectives with computational Perspectives (Boland & Tenkasi, 1995; Nygaard & Sørgaard, 1987; Winograd & Flores, 1986). (In this proposal, Perspective–with-a-capital-P will refer to the proposed computational mechanism that mirrors human interpretive perspectives-with-a-lower-case-p.) In this sense, *Knowledge-Building Environments (KBEs) with computational Perspectives* are designed to support the essential structure of collaboration. A key working hypothesis of the proposed project is that KBEs benefit from an approach that represents the perspectival nature of collaboration. A goal of the research is to facilitate the incorporation of a computational Perspectives mechanism in KBEs for distance education.

Computational Perspectives have been explored by the PI in a number of software prototypes, in his dissertation system, and in his theoretical publications (Stahl, 1993a; 1993b; 1995; 1998; Stahl & Herrmann, 1999; Stahl et al., 1995). In a single-user system, computational Perspectives may correspond to different domains or professional viewpoints on a design problem, such as electrical, plumbing, structural, and heating concerns in architecture (Fischer et al., 1993a; Fischer et al., 1993b). In a KBE to support collaboration, computational Perspectives typically provide personal or group workspaces for the development of different sets of ideas. In this way, they can model the relationships among the various personal and group interpretive perspectives at work in the construction of collaborative knowledge. This project will introduce computational Perspectives into distance education.

Computer Support for Collaborative Knowledge-Building

The form of IT that we are interested in – collaborative Knowledge-Building Environments – represents a distinctive approach that overlaps related work in Educational Technology, Computer-Supported Collaborative Learning (CSCL), and Computer-Supported Cooperative Work (CSCW). IT support for learning has traditionally been oriented toward the transmission of information to individual students. Even where it is based on a view of student construction of knowledge, as with Intelligent Tutoring Systems (ITS) for algebra or physics, the goal is measured by testing the incorporation of pre-defined content or methods into the individual's understanding (Wenger, 1987). A more student-centered, constructivist approach is taken by Interactive Learning Environments (ILE), which might, for instance, allow students to create ecologies in SIMLIFE to learn biology, or programs in Turtle LOGO to explore math concepts (Papert, 1980). In contrast, a KBE primarily supports the group process and leaves matters of content up to the participants (which may include a teacher who raises particular content issues and helps maintain focus, or a website with content and scaffolding). In this way, it applies CSCW approaches to CSCL.

A review of CSCW technology for groups (Kraemer & Pinsonneault, 1990) distinguishes group communication support systems (GCSSs) from decision support (GDSSs). GCSSs are specific communication media like email, chat, threaded discussion, and video-conferencing. In providing computational tools for group decision making, GDSSs add tools for specific types of group interactions (e.g., voting), but tend to support isolated, focused activities that collate the work products and opinions of individual members of a group. In contrast, a KBE aims to support a broad spectrum of knowledge-building activities – such as activites (a) to (k) in our model – in a way that allows deep knowledge to evolve and emerge over time. It supports the construction and interaction of alternative formulations of knowledge. It also supports the interplay of individuals and groups more comprehensively, through integrated mechanisms of divergent computational Perspectives and convergent negotiation processes that treat the group as more than just the sum of the individuals.

Assessments of CSCL and CSCW systems have defined a number of key issues for evaluating the problems and successes of such systems. For instance, in simple threaded discussion forums common problems include: short threads (a tendency for discussions to die quickly), low participation (lack of motivation to participate), few cross-references (little convergence of ideas), and superficial content (minimal depth of investigation) (dePaula, 1998; Guzdial & Turns, 2000; Hewitt & Teplovs, 1999). On the other hand, GDSSs and GCSSs attempt to decrease communication barriers within the group, while increasing task-oriented focus, depth of analysis, and decision quality (Connolly, 1997; Kraemer & Pinsonneault, 1990). Social informatics studies have raised additional issues of software deployment and adoption in addition to questions of usability and utility (Kling, 1999). These are some of the dimensions along which KBEs must be assessed within realistic learning and working social contexts.

In summary, we want to design, develop, and assess KBEs that go beyond generic chat and discussion systems (that tend to encourage exchange of personal opinions or isolated facts, but not deep shared understanding and critical inquiry). Such systems should include specific tools and structures to promote on-going debate, knowledge management, and group decision-making; however, knowledge-building should go beyond the management and dissemination of existing knowledge to support the emergence of qualitatively new, increasingly shared knowledge within a community (Engelbart, 1962; Engelbart, 1995). The following section discusses tools to support this within the proposed project.

3. IT Artifacts for Supporting Collaboration in a Virtual Biology Lab

IT Artifacts for Biology Lab

The VIRTUALBIOLOGYLAB is a complex network of interdependent artifacts. It is a complete one-semester curriculum on the Web, intended to replace biology wet labs for high school advanced placement (AP) students. Each of 10 planned labs takes an estimated three hours for a student to work through – and enables students to conduct seminal experiments from the history of biology that would not be feasible in traditional physical wet labs (see attached letter of support from the developer). There are multiple kinds of artifacts composing the software: a guiding narrative, animations of lab equipment, simulations of lab procedures, data collection / analysis / graphing / display tools, background materials (theory, history, remedial text), links to related websites, and interactive assessment exercises. The virtual lab is designed to be used by students independent of any teacher guidance, although it is loosely coordinated with a biology theory course. Because biology AP students are sparsely scattered around a school district, it is convenient to have students conduct their labs on the Web.

IT Artifacts for Collaborative Knowledge-Building

WEBPERSPECTIVES is a knowledge-building environment to support collaborative learning. It provides a collaboratively constructed and shared external memory medium on the Web. The display is dynamically computed to show a hierarchy of notes arranged as a personal or group Perspective on the persistent, asynchronous discussion. This Perspective mechanism is an artifact that people must learn how to use and navigate to mirror and support the interpersonal relationships of collaboration. WEBPERSPECTIVES also incorporates a variety of knowledge management functions that must be learned in order to manipulate the ideas stored in the system and to build effective shared knowledge. Most of the functionality of WEBPERSPECTIVES has already been pilot tested in WEBGUIDE (Stahl, 2000c) and will not be further described in this proposal. Only the central Perspectives mechanism, which must be adapted and integrated in this project, and a proposed new search and hyper-linking tool will be described.

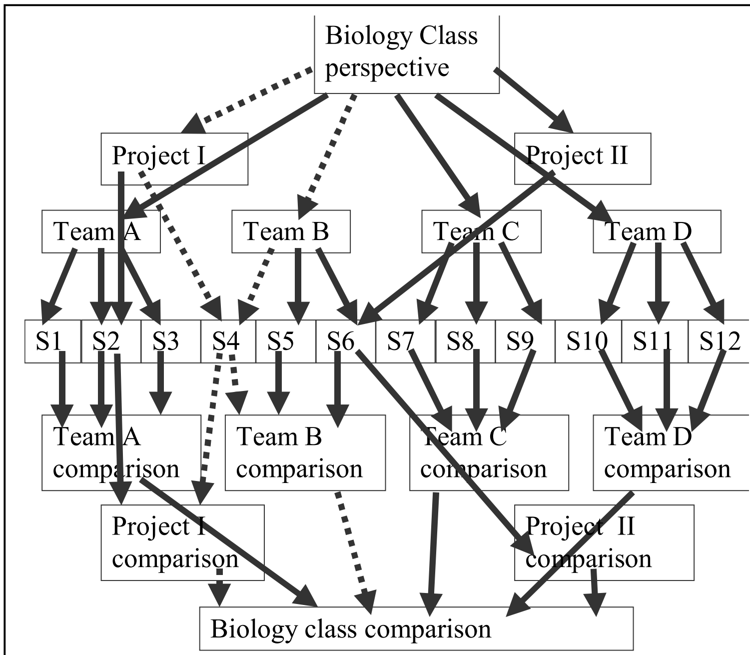

Figure 2. *A sample diagram showing the inheritance of content among Perspectives for a biology class. The class is divided into small work groups: Team A, B, C, D. Some students belong to special Projects I or II. Note how S4, a student's personal perspective, inherits information from the class perspective, Team B, and Project I, and how notes in S4 are in turn inherited in the corresponding comparison perspectives.*

IT Artifacts for Perspectives

The core of WEBPERSPECTIVES is a Perspectives server that queries a database of textual contributions to the on-going discussion and provides user interface clients with the notes that are to be displayed in the Perspective requested by the user. The Perspectives associated with a particular knowledge-base form a non-cyclical lattice (each Perspective may have multiple parents or super-groups and multiple children or subgroups). The knowledge-base for a biology class would typically have a Perspective for questions and ideas shared by the whole class, several subgroup Perspectives for teams of students who work together, a personal Perspective for each student, and comparison Perspectives that bring together contributions from the Perspectives of all members of a group (see figure 2). The algorithm for computing the contents of a selected Perspective is outlined in figure 3. This algorithm allows new perspectives to be defined dynamically and interactively through entries in the knowledge-base.

```
visible (p)
      for all nodes, if node was created in p, add node to result set
      for each parent of p in the perspective lattice, add the result set
of visible(parent)
      for each node deleted in p, remove node from result set
      for each node edited in p, remove node from result set
      for each node virtually copied into p, add node to result set
      return ordered set of nodes in the result set
```

Figure 3. *Recursive algorithm to compute set of nodes visible in perspective p*.

Computational Perspectives provide a new, dynamic, personalized form of on-line information management (Stahl, 1995). A Perspective defines an electronic workspace in which a person or group can develop ideas and manage information that belongs together – for instance because it represents the beliefs and viewpoint of a particular person, group, domain, or intellectual position. Perspectives structure a shared information space so that special coherent views can be built up and displayed. The mechanism of computational Perspectives is very general and flexible.

The design philosophy behind computational Perspectives as implemented in WEBPERSPECTIVES is that *users have complete control over the content in their personal Perspectives*. Thus, if my personal Perspective inherits conflicting ideas from different team Perspectives that I belong to, I can delete, edit, and rearrange those ideas at will. Other users can view the contents of my personal Perspective (except for content that I have designated as private) and they can copy items, link to them, initiate public discussions of them, and propose them for incorporation in team Perspectives – *but none of this affects how the content of my Perspective is displayed to me*. This allows me to build my own Perspective on the topics that are under consideration by the group. I can see what knowledge others are building, incorporate that knowledge into my Perspective, or join in with others to share, discuss, and negotiate. The same design philosophy applies of course to team Perspectives: team members jointly (through negotiation processes) have complete control over the content of their team Perspective.

Inheritance is a central defining mechanism of computational Perspectives as used in this proposal. The ability to define arbitrarily complex networks of Perspectives with multiple layers of sub-groups between the group Perspective and the individual personal Perspectives, and to have the automatic inheritance of content through the network distinguishes this approach from all other systems of "views" and "perspectives." Inheritance in this sense is not class inheritance, but "content inheritance." A given Perspective can inherit content from multiple other Perspectives. This content is aggregated (logical union) in the given Perspective, where it can be over-ridden with edits, deletions, rearrangements, virtual-copying (linking), and additions. The inheritance mechanism is derived from efficient approaches explored in hypermedia, including "delta memory" and "transclusion" (Boborow & Goldstein, 1980; McCall et al., 1990; Mittal et al., 1986; Nelson, 1981; Nelson, 1995). For a discussion of related work, see (Stahl & Herrmann, 1999).

Because new Perspectives can be defined (either in advance or during system use) to inherit from any (non-cyclical) other Perspectives, it is generally useful to define "comparison Perspectives" that aggregate the ideas from team members, including those ideas that have not been agreed upon and migrated to the team Perspective. This is handy for keeping an eye on what one's fellow team members are thinking. Typically, we have set up the inheritance network of Perspectives to have a diamond-shaped profile, diverging out from the total group Perspective via teams to all the personal Perspectives, and then converging back via team comparisons to the group comparison Perspective. This models a collaborative knowledge-building process that combines divergent brainstorming and convergent negotiation. Various special displays can also be computed using this inheritance computation by treating discussions, negotiations, historical archives, etc. as pseudo-Perspectives that have special inheritance and exclusion rules. Once the Perspectival data computation has been returned, the content can be displayed in specialized interfaces that provide different kinds of functionality useful for further knowledge-building.

IT Artifacts for Intelligent Hyper-Linking

Research in KBEs like CSILE has shown that it is difficult to locate related ideas within a shared database of discussion notes (Hewitt et al., 1998; Hewitt & Teplovs, 1999). Therefore, in Year III, we will add functionality to automatically locate the notes most closely related to a given note, such as a new idea just entered into my personal Perspective or an old note proposed for inclusion in the group Perspective.

We will use Latent Semantic Analysis (LSA) (Landauer & Dumais, 1997; Landauer et al., 1998; Stahl & dePaula, 2001) to analyze the semantic content of notes and to measure the semantic relatedness of pairs of notes. LSA is based upon a statistical analysis (singular value decomposition) of co-occurrences of terms in a large corpus of text. It determines the relatedness of words even if they did not occur together explicitly – hence the term "latent". LSA incorporates some refinements that make its performance closer to that of humans than similar methods (see special issues of *Discourse Analysis* 1997 and *Interactive Learning Environments* 2000 on LSA assessment studies). The PI and his graduate assistant are currently completing a four year project (sponsored by the McDonnell Foundation CSEP Program) that successfully uses LSA in a Web-based educational system tested in middle school classrooms (Kintsch et al., 2000; Stahl & dePaula, 2001; Steinhart, 2000).

Automated linking of related notes will involve a fairly straight-forward application of LSA. It will be handled within the Perspectives Server, running on a computer with access to the necessary files for LSA. A corpus of biology text (including the content of VIRTUALBIOLAB and the associated theory course) will be subjected to LSA analysis to define a semantic space. Periodically (e.g., each night) the site's shared database of notes will be folded into this corpus to redefine the space and to compute the vector for each note within this space. In real time, when linking is requested for a new note, the new note's vector can be quickly computed and a list of existing notes with the closest vectors in the semantic space can be produced without noticeable delay.

With this hyper-linking, students will be pointed from the themes of their own notes to places throughout the system and throughout the interactive knowledge-building discussions where the same and related themes occur. We will experiment with different interfaces to try alternative approaches to incorporating this functionality into KBEs. For instance, it can be left to users to ask for lists of notes related to a given note. Alternatively, a software agent can automatically check to see if there are notes within a given closeness to certain notes: newly entered notes, notes proposed for negotiation, notes being read or edited, etc. The agent can then suggest that links be established from the given note to similar ones. The different interfaces can be tried out in our trials.

An Architecture to Integrate the IT Artifacts

A specific task of the proposed project is to structure the Perspective computation as a self-contained module with a well-defined application programming interface (API). This will form a Perspectives Server, a Java application that runs on the Web server along with the database system. It will be separate from a client that runs in a Web browser on the client's computer. This separation of functions into a server and a client will have many advantages. It will speed the functioning because the intensive computation of Perspective content will be done on a central server that is faster than typical student computers. Also, calls to the database system will take place locally rather than across the Internet. In terms of system development, it will mean that developers can build systems that incorporate Perspectives without having to worry about the Perspective algorithms or the database calls. They will use an API that lets them request data that should be shown to a given user in a given Perspective. They can then just focus on how best to display this data in the interface.

The Perspectives Server will be a self-contained Java application. It will be released as Open Source with clear documentation on how to use it to get Perspective data for display. The data will be delivered as an XML text stream that can be used by any Web technology, such as HTML, Perl, or Java. Although it is anticipated that the Perspectives Server will generally be used as a black box, its Open Source availability will allow programmers to modify it if necessary.

The Perspectives Server will be a form of middle-ware, operating between the database and the client software (see Figure 4). It will instantiate a three-tier, model-controller-view architecture that defines independent layers for the data schema or model, the data computation or control, and the interface display or view. The database management system can be any standard relational SQL system like mySQL or Oracle. The middle layer can be the Perspectives Server or a stripped down version that does not compute Perspectives. And the interface can be any kind of applet, Web page, or Web application that conforms to the API standard (see Figure 4).

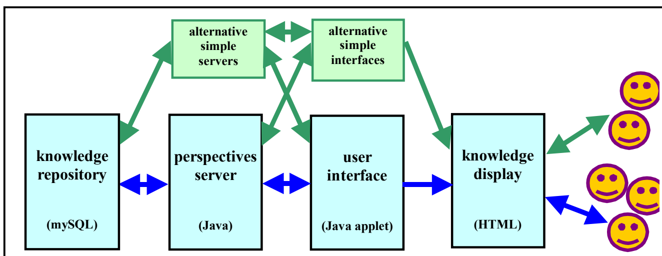

Figure 4. *Architecture for* `WebPerspectives`.

4. Methodology for Assessing IT Artifacts

Micro-Ethnography

For assessing software functionality and usability in this project, we adopt a recent tradition of human interaction analysis (Jordan & Henderson, 1995) that we refer to as "micro-ethnography." This methodology builds on a convergence of conversation analysis (Sacks, 1992), ethnomethodology (Garfinkel, 1967), nonverbal communication (Birdwhistell, 1970), and context analysis (Kendon, 1990). An integration of these methods has only recently become feasible with the availability of videotaping and digitization that records human interactions and facilitates their detailed analysis. It involves close attention to the role that various micro-behaviors – such as turn-taking, participation structures, gaze, posture, gestures, and manipulation of artifacts – play in the tacit organization of interpersonal interactions. Utterances made in interaction are analyzed as to how they shape and are shaped by the mutually intelligible encounter as a holistic context – rather than being taken as expressions of individuals' psychological intentions or of external social rules (Streeck, 1983).

Micro-ethnographic research typically involves the following components:

- A specific setting, or research site – such as several students gathered around a computer running VIRTUALBIOLAB.
- 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 – such as a biology class.
- A recognition that culture (which includes the meaning and use of shared artifacts) is a product and a process of naturally-occurring communication, simultaneously co-constructed and experienced by participants – and thereby made available for empirical study and interpretation by researchers.
- A use of recent technologies, like digitized video, that allow researchers to look at in detail the orderly performance of social life – such as the negotiation of learning between teacher and student or among collaborating peers.

Micro-ethnography can be adapted from the study of human-human interaction to that of human-computer interaction or computer-mediated collaboration. Our pilot studies suggest that such an adaptation of the methodology can be accomplished effectively.

Micro-ethnography and Human-Computer Interaction

Our research approach brings together educational software design and micro-analytic research. We use micro-ethnography to analyze empirical student interactions with educational software artifacts. Techniques related to micro-ethnography, such as video analysis and conversation analysis, have previously been used to analyze human-computer interaction in limited cases (Bødker, 1989; Bødker, 1996; Frohlich & Luff, 1990; Hollan et al., 2000; McIlvenny, 1990; Nardi, 1996; Roschelle, 1996; Suchman, 1987; Suchman & Trigg, 1991). However, these cases typically did not analyze interactions at the micro-behavior level, including such things as gesture and posturing, which are important means of making understandings visible in face-to-face communication (suggestive exceptions include (Hutchins & Palen, 1998; Streeck, 1996)). But, most importantly, these studies did not investigate learning technologies. Nor did they investigate learning taking place through the interactions. Those that did look at learning (like Roschelle (1996)) did not use this to feed back into the design of the technology. Thus, our project is undertaking an approach that is unique in combining all three:

- Analysis of interaction at a micro level.
- Analysis of the learning taking place.
- Application of the analysis to revision of the technology.

The Assessment Process

Our gathering and analysis of data involves the PI working closely with the graduate student project members. In addition, our Advisory Board members participate in workshops held monthly. The workshops not only review project progress and plan next steps, but they importantly include group data sessions for the analysis of data. The data gathering and analysis process for the VIRTUALBIOLAB trials will typically proceed through the following steps:

- Videotaping of students. Two or three students are gathered around a computer. Cameras and microphones are set up to capture the facial expressions and body movements of all participants. The monitor image is also captured. Microphones are arranged to capture all speech as clearly as possible and to distinguish the speakers.

- The video is combined (picture-in-picture) and time-code is burned in to provide a frame-by-frame reference system.
- A minute-by-minute record log is created, describing in a sentence or two what takes place each minute. This is typically done by a graduate student and reviewed by a PI. The log may be revised later.
- A list of interesting episodes is created. Episodes are meaningful interactions lasting up to several minutes. The list is discussed by the whole project team at a group workshop.
- Selected episodes are digitized and made available electronically. This allows them to be replayed easily, looped, freeze-framed, slowed down, and studied by project members at distant locations.
- A detailed transcript is created. It transcribes both speech and visible behaviors. Speech of different participants is color-coded. The transcripts are printed and posted on the Web with the digitized clips.
- Each episode is assigned to a project team member who "owns" that piece of data. The owner watches the clip many times to understand what is happening there.
- A data session is conducted with the whole project team at a group workshop. This is a collaborative analysis of the data's empirical details. Usually, about two hours are spent on a single episode. The session is led by the owner of the data, who presents the episode and raises issues. The owner may audio-tape this session to preserve ideas and interpretations that come up.

The owner of the episode returns to a study of the video clip. At this point, the transcript may be revised and extended to include more details of interaction. The owner may invite other project team members to view and discuss the clip. The owner may present the clip at another data session. Finally, the owner drafts a micro-ethnographic analysis of the episode. This is distributed for comment. The analysis includes:

- A detailed description of the actions of all participants and their interactions.
- A discussion of what learning is evidenced in the data.
- A discussion of the role of any artifacts.
- A discussion of problems with the software, learning problems, etc.

The analyses of the episodes are reviewed by the whole project team and various suggestions are made based on this:

- Proposed revisions to the software.
- Changes to the list of interesting episodes, such as the inclusion of additional episodes.
- Alterations to the research plan, such as scheduling additional usage sessions or changing the way they are conducted.
- Revisions to the research methodology and theoretical framework.

5. Results from Previous Research

The proposed project builds upon a series of activities that we have already started to work on. These activities – that either grew out of our previous engagements or were conducted to explore the basis for this proposal – have led to the design of our project and are suggestive of its likely success. The project takes advantage of unique opportunities at the University of Colorado:

- The development of VIRTUALBIOLAB, which is currently underway in the Molecular, Cellular and Developmental Biology Department.
- The experience of the PI and his colleagues and students at the Center for LifeLong Learning and Design in the Computer Science Department in design and development of computer support for collaborative learning – including the Perspectives mechanism.
- The expertise of Advisory Board members and graduate students from the Communication Department in applying micro-ethnography to the human interaction with technology.
- The participation of a number of people on the project Advisory Board, who bring complementary expertise in education, human-computer interaction, technology adoption, and project assessment.

Following are summaries of related work conducted by the PI and colleagues as preparation for this proposal and in related grants funded by NSF and other sources:

Pilot Studies

VirtualBiologyLab (http://www.virtuallaboratory.net)

VirtualBiologyLab is a Web-based curriculum to substitute for biology wet labs in introductory freshman biology courses for non-majors. Currently under development, it will soon consist of ten labs, each of which takes approximately three hours for a student to work through. Project staff has begun to review this software with the designer, Professor Mike Klymkowsky, who is closely involved in this project (see attached letter of support).

WebGuide (http://www.cs.colorado.edu/~gerry/webguide)

WebGuide is a knowledge-building environment for discussing topics via the Web developed by the PI and colleagues over the past two years. It has been used in a middle school environmental science class and in two college seminars on CSCL (Stahl, 1999d). WebGuide goes beyond similar discussion-based systems by supporting the representation and development of personal and group Perspectives (Stahl, 1999b; Stahl, 1999c).

SimRocket (http://www.cs.colorado.edu/~gerry/previous/simrocket)

The PI designed and implemented SimRocket, a computer simulation of a rocket launch. The PI was invited to try it in a local Boulder school with five boys engaged in a model rocket science project. The teacher guided the students (grouped in front of two computers) to fire each of 7 virtual rockets with different characteristics six times and to average the resultant heights in order to predict the height of an 8^{th} rocket. Project staff then engaged in micro-ethnographic analysis of this three-hour interaction – during data sessions in the Communication Department, the seminar on artifact theory, a summer workshop on micro-ethnography, and pilot sessions for this proposal.

Artifacts Seminar (http://www.cs.colorado.edu/~gerry/readings)

The PI organized a seminar on artifact theory, primarily as a pilot project for this proposal. Core members of the project team met along with other faculty and graduate students from Communication, Education, Philosophy, and Computer Science. We reviewed theoretical texts on the nature of artifacts from cognitive science, CSCL, communication, cultural studies, psychology, philosophy, and social theory. We also held data sessions on episodes from the `SimRocket` tapes. Out-of-class discussions were held in `WebGuide` and we conducted a SimRocket experiment mediated by WebGuide.

StateTheEssence (http://www.cs.colorado.edu/~gerry/projects/essence)

StateTheEssence is Web-based software developed by the PI to help middle school students develop their text summarization skills. It relied centrally on latent semantic analysis (LSA) technology, as developed by co-PIs Walter Kintsch and Thomas Landauer. It was used in an interdisciplinary four-year research project at a local Boulder public school. After undergoing considerable revision and refinement based on testing with students, the software was shown to improve text summarization, particularly in cases where the original text was somewhat difficult for the student to understand (Kintsch et al., 2000; Stahl & dePaula, 2001; Steinhart, 2000). Evaluation of this software was conducted by means of controlled experiments and teacher ratings.

Grants Funded by NSF

Organizational Memory and Organizational Learning

"Conceptual Frameworks and Computational Support for Organizational Memories and Organizational Learning (OMOL)," PIs: Gerhard Fischer, Gerry Stahl, Jonathan Ostwald, September 1997 – August 2000, $725,000, from NSF CSS Program #IRR-9711951.

This grant led to the current proposal's focus on Web-based learning environments. The OMOL project started from a model of computer support for organizations as Domain-Oriented Design Environments (DODEs) in which both domain knowledge and local knowledge are stored in the form of artifact designs and associated design rationale. This CSCW model evolved into one of Collaborative Information Environments (CIEs), that emphasized the interactive, asynchronous, persistent discussion of concepts and issues within an organization. Gradually, interest in organizational learning aspects led to involvement in CSCL and the model of collaborative Knowledge-Building Environments (KBEs). A number of software prototypes were developed to explore the use of the Web as a communication and collaboration medium, including:

- DYNACLASS: A discussion forum for use in college courses. It features ties to an interactive glossary and bibliography, as well as email notification and specialized displays.
- WEBGUIDE: Differs from DYNACLASS in providing more control over rearrangement of notes; features computational Perspectives.

Work on this grant led to the focus on KBEs as models of computer support for organizational memory and collaborative learning. In particular, it provided a number of different systems, each with useful functionality. As we tested and deployed these systems, we confronted serious issues of adoption and focused our concerns increasingly on socio-technical and social informatics issues: motivation, media competition, critical mass, social practices, seeding, management, re-seeding, convergence of ideas, peer-to-peer collaboration, deployment strategies. These issues led to a new research agenda (Stahl, 2000a) and this proposal.

Environmental Perspectives in a Middle School Classroom

"Collaborative Web-Based Tools for Learning to Integrate Scientific Results into Social Policy," PIs: Ray Habermann, Gerry Stahl, November 1998 – July 1999, $89,338, NSF, #EAR-9870934.

This grant funded the initial implementation of WEBGUIDE as an integrated JAVA applet KBE supporting personal and group Perspectives. It was a joint effort between the PI, a middle school teacher, and a research group at the National Oceanographic and Atmospheric Administration (NOAA) labs in Boulder. The teacher taught an environmental science class in which he wanted to spend the year having his students interview various adults and construct a set of contrasting perspectives (conservationist, regulatory, business, community) on a particular local environmental issue that the students had previously been involved in. WEBGUIDE was used by the students to collect notes on their interviews and to formulate personal and team perspectives on the issue. Results of this software trial were analyzed and presented at the AERA, CSCL, ICLS, CILT, WebNet, and Group conferences (Stahl, 1998b; Stahl, 1999a; Stahl, 1999b; Stahl, 1999c; Stahl, 1999d; Stahl, 2000b; Stahl & Herrmann, 1999). These findings led to a recognition of the need for software architectures, standards, and components for KBEs as proposed in the current proposal.

Interoperability among Knowledge-Building Environments

"Interoperability Among Knowledge-Building Environments," PI: Gerry Stahl, September 1999 – August 2000, $9,124, from NSF-funded Center for Innovative Learning Technology (CILT), Subcontract #17-000359 under NSF grant #EIA-9720384.

This was a seed grant whose purpose was to stimulate collaboration among KBE research groups. This grant resulted in a semester-long student project involving three graduate and three undergraduate students creating an XML DTD that defines a data format for data imported from several different KBE prototypes and displayed in a Web browser using XSL. The grant supported a workshop organized by the PI, entitled "Collaborating on the Design and Assessment of KBEs in the 2000's" at CSCL '99 at Stanford. This workshop attracted over 60 participants and was preceded by an on-line discussion of 28 submitted position papers. This grant led to an emphasis on collaboration among KBE research groups and the need to develop and disseminate theory and methodology for developing educational artifacts, as proposed here.

Other Grants

Incorporating Automated Text Evaluation into Collaborative Software Environments

"Allowing Learners to be Articulate: Incorporating Automated Text Evaluation into Collaborative Software Environments," PIs: Walter Kintsch, Gerhard Fischer, Thomas Landauer (Stahl served as co-PI and primary software developer), calendar 1997-2000, $1,400,000 for four-years, from the McDonnell Foundation's Cognitive Science in Education (CSEP) program.

This grant supported the design, implementation, and testing of STATETHEESSENCE, Web-based software to teach middle school students summarization skills.

New Media to Support Collaborative Knowledge-Building

"New Media to Support Collaborative Knowledge-Building: Beyond Consumption and Chat," PI: Stahl, November 2000 through March 2001, $19,752, from the Lab for New Media at CU, sponsored by the Omnicom Corporation.

The grant was to test WEBGUIDE in the Artifacts Seminar and to make a number of technical improvements to WEBGUIDE'S functionality.

6. Plan for Proposed Research

We recently submitted an NSF ROLE proposal to conduct research related to that proposed here. NSF's staff review of our ROLE preproposal assigned it the highest possible ratings and suggested combining it with an ITR proposal. This ITR proposal is a direct response to that suggestion. If both the ROLE and the ITR proposals are funded, then the ITR will extend the PI's support to 12 months, allowing him to direct this research full-time. It will also support 3 graduate students to focus on the technology development for the distance education component of the ROLE proposal. If only one proposal is funded, then a much reduced version of the whole undertaking will be possible. The ROLE proposal focuses on development of the micro-ethnographic methodology for HCI, and tries it out with three software systems: SimRocket, VIRTUALBIOLAB for college freshman, VIRTUALBIOLAB for distributed high school AP students. The ITR proposal focuses on the Perspectives technology for distance education and uses the micro-ethnographic methodology for assessment.

Project Schedule

The project focus is on the development of information technology for distributed collaborative learning. This centers on the design and development of WEBPERSPECTIVES, its integration with VIRTUALBIOLAB, and its eventual dissemination as Open Source software. During the school year, this software will be tested with small groups of college and high school students. Assessment of these trials will feed back into the software development. Project findings will be broadly disseminated. Below is a timeline for major phases of the project:

	Software Development	***Micro-ethnographic Assessment***	***Dissemination***
Fall '01	Development of WEBPERSPECTIVES	Pilot testing of VIRTUALBIOLAB	Group 2001 in Boulder
Spring '02	Extensions to WEBPERSPECTIVES	Testing of VIRTUALBIOLAB	CSCL 2002 in Boulder
Summer '02	Integration of WEBPERSPECTIVES with VIRTUALBIOLAB		
Fall '02	Addition of negotiation	Testing of VIRTUALBIOLAB	
Spring '03	WEBPERSPECTIVES maintenance	Pilot testing with WEBPERSPECTIVES	Conference paper
Summer '03	WEBPERSPECTIVES revision		Conference paper
Fall '03	Addition of hyper-linking	Testing with WEBPERSPECTIVES	European conference
Spring '04	System clean-up	Testing with WEBPERSPECTIVES	Conference demo
Summer '04	Open Source release	Report on analysis of testing	Journal article

Plan for Assessment

We will engage in formative evaluation of our project throughout. That will be an important function of our Advisory Board, which includes assessment experts, and will form a regular part of the monthly workshops. We will check that we are making progress toward our project goals in accordance with the project timeline and are following our data analysis procedures.

The micro-analytic approach that the project will develop provides a built-in assessment process for the project. By videotaping sessions of students working with artifacts, we will derive a formative evaluation of the learning facilitated by the artifacts. By the end of the project, we will be able to compare in a detailed and documented way how well our revised versions of educational software artifacts perform as compared to how they worked in the pilot studies and in earlier phases of the project.

In addition to the micro-ethnographic analysis which examines both how students learn with computer technologies and their learning processes as revealed through their interactions (computer-mediated and face-to-face), it is important to understand how students relate to the technologies. In order to understand this, a triangulated approach to assessment will be adopted. Some students in the core trials of VIRTUALBIOLAB will be given a set of preassignment questions to gauge their prior knowledge and understanding of the concepts. Once they have completed the trial, they will be asked the same questions so that we can calculate their learning gains. In addition, we will interview these students in order to understand their perceptions of the artifacts as effective learning tools. This information will be gathered with each iteration and use of the software under development, and the comments and perceptions will be fed back into the development of software and the articulation of learning processes that involve computer software and computer-mediated collaboration. Understanding student perceptions of their experiences will also enable us to track our progress toward our research goals and to evaluate the effectiveness of the software by answering the critical question of, does it work: have we effectively supported distance collaborative knowledge-building?

Project Management

The PI will be personally responsible for coordinating activities associated with the project. He will supervise the work of students and consultants and ensure that they are working in accordance with the project plan, including the procedure for the collection and analysis of data. The PI will make certain that the plan is followed and the timetable met (taking into account changes adopted during the life of the project). He will also attempt to mediate any conflicts that arise within the diverse and interdisciplinary project staff. The PI will engage project Advisory Board consultants who are assessment specialists to assist in on-going project evaluation and to conduct a quarterly project review for reporting to the Advisory Board.

Data collection and analysis issues including sampling and confidentiality will conform to rigorous research conventions and University of Colorado Human Subjects standards.

Plan for Advancing Knowledge within Related Fields

We will establish a website for both internal use and broad dissemination. The website will collect and coordinate materials and findings of the project. It will include logs of our videotapes, digitized clips of selected episodes, detailed transcripts, analyses of interactions, etc. It will also include all papers submitted to journals and conferences.

This project and its findings will be broadly disseminated in the CSCL, CSCW, HCI, education, and communication research communities through conferences and journals. It will be particularly prominent at CSCL 2002 and subsequent meetings of CSCL, AERA, CSCW, Group, ICLS, and WebNet. It will also significantly impact the release of a published VirtualBiologyLab curriculum at the college and the high school level.

The Project Advisory Board

The project team includes a number of Advisory Board members at the University of Colorado who bring important complementary skills and expertise from education, ethnography, human-computer interaction, and assessment. Science and math content expertise is provided by Kalmon, Nathan, and Otero. In addition, the developer of VIRTUALBIOLAB is involved (Klymkowski). Advisory board members attend monthly workshops to review project progress and to participate in data sessions. Individual members may take a more active role during specific project periods as needed. The breadth of the team is important to provide an interdisciplinary audience for the analysis of the data, as well as for the on-going design and assessment (esp. Barker, Garvin-Doxas, Palen) of the project.

Lecia Barker is Director of Evaluation and Assessment for ATLAS, the Alliance for Technology, Learning and Science. Her PhD dissertation in Communication was on the discursive construction of virtual community in LAMDAMOO, a computational artifact. She is currently Evaluator or co-PI in 7 grants, mostly from NSF.

Robert Craig is an Associate Professor of Communication who specializes in communication theory and discourse analysis. He has studied interactive discourse in college classrooms, especially critical thinking courses. He has written on theory of communication, grounded theory, and communication as a research field.

Kathy Garvin-Doxas conducts quantitative and qualitative assessment and evaluation of the SOLAR SYSTEM COLLABORATORY – a web-based freshman astronomy course for non-majors; for the past 3 years she has been evaluating the implementation of collaborative learning techniques at CU. Her PhD dissertation in Communication was a Bakhtinian analysis of collaboration in an organization becoming more participatory.

Stevan Kalmon is now a Regional Technology Consultant for the Colorado State Department of Education. Previously he was a high school teacher at New Vista H. S. in Boulder and educational advisor to L^3D. He will be a liaison for working with high schools in the later part of the project.

Michael Klymkowsky is the designer and developer of the VIRTUALBIOLAB. He is a Professor of Molecular, Cellular & Developmental Biology at CU. He has previously published textbooks and a CD-ROM (see his appended letter of support for details).

Curtis LeBaron is an Assistant Professor of Communication. He studied with Streeck and Hopper, founders of micro-ethnography, and has subsequently developed the field further and applied it to learning and to the analysis of artifact usage.

Mitchell Nathan is Assistant Professor in the CU School of Education. His specialty is learning and teaching in school settings, and educational technology. He conducts extensive field research in high school algebra classrooms. After earning his PhD in cognitive psychology, he did research at the Learning Research and Development Center at Pittsburgh and Vanderbilt University Learning Technology Center, where he worked on *Jasper* and *Scientists in Action*.

Valerie Otero joined the faculty of the CU School of Education in January 2001 as a science education specialist. She was a co-developer of curriculum materials and simulation visualization tools in a five-year NSF-funded project entitled: *Constructing Physics Understanding in a Computer Supported Learning Environment*. Her PhD dissertation was on the shifting role of visualization tools in the process of learning electrostatics in a collaborative environment.

Leysia Palen is an Assistant Research Professor in Computer Science and a member of L^3D. She specializes in the adoption and use of everyday artifacts like mobile phones and electronic and group-sharing calendars. She studied CSCW issues and ethnographic methods at UCSD and UC Irvine.

Tamara Sumner is Assistant Professor of Computer Science at CU and is a member of L^3D and ICS. She teachers HCI, AI, and the Internet. She is co-founder and co-editor of JIME. Her research includes digital libraries in geo-science and on-line scholarly publication. Previously she developed distance education courses at the Open University in England.

Investigation of Innovative Concepts

The project centers on exploring the use of computational Perspectives to support collaboration in distance education. The project's theory argues that collaboration is essentially structured by the interaction of personal and group perspectives. A system that can mirror or represent this structure may be able to provide valuable support for the difficult process of collaboration in learning. The theory of knowledge-building also argues that collaboration is crucial to the kind of learning that needs to take place in science education. Although there seems to be a tremendous potential for advances in the quality of distance education through Perspectival support of collaboration, the effort faces serious hurdles. In particular, our pilot studies show that adoption and motivation are difficult issues that confront the design of this software. The project will therefore adopt a micro-analytic approach to studying how small groups of students interact with different versions of WEBPERSPECTIVES and VIRTUALBIOLAB.

Project Context and Resources

The proposed project will have considerable institutional support from the University of Colorado. The PI is a Research Professor active in both the Institute of Cognitive Science (ICS) and the Center for LifeLong Learning and Design (L^3D). He is on the Steering Committee of the international SIGGroup conference, GROUP '01, and is Program Chair of the international CSCL '02 conference (both being held in Colorado). These affiliations will provide support and visibility to this project.

Through its Advisory Board, the project brings together a valuable set of experienced researchers from Education, Communication, Computer Science, and project assessment.

7. Expected Impact of Proposed Research

Expected Advances in Related Fields

The proposed research has implications for several fields. The WEBPERSPECTIVES software will be relevant to computer support for collaboration generally (CSCW and CSCL). The micro-ethnographic studies of VIRTUALBIOLAB with WEBPERSPECTIVES will provide insight into human-computer interaction, processes of collaborative learning, and methodology for assessing distance education software.

Expected Contribution to Teaching, Training and Learning

The project is focused on issues of teaching, training, and learning in distance education, particularly how to support collaboration in distance education.

The project will itself provide a teaching, learning, and training opportunity for the PI, Advisory Board members, graduate research assistants, and students in courses at the University of Colorado associated with the project through class projects.

Expected Broadening of Participation

Distance education offers the possibility of participation in quality educational experiences regardless of gender, ethnicity, disability, or geographic region. Studies show that disadvantaged and socially oppressed people often feel freer to participate in computer-mediated interactions, where their personal characteristics are not as immediately visible. The real gain will happen when everyone can engage in serious collaboration without these traditional restrictions to participation. WEBPERSPECTIVES is designed to promote such participation in a way that individuality is not lost in the process.

Expected Enhancement of the Infrastructure for Research and Education

WEBPERSPECTIVES and VIRTUALBIOLAB are two direct contributions to the software infrastructure for education. The use of micro-ethnography provides a methodological contribution to research in education.

Expected Dissemination

Project results will be widely disseminated. WEBPERSPECTIVES will be made available as an Open Source component; the PI has already had requests from California and Germany for this. VIRTUALBIOLAB will be published by a commercial textbook publisher in both college and high school versions. This project will significantly improve the quality of this distance education curriculum by subjecting it to extensive and detailed assessment in use situations. The addition of WEBPERSPECTIVES to this curriculum will add an important collaborative dimension to it.

Expected Benefits to Society

Science education for the general public, such as biology for non-specialists, is of obvious importance in our technological age, especially as genetic technology starts to change daily life. As we become an increasingly global society, the ability to collaborate freely over computer networks assumes increasing urgency. We are still far from understanding how to support collaboration. This project explores one promising mechanism: the representation of knowledge-building perspectives.

References

Bereiter, C. (2000) *Education and Mind in the Knowledge Age*. Available at: http://csile.oise.utoronto.ca/edmind/main.html.

Birdwhistell, R. (1970) *Kinesics and Context,* University of Pennsylvania Press, Philadelphia, PA.

Boborow, D. & Goldstein, I. (1980) *An experimental description-based programming environment: Four reports,* Technical Report No. CSL-81-3, Xerox Palo Alto Research Center, Palo Alto, CA.

Bødker, S. (1989) A human activity approach to user interfaces, *Human-Computer Interaction,* 4 , pp. 171-195.

Bødker, S. (1996) Applying activity theory to video analysis: How to make sense of video data in HCI. In B. Nardi (Ed.) *Context and Consciousness: Activity Theory and Human-Computer Interaction,* MIT Press, Cambridge, MA, pp. 147-174.

Boland, R. J. & Tenkasi, R. V. (1995) Perspective making and perspective taking in communities of knowing, *Organization Science,* 6 (4), pp. 350-372.

Brown, A. & Campione, J. (1994) Guided discovery in a community of learners. In K. McGilly (Ed.) *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice,* MIT Press, Cambridge, MA, pp. 229-270.

Brown, J. S. & Duguid, P. (1991) Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation, *Organization Science,* 2 (1), pp. 40-57.

Chaiklin, S. & Lave, J. (Eds.) (1993) *Understanding Practice: Perspectives on Activity and Context,* Cambridge University Press, New York, NY.

Cole, M. (1996) *Cultural Psychology,* Harvard University Press, Cambridge, MA.

Connolly, T. (1997) Electronic brainstorming: Science meets technology in the group meeting room. In S. Kiesler (Ed.) *Culture of the Internet,* Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 263-276.

Cuthbert, A. (1999) Designs for collaborative learning environments: Can specialization encourage knowledge integration?, In: Proceedings of *Computer Supported Collaborative Learning (CSCL '99)*, Palo Alto, CA, pp. 117-126.

dePaula, R. (1998) *Computer Support for Collaborative Learning: Understanding Practices and Technology Adoption*, Masters Thesis, Telecommunications Department, University of Colorado, Boulder, CO.

Donald, M. (1991) *Origins of the Modern Mind: Three Stages in the Evolution of Culture and Cognition,* Harvard University Press, Cambridge, MA.

Engelbart, D. (1962) *Augmenting Human Intellect: A Conceptual Framework, Summary Report 3578,* Stanford Research Institute, Menlo Park, CA.

Engelbart, D. C. (1995) Toward augmenting the human intellect and boosting our collective IQ, *Communications of the ACM,* 38 (8), pp. 30-33.

Engeström, Y. (1999) Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen, & R.-L. Punamäki (Eds.), *Perspectives on Activity Theory,* Cambridge University Press, Cambridge, UK, pp. 19-38.

Engeström, Y., Miettinen, R., & Punamaki, R.-L. (Eds.) (1999) *Perspectives on Activity Theory,* Cambridge University Press, New York, NY.

Fischer, G., Nakakoji, K., Ostwald, J., Stahl, G., & Sumner, T. (1993a) Embedding computer-based critics in the contexts of design, In: Proceedings of *Conference on Human Factors in Computing Systems (INTERChi '93)*, Amsterdam, Holland, pp. 157-164. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1990-1997/chi93/CHI93.html.

Fischer, G., Nakakoji, K., Ostwald, J., Stahl, G., & Sumner, T. (1993b) Embedding critics in design environments., *Knowledge Engineering Review,* 4 (8), pp. 285-307. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/ker/index.html.

Frohlich, D. & Luff, P. (1990) Applying the technology of conversation to the technology for conversation. In P. Luff, N. Gilbert, & D. Frohlich (Eds.), *Computers and Conversation,* Academic Press, New York, NY.

Gadamer, H.-G. (1960/1988) *Truth and Method,* Crossroads, New York, NY.

Garfinkel, H. (1967) *Studies in Ethnomethodology,* Prentice-Hall, Englewood Cliffs, NJ.

Guzdial, M. & Turns, J. (2000) Sustaining discussion through a computer-mediated anchored discussion forum, *Journal of the Learning Sciences* .

Habermas, J. (1981/1984) *Reason and the Rationalization of Society, Volume One, The Theory of Communicative Action* (T. McCarthy, Trans.), Beacon Press, Boston, MA.

Heidegger, M. (1927/1996) *Being and Time: A Translation of Sein und Zeit,* (J. Stambaugh, Trans.), SUNY Press, Albany, NY.

Hewitt, J., Scardamalia, M., & Webb, J. (1998) *Situative design issues for interactive learning environments,* Available at http://csile.oise.on.ca/abstracts/situ_design.

Hewitt, J. & Teplovs, C. (1999) An analysis of growth patterns in computer conferencing threads, In: Proceedings of *Computer Supported Collaborative Learning (CSCL '99)*, Palo Alto, CA, pp. 232-241.

Hollan, J., Hutchins, E., & Kirsh, D. (2000) Distributed cognition: Toward a new foundation of human-computer interaction research, *ACM Transactions on Computer-Human Interaction,* 7 (2), pp. 174-196.

Hutchins, E. (1996) *Cognition in the Wild,* MIT Press, Cambridge, MA.

Hutchins, E. & Palen, L. (1998) Constructing meaning from space, gesture and speech. In L. B. Resnick, R. Saljo, C. Pontecorvo, & B. Burge (Eds.), *Discourse, Tools, and Reasoning: Situated Cognition and Technologically Supported Environments,* Springer Verlag, Heidelberg, Germany.

Jordan, B. & Henderson, A. (1995) Interaction analysis: Foundations and practice, *Journal of the Learning Sciences,* 4 (1), pp. 39-103. Available at: http://lrs.ed.uiuc.edu/students/c-merkel/document4.HTM.

Keegan, D. (1986) *Foundations of Distance Education,* Routledge, London, UK.

Kendon, A. (1990) *Conducting Interaction: Patterns of Behavior in Focused Encounters,* Cambridge University Press, Cambridge, UK.

Kintsch, E., Steinhart, D., Stahl, G., Matthews, C., Lamb, R., & the LSA Research Group (2000) Developing summarization skills through the use of LSA-backed feedback, *Interactive Learning Environments,* 8 (2), pp. 87-109.

Kling, R. (1999) What is social informatics and why does it matter?, *D-Lib Magazine,* 5 (1).

Koschmann, T. (Ed.) (1996) *CSCL: Theory and Practice of an Emerging Paradigm,* Lawrence Erlbaum Associates, Hillsdale, NJ.

Kraemer, K. & Pinsonneault, A. (1990) Technology and groups: Assessment of the empirical research. In J. Galegher, R. Kraut, & C. Egido (Eds.), *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work,* Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 375-405.

Landauer, T. K. & Dumais, S. T. (1997) A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction and representation of knowledge, *Psychological Review,* 104 (2), pp. 211-240.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998) Introduction to latent semantic analysis, *Discourse Processes,* 25 (1), pp. 259-284.

Latour, B. & Woolgar, S. (1979) *Laboratory Life,* Sage Publications, Thousand Oaks, CA.

Lave, J. (1991) Situating learning in communities of practice. In L. Resnick, J. Levine, & S. Teasley (Eds.), *Perspectives on Socially Shared Cognition,* APA, Washington, DC, pp. 63-83.

Lave, J. & Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation,* Cambridge University Press, Cambridge, UK.

McCall, R., Bennett, P., d'Oronzio, P., Ostwald, J., Shipman, F., & Wallace, N. (1990) PHIDIAS: Integrating CAD graphics into dynamic hypertext. In A. Rizk, N. Streitz, & J. Andre (Eds.), *Hypertext: Concepts, Systems and Applications. Proceedings of the European Conference on Hypertext (ECHT '90),* Cambridge University Press, Cambridge, UK, pp. 152-165.

McIlvenny, P. (1990) Communicative action and computers: Re-embodying conversation analysis? In P. Luff, N. Gilbert, & D. Frohlich (Eds.), *Computers and Conversation,* Academic Press, New York, NY.

Mittal, S., Bobrow, D., & Kahn, K. (1986) Virtual copies at the boundary between classes and instances, In: Proceedings of *Object-Oriented Programming Systems, Languages and Applications (OOPSLA '86)*, Portland, OR, pp. 159-166.

Nardi, B. (Ed.) (1996) *Context and Consciousness: Activity Theory and Human-Computer Interaction,* MIT Press, Cambridge, MA.

Nelson, T. (1981) *Literary Machines,* Mindful Press, New York, NY.

Nelson, T. H. (1995) The heart of connection: Hypermedia unified by transclusion, *Communications of the ACM,* 38 (8), pp. 3-33.

Nygaard, K. & Sørgaard, P. (1987) The perspective concept in informatics. In: G. Bjerknes, P. Ehn, & M. Kyng (Eds.), *Computers and Democracy: A Scandinavian Challenge,* Avebury, Aldershot, UK, pp. 371-393.

Papert, S. (1980) *Mindstorms: Children, Computers and Powerful Ideas,* Basic Books, New York, NY.

Pea, R. (1993) The collaborative visualization project, *Communications of the ACM,* 36 (5), pp. 60-63.

Roschelle, J. (1996) Learning by collaborating: Convergent conceptual change. In: T. Koschmann (Ed.) *CSCL: Theory and Practice of an Emerging Paradigm,* Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 209-248.

Russell, T. (Ed.) (1999) *The No Significant Difference Phenomenon,* Mindspring Press. Available at: http://cuda.teleeducation.nb.ca/nosignificantdifference/.

Sacks, H. (1992) *Lectures on Conversation,* Blackwell, Oxford, UK.

Scardamalia, M. & Bereiter, C. (1996) Computer support for knowledge-building communities. In: T. Koschmann (Ed.) *CSCL: Theory and Practice of an Emerging Paradigm,* Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 249-268.

Stahl, G. (1975) *Marxian Hermeneutics and Heideggerian Social Theory: Interpreting and Transforming Our World*, Ph.D. Dissertation, Department of Philosophy, Northwestern University, Evanston, IL. Available at: http://www.cs.colorado.edu/~gerry/publications/dissertations/philosophy/.

Stahl, G. (1993a) *Interpretation in Design: The Problem of Tacit and Explicit Understanding in Computer Support of Cooperative Design*, Ph.D. Dissertation, Department of Computer Science, University of Colorado, Boulder, CO. Available at: http://www.cs.colorado.edu/~gerry/publications/dissertations/computer.

Stahl, G. (1993b) Supporting situated interpretation, In: Proceedings of *Annual Meeting of the Cognitive Science Society (CogSci '93)*, Boulder, CO, pp. 965-970. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1990-1997/cogsci93/CogSci.html.

Stahl, G. (1995) *Supporting Personalizable Learning,* Technical Report No. CU-CS-788-95, Department of Computer Science, University of Colorado, Boulder, CO. Available at: http://www.cs.colorado.edu/~gerry/publications/techreports/personalize/.

Stahl, G. (1998a) Collaborative information environments for innovative communities of practice, In: Proceedings of *German Computer-Supported Cooperative Work Conference (D-CSCW '98): Groupware und organizatorische Innovation*, Dortmund, Germany, pp. 195-210. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1998/dcscw98/dcscw.html.

Stahl, G. (1998b) Presentation of WebGuide, In: Proceedings of *Annual conference of the Center for Innovative Learning Technologies (CILT '98)*, San Jose, CA.

Stahl, G. (1999a) demo: WebGuide: Computational perspectives for learning communities, In: Proceedings of *Annual conference of the Center for Innovative Learning Technologies (CILT '99)*, San Jose, CA. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/cilt99/index.html.

Stahl, G. (1999b) POW! Perspectives on the Web, In: Proceedings of *WebNet World Conference on the WWW and Internet (WebNet '99)*, Honolulu, HA. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/webnet99/webnet99.html.

Stahl, G. (1999c) Reflections on WebGuide: Seven issues for the next generation of collaborative knowledge-building environments, In: Proceedings of *Computer Supported Collaborative Learning (CSCL '99)*, Palo Alto, CA, pp. 600-610. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/cscl99/ -- and -- http://kn.cilt.org/cscl99/A73/A73.HTM.

Stahl, G. (1999d) WebGuide: Guiding collaborative learning on the Web with perspectives, In: Proceedings of *Annual Conference of the American Educational Research Association (AERA '99)*, Montreal, Canada. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/aera99/ .

Stahl, G. (2000a) Collaborative information environments to support knowledge construction by communities, *AI & Society,* 14 , pp. 1-27. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/ai&society/.

Stahl, G. (2000b) A model of collaborative knowledge-building, In: Proceedings of *Fourth International Conference of the Learning Sciences (ICLS 2000)*, Ann Arbor, MI, pp. 70-77. Available at:

http://www.cs.colorado.edu/~gerry/publications/conferences/2000/icls/ -- and -- http://www.umich.edu/~icls/proceedings/abstracts/ab70.html.

Stahl, G. (2000c) WebGuide: Guiding collaborative learning on the Web with perspectives, *Journal of Interactive Media in Education (JIME)* . Available at: http://www-jime.open.ac.uk/00/stahl/.

Stahl, G. & dePaula, R. (2001) Evolution of an interactive medium for learning to write summaries (in preparation). Available at: http://www.cs.colorado.edu/~gerry/publications/journals/ILE/ile.html.

Stahl, G. & Herrmann, T. (1999) Intertwining perspectives and negotiation, In: Proceedings of *International Conference on Supporting Group Work (Group '99)*, Phoenix, AZ. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/group99/.

Stahl, G., Sumner, T., & Owen, R. (1995) Share globally, adapt locally: Software to create and distribute student-centered curriculum, *Computers and Education. Special Issue on Education and the Internet,* 24 (3), pp. 237-246. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/c&e/.

Steinhart, D. (2000) *Designing, Testing, and Evaluating Summary Street, an LSA-Based Summarization Tool*, Ph. D. Dissertation, Department of Psychology, University of Colorado, Boulder, CO.

Streeck, J. (1983) *Social Order in Child Communication: A Study in Microethnography,* Benjamins, Amsterdam, NL.

Streeck, J. (1996) How to do things with things, *Human Studies,* 19 , pp. 365-384.

Suchman, L. (1987) *Plans and Situated Actions: The Problem of Human-Machine Communication,* Cambridge University Press, Cambridge, UK.

Suchman, L. & Trigg, R. (1991) Understanding practice: Video as a medium for reflection and design. In J. Greenbaum & M. Kyng (Eds.), *Design at Work: Cooperative Design of Computer Systems,* Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 65-90.

Vygotsky, L. (1930/1978) *Mind in Society,* Harvard University Press, Cambridge, MA.

Wenger, E. (1987) *Artificial Intelligence and Tutoring Systems,* Morgan Kaufman, Los Altos, CA.

Wenger, E. (1998) *Communities of Practice,* Cambridge University Press, Boston, MA.

Winograd, T. & Flores, F. (1986) *Understanding Computers and Cognition: A New Foundation of Design,* Addison-Wesley, Reading, MA.

Biographical Sketch

Gerry Stahl, Principal Investigator

Center for LifeLong Learning and Design
Department of Computer Science, and
Institute of Cognitive Science
University of Colorado, Boulder, CO 80309-0430

(303) 492-3912 (phone)
(303) 492-2844 (fax)
Gerry.Stahl@Colorado.edu
www.cs.colorado.edu/~gerry

Professional Preparation

	University of Colorado
1996-99	Postdoctoral Research Fellow
1993	Ph.D. in Computer Science
1990	M.S. in Computer Science
	Northwestern University
1975	Ph.D. in Philosophy
1971	M.A. in Philosophy
	University of Frankfurt
1973	Graduate study in critical social theory
	University of Heidelberg
1968	Graduate study in continental philosophy
	Massachusetts Institute of Technology (MIT)
1967	B.S. in Humanities & Science (math & philosophy)

Appointments and Professional Experience

	Assistant Research Professor
1999-present	Department of Computer Science and Institute of Cognitive Science, Boulder, CO
	Post Doctoral Research Fellow
1996-1999	Center for LifeLong Learning and Design, Boulder, CO
	President
1995-1996	Personalizable Software, Niwot, CO
	Director of Software R&D
1993-1996	Owen Research Inc., Boulder, CO
	Graduate Research Assistant
1990-1993	College of Environmental Design, Boulder, CO
	Intern Interface Developer
1990-1991	US West Advanced Technology, Denver & Boulder, CO
	Computer Science Instructor & Teaching Assistant
1989-1990	University of Colorado, Boulder, CO
	Executive Director
1984-1989	Community Computerization Project, Philadelphia, PA
	Planning and Evaluation Specialist
1979-1984	Southwest Germantown Community Devel. Corp., Philadelphia, PA
	Community Organizer & VISTA Supervisor
1978-1979	Philadelphia Council of Neighborhood Organizations, Philadelphia, PA
	Systems Programmer
1974-1977	Temple University, Philadelphia, PA
1970-1971	Northwestern University, Evanston, IL
1969-1970	Temple University, Philadelphia, PA
	Applications Programmer
Summer 1966	Brown Bovari Cie, Baden, Switzerland
Summer 1965	University of Pennsylvania, Philadelphia, PA

Related Publications:

Stahl, G. (1993) Supporting situated interpretation, In: *Proceedings of Annual Meeting of the Cognitive Science Society* (CogSci '93), Boulder, CO, pp. 965-970. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1990-1997/cogsci93/CogSci.html.

Stahl, G. (1999a) POW! Perspectives on the Web, In: *Proceedings of WebNet World Conference on the WWW and Internet* (WebNet '99), Honolulu, HA. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/webnet99/webnet99.html.

Stahl, G. (1999b) Reflections on WebGuide: Seven issues for the next generation of collaborative knowledge-building environments, In: *Proceedings of Computer Supported Collaborative Learning* (CSCL '99), Palo Alto, CA, pp. 600-610. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/cscl99/.

Stahl, G. (2000) A model of collaborative knowledge-building, In: *Proceedings of International Conference of the Learning Sciences* (ICLS 2000), Ann Arbor, MI. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/2000/icls/.

Stahl, G. & Herrmann, T. (1999) Intertwining perspectives and negotiation, In: *Proceedings of International Conference on Supporting Group Work* (Group '99), Phoenix, AZ. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1999/group99/.

Significant Publications:

Stahl, G. (1996) Armchair missions to Mars: Using case-based reasoning and fuzzy logic to simulate a time series model of astronaut crews, *Knowledge-Based Systems*, 9, pp. 409-415. Also in: Pal, Dillon & Yeung (2000) *Soft Computing in Case Based Reasoning*, London, UK, Springer Verlag, pp. 321-334. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/crew/index.html.

Stahl, G. (1998) Collaborative information environments for innovative communities of practice, *Proceedings of the German Computer-Supported Cooperative Work Conference* (DCSCW '98), Dortmund, Germany. Available at: http://www.cs.colorado.edu/~gerry/publications/conferences/1998/dcscw98/dcscw.html.

Stahl, G. (1999) WebGuide: Guiding collaborative learning on the Web with perspectives, *Annual Conference of the American Educational Research Association* (AERA '99), Montreal, Canada. Also in: *Journal of Interactive Media in Education (JIME)* (2000). Available at: http://www-jime.open.ac.uk/00/stahl/ and http://www.cs.colorado.edu/~gerry/publications/conferences/1999/aera99/.

Stahl, G. (2000) Collaborative information environments to support knowledge construction by communities, *AI & Society*, 14, pp. 1-27. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/ai&society/.

Stahl, G., Sumner, T., & Owen, R. (1995) Share globally, adapt locally: Software to create and distribute student-centered curriculum, *Computers and Education*. Special Issue on Education and the Internet, 24 (3), pp. 237-246. Available at: http://www.cs.colorado.edu/~gerry/publications/journals/c&e/.

Major Recent Grants (last 3 Years)

- 2000-2001: “New Media to Support Collaborative Knowledge-Building: Beyond Consumption and Chat” (PI) $19,752; sponsor: Lab for New Media at CU and the Omnicom Corporation.
- 1997-2000: “Allowing Learners to be Articulate: Incorporating Automated Text Evaluation into Collaborative Software Environments” (primary author and primary software developer; PIs: Gerhard Fischer, Walter Kintsch and Thomas Landauer) $678,239; Sponsor: James S. McDonnell Foundation.
- 1997-2000: “Conceptual Frameworks and Computational Support for Organizational Memories and Organizational Learning” (co-PI with Gerhard Fischer and Jonathan Ostwald), $725,000; Sponsor: NSF.
- 1999-2000: "Interoperability among Knowledge Building Environments" (PI) $9,124; Sponsor: Center for Innovative Learning Technology / SRI.
- 1998-1999: "Collaborative Web-Based Tools for Learning to Integrate Scientific Results into Social Policy" (co-PI with Ray Habermann) $89,338; Sponsor: NSF.

Collaborators:

Thomas Herrmann (and the Informatics and Society research group at Dortmund), Timothy Koschmann (and the Problem-Based Learning research group at Southern Illinois), Chris Hoadley (SRI & Stanford), Alex Cuthbert (Berkeley), Charles Hendricksen (Washington), Geri Gay (Cornell), Simon Buckingham Shum (Open University).

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Colorado at Boulder

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Gerry Stahl

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerry Stahl - PI	4.00	0.00	0.00	$ 29,762	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	4.00	0.00	0.00	29,762	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				43,056	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				72,818	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,754	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				82,572	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				6,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				12,431	
TOTAL OTHER DIRECT COSTS				23,431	
H. TOTAL DIRECT COSTS (A THROUGH G)				108,003	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 47% of MTDC (Rate: 47.0000, Base: 16012) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				45,474	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				153,477	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 153,477	$

M. COST SHARING PROPOSED LEVEL $ 0 — AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Gerry Stahl		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** I- Indirect Costs**
47.4% of MTDC (Rate: 47.4000, Base 80060)

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Colorado at Boulder			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Gerry Stahl			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerry Stahl - PI	4.00	0.00	0.00	$ 31,101	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	4.00	0.00	0.00	31,101	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				44,994	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				76,095	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				10,059	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				86,154	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				6,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				12,825	
TOTAL OTHER DIRECT COSTS				22,825	
H. TOTAL DIRECT COSTS (A THROUGH G)				110,979	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 47% of MTDC (Rate: 47.0000, Base: 98654)					
TOTAL INDIRECT COSTS (F&A)				46,367	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				157,346	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 157,346	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* Gerry Stahl	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

 *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY PROPOSAL BUDGET
YEAR 3

ORGANIZATION University of Colorado at Boulder				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Gerry Stahl				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Gerry Stahl - PI	4.00	0.00	0.00	$ 32,501	$	
2.						
3.						
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	4.00	0.00	0.00	32,501		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (3) GRADUATE STUDENTS				47,019		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				79,520		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				10,378		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				89,898		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				3,000		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				6,000		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				13,232		
TOTAL OTHER DIRECT COSTS				22,232		
H. TOTAL DIRECT COSTS (A THROUGH G)				114,130		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 47% of MTDC (Rate: 47.0000, Base: 101398)						
TOTAL INDIRECT COSTS (F&A)				47,657		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				161,787		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 161,787	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI / PD TYPED NAME & SIGNATURE* Gerry Stahl	DATE			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE			Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Colorado at Boulder**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Gerry Stahl**				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerry Stahl - PI	12.00	0.00	0.00	$ 93,364	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	12.00	0.00	0.00	93,364	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (9) GRADUATE STUDENTS				135,069	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				228,433	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				30,191	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				258,624	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				6,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				12,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				18,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				38,488	
TOTAL OTHER DIRECT COSTS				68,488	
H. TOTAL DIRECT COSTS (A THROUGH G)				333,112	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				139,498	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				472,610	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 472,610	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				
PI / PD TYPED NAME & SIGNATURE* **Gerry Stahl**	DATE			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE*	DATE		Date Checked	Date Of Rate Sheet	Initials - ORG

NSF Form 1030 (10/99) Supersedes all previous editions C***SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)**

BUDGET JUSTIFICATION

Salaries

PI

The PI will work full-time on this project. He is a Research Professor with no teaching responsibilities. He will manage the project and supervise the project team. The current proposal requests 4 months per year of salary. A pending NSF ROLE proposal requests 9 months per year and would be re-allocated if both proposals are funded.

GRAs

3 doctoral students will be paid for half-time work on the project during the academic year (20 hours per week for 9 months). They will receive tuition reimbursement as well as GRA stipends.

URAPs

3 Undergraduate Research Apprentice Program participants will be paid at an hourly rate for half-time work on the project during the academic year. They will be paid from separate funds.

Other Students

Other undergraduate and graduate students in Computer Science, Communication and Education will participate in the project through class group assignments associated with the project: e.g., interface design, interaction transcription, curriculum design.

Travel

Domestic

Travel expenses are budgeted for 2 trips per year to conferences.

Foreign

No foreign travel is budgeted.

Other Direct Costs

Materials and Supplies

Funds are budgeted for equipment needed to gather and analyze data, including video cameras, microphones, video digitization hardware and software, computer memory, etc.

Consultants

Some project Advisory Board members will be reimbursed as consultants for participation in monthly Advisory Board workshops at a rate of $150/ meeting for preparation and attendance. Funds have been budgeted for 40 of these participations a year. Some of these funds may be used to enable Advisory Board members to work at $450/day to engage in project tasks as needed from time to time.

Indirect Costs

Per HHS agreement dated 8/16/99, indirect costs are calculated at 47.4% of M.T.D.C. for the period 7/1/99 - 6/30/02 and 47% of M.T.D.C for the period 7/1/02 - 6/30/04.

CURRENT AND PENDING SUPPORT

Investigator: **Gerry Stahl**	Other agencies (including NSF) to which this proposal has been/will be submitted. **None**

Support: Current Pending **X** Submission Planned in Near Future

Project/Proposal Title: **ITR/PE (EHR): Information Technology for Distributed Collaborative Learning in a Virtual Biology Lab** (this proposal)

Source of Support: **NSF - ITR**

Total Award Amount: **$472,610** Total Award Period Covered: **9/1/01 – 8/31/04**

Location of Project: **University of Colorado at Boulder**

Person-Months Per Year Committed to the Project. Cal: **4** Acad: Sumr:

Support: Current Pending **X** Submission Planned in Near Future

Project/Proposal Title: **The Role of Computational Cognitive Artifacts in Collaborative Learning and Education**

Source of Support: **NSF - ROLE**

Total Award Amount: **$970,972** Total Award Period Covered: **5/1/01 – 4/30/04**

Location of Project: **University of Colorado at Boulder**

Person-Months Per Year Committed to the Project. Cal: **9** Acad: Sumr:

Support: Current **X** Pending Submission Planned in Near Future

Project/Proposal Title: **New Media to Support Collaborative Knowledge-Building: Beyond Consumption and Chat**

Source of Support: **Omnicom Corporation**

Total Award Amount: **$19,752** Total Award Period Covered: **11/1/00-4/30/01**

Location of Project: **University of Colorado at Boulder**

Person-Months Per Year Committed to the Project. Cal: **3** Acad: Sumr:

FACILITIES, EQUIPMENT AND OTHER RESOURCES

Computational Facilities

The Center for LifeLong Learning and Design, the Department of Computer Science, and the Institute of Cognitive Science at the University of Colorado, Boulder, have created a first-class computational environment for research in artificial intelligence, cognitive science, human-computer interaction, and social factors.

Over the last 15 years, the Department of Computer Science received a Coordinated Experimental Research (CER) grant and three Institutional Infrastructure grants from NSF. These grants have allowed the department to acquire some of the most modern machines and create a computationally rich research environment. In addition, these grants provided a basic level of networking infrastructure for the department.

The PI (Stahl) is a Senior Research Scientist on the new NSF/CISE Research Infrastructure grant. This grant will support the purchase of several laptop computers to facilitate project work and communication within the project.

The Communication Department maintains a lab for digital video analysis. This lab will be available to project staff.

Office Space

The College of Engineering and the Department of Computer Science provide faculty, staff, and Ph.D. students with office space. A unique Discovery Learning Center (DLC) is currently under construction as the next phase of the development of the College of Engineering complex. DLC will have the capacity to link to other sites, on campus, with our partners, in the community, and around the world, through state-of-the-art technology. Building completion is expected in August 2001, during the first phase of the project. L^3D is the major tenant in the DLC. The PI, some of the project staff, and proposed activities will be housed in the DLC. Most trials of educational artifacts will be conducted and videotaped in a specially designed area of the DLC. There will be space there for project workgroups and for the monthly Advisory Board meetings. The DLC is specifically designed to provide space for projects like the proposed one, which include undergrads, grad students and faculty, which are interdisciplinary, and which take advantage of digital technologies.

UNIVERSITY OF COLORADO. BOULDER
COLORADO

Molecular, Cellular & Developmental Biology
Michael W. Klymkowsky, Professor
phone: 303-492-8508 / 7744 (fax)
e-mail klym@spot.colorado.edu

Tuesday, January 16, 2001

Professor Gerry Stahl
Computer Science
University of Colorado, Boulder
Boulder, Colorado 80309-0430

Dear Gerry,

I am pleased to give my enthusiastic support for your NSF ITR Program proposal: "Information Technology for Distributed Collaborative Learning in a Virtual Biology Lab". I have been involved in a number of media and web-based educational projects, *e.g.* developing web-sites to support courses I have taught[1], writing and editing the "teachware" CD-ROM "The Dynamic Cell" published by Springer-Verlag[2], and authoring the "Working with the Literature" section of the web-site that accompanies W.H. Freeman's best selling text "Molecular Cell Biology" by Lodish et al[3]. I have had first hand experience with laboratory courses, having completely redesigned the laboratory course (MCDB 3140) that accompanies our Cell Biology course (MCDB 3120).

I have read your NSF proposal and am happy to participate in the project. I believe that your work is likely to be useful to those developing web-delivered teaching applications in the natural sciences and other subjects. Over the past year Tom Lundy and I, working through our company virtuallaboratory.net, inc. (DUNS number: 001394381), have been developing web-based curricula and interactive FLASH 5-based web applications for high school "Advanced Placement", introductory and advanced college-level biology (virtuallyBiology™) and genetics (virtuallyGenetics™) courses. We are in final contract negotiations with W.H. Freeman & Co to produce college level virtuallyBiology™ WebLabs; the first series of these labs are scheduled for release in January 2002 and have begun developing a similar series of virtuallyGenetics™ labs. Negotiations are on going with CogitoLearningMedia, Inc. to produce and distribute virtuallyBiology™ labs aimed at the high school AP audience. A number of our web-based labs are currently ready for student testing[4]. In the spring and fall of 2001, we will recruit students to test these labs. My department is supportive of the use of web-based labs and I am scheduled to teach a new course, MCDB 1111: Biofundamentals, in the spring of 2002. This introductory level course will use web labs as a substitute for conventional "wet" labs.

---

[1] MCDB 4444: The Diseased Cell: http://spot.Colorado.edu/~klym/class4444.html; MCDB 3330: Evolution & Creationism: http://spot.Colorado.edu/~klym/class3330.html; MCDB 1150: Introduction to Molecular Biology: http://spot.Colorado.edu/~klym/class1150.html and MCDB 3120: Cell Biology: http://spot.Colorado.edu/klym/CellHome.htm
[2] http://www.springer.de/lifesci/dynamic-cell/
[3] http://www.whfreeman.com/lodish/con_index.htm?99ww1
[4] These labs can be viewed at our web site: http://www.virtuallaboratory.net

Wet labs are a cornerstone of the conventional biology curriculum. There are, however, many reasons to believe that interactive web-based labs will prove to be significantly more effective in teaching the basics concepts of experimental science. Web-based labs are not constrained by time, student technique, institutional facilities, or the availability of well-trained personnel and ancillary resources. Classic experiments, such as the studies of Luria & Delbruck which revealed the random nature of mutations or those of Monod and Jacob which established the regulatory organization of the gene, can be readily recreated using web-based applications. It is possible to create experiments in evolutionary and ecological biology that are impossible to perform in conventional lab courses. More to the point, conventional labs are subject to a very strong, and generally unacknowledged, selection pressure against exercises that are time consuming or that have a significant chance of "failure". This inevitably leads to a simplification of the experiments attempted, often at the expense of didactic substance.

In contrast, web-based laboratories enable (and truth to tell, force) students to discover for themselves how critical ideas were established in an experiential, "minds on" way. While conventional laboratory courses can often turn students off to science, web-based laboratories can inspire students - particularly in an age when more and more biology will be done using computers, both in "data mining" and the modeling of biologic systems.

There is a strong and quite sound argument that physical laboratories are essential to the training of practicing biologists. However, even here logic seems to favor web-based labs at the introductory and intermediate levels. Over the years, I have hosted over 30 independent study undergraduate students in my laboratory; I have consistently found the "training" they received in their laboratory experiences left them conceptually and technically unprepared for lab work. Web-based labs can provide a level of conceptual rigor that conventional labs do not approach, constrained as they are by the realities of biologic systems and educational economics. More importantly, large introductory laboratory courses are expensive (~$500-$600 per student here at the University of Colorado). They effectively drain scare resources away from smaller and more effective upper division laboratory courses and independent study experiences that are essential in the training of future biologists.

Finally, it is clear to us that in a project as revolutionary as our interactive WebLabs, student and instructor feedback, and responsive redesign and design modification are critical to the development of optimally effective teaching applications. Your project promises to provide the developers of web-based teaching applications critical insights into what works and what does not. As such it is fundamental to the successful development of new teaching technologies, and with them the promise of bringing high quality educational experiences to a much broader segment of the American and worldwide student population.

Sincerely,

Michael W. Klymkowsky
Professor