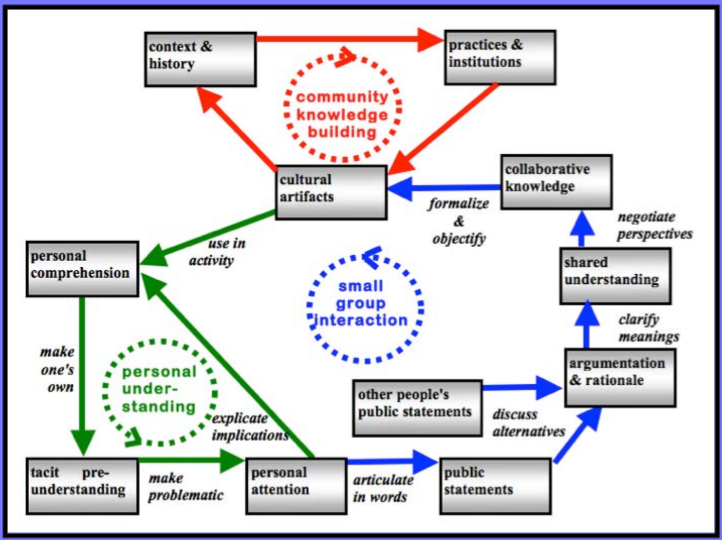
Gerry Stahl's assembled texts volume #17

Proposals for Research



Gerry Stahl

Gerry Stahl's Assembled Texts

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Gerry Stahl's assembled texts volume #17

Proposals for Research

Gerry Stahl

2010, 2022

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Introduction

The purpose of this volume is to share the proposals that I have made for research, including first of all those that have been funded and have allowed me to engage in an active research agenda, both at the University of Colorado in Boulder as a Research Professor and at Drexel University in Philadelphia as an Associate Professor and Full Research Professor.

Note in 2021: I have added some proposals I wrote during retirement as Chair of the Salt Marsh Task Force of the Chatham Conservation Foundation. To make room for these, I have deleted the texts of proposals that were not funded at Colorado and Drexel, although I still list them in this Introduction with links to the full texts.

I have also included a small number of proposals that I felt should have been funded; these document ideas that I was working on at the time they were written, but ultimately represent roads not taken. They were modest (more or less) proposals for promising, but unfulfilled, research potentials. Perhaps they document stages in the development of my thinking not otherwise visible; perhaps they will inspire a reader to pursue an otherwise forgotten trail of inquiry.

Writing effective, competitive grant proposals is a delicate business. First, one has to conceive of a program of research that one would like to undertake and that is reasonable to attempt under the proposed conditions. Then, one must convince the funding source and their reviewers that the funding proposal should be accepted. This must be accomplished with a written document of restricted form, content and length.

Preparing a proposal is a challenging writing task, requiring project planning, persuasive presentation and organized narrative. In many ways it is like writing a professional research report for a journal, such as one would compose near the end of the prospective funded project, but it needs to include more than just the concept, theory, literature review and analysis. It also needs to demonstrate why the person or group proposing is the right one to do the job and detail how the work is expected to be accomplished with the requested resources. In this publication, I only include the Proposal Summary, Proposal Description and Proposal References. The details of personnel and budget are too specific to be of interest to the reader.

I attribute my success in grantsmanship to a number of stages in my life. Most likely, I honed my natural argumentation tendencies through a decade of study of philosophy (Stahl, 2010a; 2010b). But this left my writing style too abstruse for the practical world of grant funding. Once I had completed my doctoral study of philosophy, I returned to the streets of Philadelphia as a community organizer in the 1970s of the Great Society era of federal funding. My first proposal was awarded a million dollar grant to a network of neighborhood organizations to train unemployed residents in poor neighborhoods to start energy conservation, recycling and home repair projects. I later joined the Southwest Germantown Community Development Corporation as community planner and brought in dozens of federal, state, city and foundation grants over several years to support a local credit union, an energy conservation organization and neighborhood projects in youth employment, housing rehab and economic development. This taught me not only proposal writing, but project management, especially non-profit fund accounting and budgeting. Next, I provided technical assistance to non-profit organizations throughout Philadelphia and started a computerization service for them when the first personal computers came along, developing custom accounting and service tracking software.

In 1989, I moved out West and studied computer science, artificial intelligence and cognitive science in Boulder (Stahl, 2010c). I helped writing proposals for the lab I was in and drafted the proposal that paid for my post-doc position.

After graduation, I worked with a small research start-up, drafting SBIR (federal small-business innovative research program) proposals for research in collaboration with firms and government agencies. I worked as VP for R&D, doing the programming for grants that were funded. The projects were in collaboration with the Boulder Department of Education and with the astronaut psychology group in NASA. Some of this research is reported in *Group Cognition*.

I eventually became a Research Professor at the Institute of Cognitive Science and the Department of Computer Science. This meant that I had to raise my entire salary from grants, so I began writing proposals intensively. While I was awarded some relatively small grants, I never succeeded in the almost impossible job of supporting myself as a research professor.

I went to work at a CSCW lab in Germany for a year and then joined the faculty of the College of Information Science and Technology (the iSchool) at Drexel University. There, I met the people at the Math Forum at Drexel and developed collaborations that resulted in successful grant proposals and productive research. My grants raised over six million dollars to support the VMT Project from 2003-2016.

The following pages are organized in retrospective chronology, divided in five Parts:

Part 0. Grants awarded at Chatham Conservation Foundation (2019-2021)

- "*Restoration of the Founding Homestead of Chatham*." Proposal to the Community Preservation Committee (CPC) under the Chatham Community Preservation Act (CCPA). CPA-2017-20. December 28, 2018.
- "*Frost Fish Creek Salt Marsh Preservation Studies*." Proposal to the Community Preservation Committee (CPC) under the Chatham Community Preservation Act (CCPA). CPA-2020-17. January 13, 2020.
- "*Frost Fish Creek Restoration Project Application to DER Priority Projects*." Proposal to the Massachusetts Division of Ecological Restoration (DER). CPA-2017-20. May 10, 2021.

Part I. Grants awarded at Drexel University (2003-2010)

- "*Computer-Supported Math Discourse Among Teachers and Students*." Supplementary award DRL-1448116 from the National Science Foundation Discovery Research K-12 (DR K-12) Program for $152,743 over 2 years on September 1, 2014. PI: Gerry Stahl; co-PI: Stephen Weimar. For programmer salary to develop VMT-mobile technology.
- "*Computer-Supported Math Discourse Among Teachers and Students*." Supplementary award DRL-135021 from the National Science Foundation Discovery Research K-12 (DR K-12) Program for $120,000 over 3 years on September 1, 2013. PI: Gerry Stahl; co-PI: Stephen Weimar. For participant support of teacher stipends and student prizes.
- "*Computer-Supported Math Discourse Among Teachers and Students*." Award DRL-1118773 from the National Science Foundation Discovery Research K-12 (DR K-12) Program for $1,800,000 over 5 years on September 1, 2011. PI: Gerry Stahl; co-PIs: Stephen Weimar, Jason Silverman, Michael Khoo, Sean Goggins; collaborative proposal with Rutgers, PI: Arthur Powell; other senior personnel: Andrea Forte, Jennifer Rode, Loretta Dicker, Annie Fetter, Tony Mantoan, Jay Scott. http://GerryStahl.net/publications/proposals/dr2011.pdf.
- "*Towards Optimization of Macrocognitive Processes: Automating Analysis of the Emergence of Leadership in Ad Hoc Teams*." Award N000141110221 from the Office of Naval Research Collaboration and Knowledge Interoperability (CKI) Program for $909,029 over 3 years on May 17, 2011. PI: Carolyn Rosé (CMU); co-PIs: Gerry Stahl, Sean Goggins, Emily Patterson (Ohio State), Marcela Borge (Penn State), John Carroll (Penn State), Andrew Duchon (Aptima). Proposal: http://GerryStahl.net/publications/proposals/onr2011.pdf.

- "*Theories and Models of Group Cognition*." Award from the Office of Naval Research, Collaboration and Knowledge Interoperability (CKI) Program for $675,000 over 3 years starting November 12, 2009. PI: Gerry Stahl; co-PIs: Sean Goggins, Stephen Weimar and Carolyn Rosé (CMU). http://GerryStahl.net/publications/proposals/onr2009.pdf.
- "*Dynamic Support for Virtual Math Teams*." Award DRL-0835383. Funded by the National Science Foundation Advanced Learning Technologies (ALT) Program for $306,355 over 3 years on August 1, 2009. PI: Gerry Stahl; co-PI: Stephen Weimar; Collaborative proposal with Carolyn Rosé (CMU). http://GerryStahl.net/publications/proposals/alt2008.pdf.
- "*Exploring Adaptive Support for Virtual Math Teams*." Award DRL0723580. Funded by the National Science Foundation Research and Evaluation on Education in Science and Engineering (REESE) Program for $50,000 over 1 year on August 1, 2007. PI: Carolyn Rosé (CMU); consultant: Gerry Stahl. GerryStahl.net/publications/proposals/reese2007c.pdf.
- "*Engaged Learning in Online Communities*." Award SBE-0518477. Funded by the National Science Foundation Science of Learning Center Catalyst Program for $180,762 over 3 years on October 1, 2005. PI: Gerry Stahl; co-PIs: Sharon J Derry (Wisconsin); K. Ann Renninger (Swarthmore); Mary R Marlino (UCAR); Daniel D Suthers (Hawaii). Project description: GerryStahl.net/publications/proposals/slc2005.
- "*IERI: Catalyzing & Nurturing Online Workgroups to Power Virtual Learning Communities*." Award IERI 0325447. Funded by the National Science Foundation IERI Program for $2,300,00 over 5 years on September 1, 2003. PI: Gerry Stahl; co-PIs: Stephen Weimar and Wesley Shumar. Project description: GerryStahl.net/publications/proposals/itr2003
- "*Collaboration Services for the Math Forum Digital Library*." Award DUE 0333493. Funded by the National Science Foundation NSDL Services Program for $450,000 over 3 years on August 15, 2003. PI: Gerry Stahl; co-PIs: Stephen Weimar and Wesley Shumar. Project description and proposal reviews: GerryStahl.net/publications/proposals/nsdl2003

Part II. Other proposals at Drexel University (2003-2010)

- "*Computer-Supported Math Discourse Among Teachers and Students*." Proposal DRL-1118773 to the National Science Foundation Discovery Research K-12 (DR K-12) Program for $3,500,000 over 5 years on January 6, 2011. PI: Gerry Stahl; co-PIs: Stephen Weimar, Jason Silverman, Mick Khoo, Sean Goggins; collaborative proposal with Rutgers, PI: Arthur Powell. http://GerryStahl.net/publications/proposals/dr2011.pdf.

- "*Towards Optimization of Macrocognitive Processes: Automating Analysis of the Emergence of Leadership in Ad Hoc Teams*." Proposal to the Office of Naval Research Collaboration and Knowledge Interoperability (CKI) Program for $909,029 over 3 years on February 10, 2011. PI: Carolyn Rose (CMU); co-PIs: Gerry Stahl, Sean Goggins, Emily Patterson (Ohio State), Marcela Borge (Penn State), John Carroll (Penn State), Andrew Duchon (Aptima). Proposal: http://GerryStahl.net/publications/proposals/onr2011.pdf.
- "*DR K-12: Computer-Supported Math Cognition Through Shared Visualizations and Collaborative Discourse*." Proposal DRL-6952834 to the National Science Foundation Discovery Research K-12 (DR K-12) Program for $3,500,000 over 5 years on January 7, 2010. PI: Gerry Stahl; co-PIs: Stephen Weimar, Jason Silverman, Mick Khoo, Sean Goggins; collaborative proposal with Rutgers, PI: Arthur Powell. http://GerryStahl.net/publications/proposals/dr2009.pdf.
- "*Theories and Models of Group Cognition*." Proposal to the Office of Naval Research Collaboration and Knowledge Interoperability (CKI) Program for $675,000 over 3 years on October 1, 2009. PI: Gerry Stahl; co-PIs: Sean Goggins, Stephen Weimar and Carolyn Rosé (CMU). http://GerryStahl.net/publications/proposals/onr2009.pdf.
- "*Collaborative Knowledge Work in Social-Computational Systems*." Proposal 6952103 to the National Science Foundation SES – Science, Technology and Society (SES) Program for $747,599 over 3 years on September 21, 2009. PI: Michael Khoo; co-PIs: Gerry Stahl, Eileen Abels, Sean Goggins, Jiexun Li. http://GerryStahl.net/publications/proposals/ses2009.pdf.
- "*Multidisciplinary Curriculum Improvement and Innovation Using Software Defined Radio*." Proposal to the National Science Foundation Course, Curriculum, and Laboratory Improvement (CCLI) Program (Phase I — Exploratory). Submitted for $200,000 over 2 years on May 21, 2009. PI: Kapil Dandekar (Drexel ECE); co-PI: Gerry Stahl (Drexel).
- "*Cyber-math: Developing mathematical reasoning through diverse collaborations*." Proposal to the National Science Foundation Research and Evaluation on Education in Science and Engineering (REESE) Program. Submitted for $995,571 over 3 years on November 21, 2008. PI: Arthur Powell (Rutgers, Newark); co-PI: Gerry Stahl (Drexel). http://GerryStahl.net/publications/proposals/cybermathREESE2008.pdf.
- "*Dynamic Support for Virtual Math Teams*." Proposal 0835426 to the National Science Foundation Advanced Learning Technologies (ALT) Program for $306,355 over 3 years on April 25, 2008. PI: Gerry Stahl; co-PI: Stephen Weimar; Collaborative proposal with Carolyn Rosé (CMU). GerryStahl.net/publications/proposals/alt2008.pdf.

- "*CDI-Type II: Social Computing and Data Mining in Support of Inquiry-based STEM Learning*." Preliminary proposal to the National Science Foundation Cyber-Enabled Discovery and Innovation (CDI) Program. Submitted for $2,500,931 for 4 years on Jan. 1, 2008. PI: Xiaohua Hu; co-PIs: Gerry Stahl, Eileen Abels, Yuan An, Stephen Weimar.
- "*CDI-Type I: Building a world of math discourse using a mix of platforms*." Preliminary proposal to the National Science Foundation Cyber-Enabled Discovery and Innovation (CDI) Program. Submitted for $797,303 over 3 years on Jan.8, 2008. PI: Werner Krandick (Department of Computer Science, Drexel University); co-PI: Gerry Stahl (IST, Drexel).
- " *DR-K12 R&D: STEM Inquiry Learning in the Internet Public Library and the Math Forum Model*." Proposal to the National Science Foundation Discovery Research K-12 (DR K12) Program. Submitted for $2,160,260 for 5 years on Jan. 28, 2008. PI: Deliah Neuman; co-PIs: Gerry Stahl, Tony Hu, Michael Khoo, Yuan An.
- "*Increasing Helping Behavior in Collaborative Problem Solving in the Virtual Math Teams Environment*." Proposal 735571 to the National Science Foundation Advanced Learning Technologies (ALT) Program. Submitted for $606,669 over 3 years on April 23, 2007. PI: Carolyn Rosé (CMU); co-PI: Gerry Stahl (Drexel) and co-PI: Stephen Weimar (Math Forum). GerryStahl.net/publications/proposals/alt2007.pdf.
- "*Collaborative Research: Representations for Analyzing Collaborative Knowledge Construction in Technology-mediated Learning Environments*." Proposal 723505 to the National Science Foundation Research and Evaluation on Education in Science and Engineering (REESE) Program. Submitted for $249,062 over 3 years on January 29, 2007. PI: Gerry Stahl; co-PI: Stephen Weimar (Math Forum) and Alan Zemel (Culture & Communication). Collaborative proposal with Daniel Suthers (Hawaii) for $450,999 and Cindy Hmelo-Silver (Rutgers New Brunswick). GerryStahl.net/publications/proposals/reese2007a.pdf.
- "*eMath: Diverse High School Students Developing Mathematical Reasoning through Online Collaboration*." Proposal 723605 to the National Science Foundation Research and Evaluation on Education in Science and Engineering (REESE) Program. Submitted for $995,145 over 3 years on January 29, 2007. PI: Arthur Powell (Rutgers, Newark); co-PI: Gerry Stahl (Drexel) and Carolyn Maher (Rutgers). GerryStahl.net/publications/proposals/reese2007b.pdf.
- "*Exploring Adaptive Support for Virtual Math Teams*." SGER Proposal to the National Science Foundation Research and Evaluation on Education in Science and Engineering (REESE) Program. Submitted for $50,000 over 1 year on January 29, 2007. PI: Carolyn Rosé (CMU); consultants: Gerry Stahl and the Math Forum. GerryStahl.net/publications/proposals/reese2007c.pdf.

- "*Optimizing Feedback for Eliciting Pedagogically Valuable Explanation in Collaborative Problem Solving*." Proposal to the National Science Foundation Advanced Learning Technologies Program. Submitted for 2 years on May 15, 2006. PI: Carolyn Rosé (CMU); co-PIs: Stephen Weimar and Gerry Stahl. GerryStahl.net/publications/proposals/alt2006.pdf.
- "*Engaged Learning in Online Communities*." Proposal to the National Science Foundation Science of Learning Center Catalyst Program. Submitted for $180,762 over 1.5 years on January 14, 2005. Proposal 0518477: GerryStahl.net/publications/proposals/engaged/description.pdf.
- "*Interaction Math: An Informal Online Learning Collaboratory Led by the Math Forum @ Drexel*." Proposal to the National Science Foundation Informal Science Education Program. Submitted for $2,933,126 over 5 years on January 6, 2005. PI: Gene Klotz (Math Forum); co-PIs: Gerry Stahl and Stephen Weimar. Proposal 0515544: GerryStahl.net/publications/proposals/informal/description.pdf.
- "*Studying Online Collaborative Learning at the Math Forum*." Proposal 337162 to the National Science Foundation ROLE Program. PI: Gerry Stahl; co-PIs: Scott Robertson and Wesley Shumar. Submitted for $1,790,931 over 3 years on June 1, 2003. Proposal: GerryStahl.net/publications/proposals/role2003
- "*Collaboration Services for the Math Forum Digital Library*." Proposal 333493 to the National Science Foundation NSDL Services Program. PI: Gerry Stahl; co-PIs: Stephen Weimar and Wesley Shumar. Submitted for $494,953 over 2 years on April 21, 2003. Proposal: GerryStahl.net/publications/proposals/nsdl2003
- "*Group Knowledge Construction in Digital Library Communities*." Proposal to the National Science Foundation NSDL Targeted Research Program. Submitted for $498,748 over 2 years on April 21, 2003. PI: Scott Robertson; co-PIs: Gerry Stahl and Susan Weidenbeck. Proposal 0333471: GerryStahl.net/publications/proposals/nsdl2003b
- "*ITR: Catalyzing & Nurturing Online Workgroups to Power Virtual Learning Communities*." Proposal to the National Science Foundation ITR Program. PI: Gerry Stahl; co-PIs: Stephen Weimar and Wesley Shumar. Submitted for $3,374,472 over 5 years on February 12, 2003. Proposal 0325447: GerryStahl.net/publications/proposals/itr2003
- "*Educational Online Communities for At-Risk Youth*." Proposal to foundations. Written for $88,000 over 1 year in December 2002. Proposal: GerryStahl.net/publications/proposals/nursing2003/nursing.doc

Part III. Grants awarded at the University of Colorado (1997-2001)

- 2001-2002: "*Enhancing collaborative learning among researchers, practitioners, and students at CSCL 2002*" (co-PI with Gerhard Fischer & Hal Eden) $49,860; 10/1/01-9/30/02. Sponsor: NSF. Proposal 124010.
- 2000-2001: "*New Media to Support Collaborative Knowledge-Building: Beyond Consumption and Chat*" (Principal Investigator) $19,752; Sponsor: Lab for New Media Strategy and Design. Proposal: http://GerryStahl.net/publications/proposals/media/media.pdf. Results: http://www-jime.open.ac.uk/00/stahl/.
- 1999-2000: "*Interoperability among Knowledge Building Environments*" (Principal Investigator) $9,124; Sponsor: Center for Innovative Learning Technology / SRI. Proposal: http://GerryStahl.net/publications/proposals/cilt99/proposal.pdf. Results: http://GerryStahl.net/xml.
- 1998-1999: "*Collaborative Web-Based Tools for Learning to Integrate Scientific Results into Social Policy*" (co-PI with Ray Habermann at NOAA) $89,338; Sponsor: NSF. Results: http://GerryStahl.net/publications/conferences/1999/group99/.
- 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, Computation and Social Systems program. Proposal: http://GerryStahl.net/publications/proposals/omol. Results: GerryStahl.net/publications/journals/ai&society/AI&Soc.PDF.
- 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, Cognitive Science in Education Program. Proposal: http://GerryStahl.net/publications/proposals/mcdonnell. Results: http://GerryStahl.net/publications/journals/ile2000/ile.pdf.

Part IV. Other proposals at the University of Colorado (1997-2001)

- "*Enhancing collaborative learning among researchers, practitioners, and students at CSCL 2002*" (co-PI with Gerhard Fischer & Hal Eden) $49,860; Sponsor: NSF. Proposal 124010:
- "*New Media to Support Collaborative Knowledge-Building: Beyond Consumption and Chat*" (Principal Investigator) Proposal to the Lab for New Media Strategy and Design. Submitted for $19,752 over 4 months on

September 1, 2000. Proposal: http://GerryStahl.net/publications/proposals/media/media.pdf.

- "*Interoperability among Knowledge Building Environments*" (Principal Investigator) $9,124; Sponsor: Center for Innovative Learning Technology / SRI. Proposal: http://GerryStahl.net/publications/proposals/cilt99/proposal.pdf.
- "*Collaborative Web-Based Tools for Learning to Integrate Scientific Results into Social Policy*" (co-PI with Ray Habermann at NOAA) $89,338; Sponsor: NSF.
- "Conceptual Frameworks and Computational Support for Organizational Memories and Organizational Learning" (co-PI with Gerhard Fischer and Jonathan Ostwald) $725,000; Sponsor: NSF, Computation and Social Systems program. Proposal: http://GerryStahl.net/publications/proposals/omol.
- "*Allowing Learners to be Articulate: Incorporating Automated Text Evaluation into Collaborative Software Environments*" (primary proposal author and post-doc; PIs: Gerhard Fischer, Walter Kintsch and Thomas Landauer) $678,239; Sponsor: James S. McDonnell Foundation, Cognitive Science in Education Program. Proposal: http://GerryStahl.net/publications/proposals/mcdonnell.
- "*CSS: Perspectives on Collaboration: a Micro-ethnographic Study of Computational Perspectives in Computer Support for Collaborative Knowledge-Building at a Virtual Biology Laboratory*." (Principal Investigator) Proposal 117630 to the National Science Foundation CSS Program. Submitted for $307,718 over 3 years on February 15, 2001. Proposal: http://GerryStahl.net/publications/proposals/css2001/css2001.pdf.
- "*ITR/PE (EHR): Information Technology for Distributed Collaborative Learning in a Virtual Biology Lab*." (Principal Investigator) Proposal 112397 to the National Science Foundation ITR Program. Submitted for $472,610 over 3 years on January 18, 2001. Proposal: http://GerryStahl.net/publications/proposals/itr2001/proposal.pdf.
- "*ROLE proposal: The Role of Computational Cognitive Artifacts in Collaborative Learning and Education*" (Principal Investigator) Proposal 106950 to the National Science Foundation ROLE Program. Submitted for $970,971 over 3 years on December 1, 2000. Proposal: http://GerryStahl.net/publications/proposals/role/role.pdf.
- "*ROLE Pre-proposal: The Role of Computational Cognitive Artifacts in Collaborative Learning and Education*" (Principal Investigator) Proposal 96877 to the National Science Foundation ROLE Program. Submitted for $750,000 over 3 years on September 1, 2000. Encouraged full submission. Proposal: http://GerryStahl.net/publications/proposals/role/role2pre.pdf.

- "*ROLE Pre-proposal: Research on Collaboration in Learning and on Collaboration Technology in Education*" (Principal Investigator) Proposal 83440 to the National Science Foundation ROLE Program. Submitted for $720,000 over 3 years on February 29, 2000. Encouraged full submission. Proposal: http://GerryStahl.net/publications/proposals/role/role1pre.pdf.
- "*ITR/IM: Perspectives on Collaborative Knowledge-Building*" Proposal 82829 to the National Science Foundation ITR Program. (Principal Investigator) Submitted for $489,560 over 3 years on February 17, 2000. Proposal: http://GerryStahl.net/publications/proposals/itr_kbe/itr-kbe.pdf.
- "*IT Support for Knowledge-Building in Workgroups*" (Principal Investigator) Proposal 82263 to the National Science Foundation CSS Program. Submitted for $399,190 over 3 years on February 15, 2000. Proposal: http://GerryStahl.net/publications/proposals/omol2000/OMOL.2000.pdf.
- "*Collaborative Research on Knowledge-Building Environments: Growing a National and International Research Community for Distance Learning Information Technology*" (Principal Investigator) Proposal 77095 to the National Science Foundation. Pre-proposal submitted for $2,700,000 over 5 years on January 5, 2000. Proposal: http://GerryStahl.net/publications/proposals/collab/collab.pdf.
- "*Models for Organizing Collaboration: Ways of Supporting Distributed Learning*" Proposal to Lotus Corporation. (Principal Investigator) Submitted for $68,000 over 1 year on January 18, 2000. Proposal: http://GerryStahl.net/publications/proposals/lotus/lotus.pdf.
- "*POW! Perspectives on the Web*" (Principal Investigator) Proposal to the Colorado Advanced Software Institute (CASI). Submitted for $40,000 over 1 year on November 30, 1999. Proposal: http://GerryStahl.net/publications/proposals/casi.
- "*POW! Perspectives on the Web*" (Principal Investigator) Proposal to Intel Corporation. Submitted for $190,000 over 3 years on October 18, 1999. Proposal: http://GerryStahl.net/publications/proposals/intel.
- "*Research CyberStudio*" (Principal Investigator) Internal research concept paper. Proposal: http://GerryStahl.net/publications/proposals/cyberstudio.

Note

This book does not include pre-proposals or versions of proposals that were resubmitted. It also does not include collaborative proposals that were primarily written by colleagues. Digital versions of most of my academic funding proposals are available at: http://gerrystahl.net/research.

References

Stahl, G. (2010a). *Essays in philosophy*. Philadelphia, PA: Gerry Stahl at Lulu. 182 pages. Web: http://GerryStahl.net/elibrary/philosophy.

Stahl, G. (2010b). *Marx and Heidegger*. Philadelphia. PA: Gerry Stahl at Lulu. 217 pages. Web: http://GerryStahl.net/elibrary/marx.

Stahl, G. (2010c). *Tacit and explicit understanding*. Philadelphia, PA: Gerry Stahl at Lulu. 438 pages. Web: http://GerryStahl.net/elibrary/tacit.

Contents

Part 0: Proposals at the Chatham Conservation Foundation

Restoration of the Founding Homestead of Chatham

Proposal to the Community Preservation Committee (CPC) under the Chatham Community Preservation Act (CCPA)

Application Number: CPA-2017-20

Application Date: December 28, 2018

Project Title: Restoration Master Plan for Chatham Conservation Foundation, 0 Orleans Rd, 9K-3B-C3, Chatham, Ma.

Organization Name: Chatham Conservation Foundation

Organization Address: 540 Main Street, Chatham, MA 02633

Email: PatternsofNature@outlook.com

Website: https://ChathamConservationFoundation.org

Names of Governing Board, Trustees, Directors or Members:

Bob Lear, Carol Odell, Cathy Weston, Dave McNally, Edyth Tuxbury, Gary Toenniessen, Gerry Stahl, Jack Farrell, Jane Harris, Jeanne Branson, Nat Mason, Oonie Burley, Paul Chamberlin, Peter O'Neill, Rachel Barnes, Roy Meservey, Tim Willis, Tony Murphy

Federal Tax ID Number (If non-profit): 04-6047692

Submitter or Project Director: Eunice D. Burley, President

Contact Phone: (508) 801-3348

Relevant Town Committee (if applicable):

Amount Requested from CPA Funds: $87,000

Project Description:

This CPC project restores what is perhaps the most historic site in Chatham in order to (a) clear invasive species and preserve valuable open space, (b) protect archeological and historical resources of Chatham and (c) protect and enhance the scenic quality of the entrance to Chatham from Pleasant Bay and Ryder's Cove.

As the Town website notes, "The arrival of English colonists began about 1656 when William Nickerson… made the first land purchase from Sachem Mattaquason of the Monomoyicks…. [He] ultimately owned [almost] all of what is now Chatham. In 1664 Nickerson settled his family on the west side of Ryder's Cove." The site of the original William Nickerson homestead is now owned by the Chatham Conservation Foundation (CCF). It adjoins the current site of the Caleb Nickerson House Museum, owned by the Nickerson Family Association (NFA). CCF and NFA are collaborating to discover and preserve the history of Chatham and to make it available to the public on these two adjoining properties. Unrelated to this project, CCF and NFA have recently unveiled public billboards commemorating the history of the Monomoyicks, CCF has restored and opened the historic Mayo House in the heart of the Chatham Village and NFA has relocated and maintained the historic Caleb Nickerson House as an historic museum.

Last summer, NFA applied for and received funding from CPC to undertake an archaeological excavation on the property owned by CCF at 0 Orleans Road, 9K-3B-C3. The excavation work will continue through the early fall of 2019. Several thousand historic artifacts have already been uncovered from the 1664 Nickerson founding colonial house in Chatham. The artifacts will be archived and the most significant will be publically displayed at multiple museums and other sites around Chatham after the dig is completed. This excavation has already proven to be a very significant archaeological site for New England history, far surpassing expectations. For the first time, the actual site of the founding homestead was definitively located and documented on this site. The archeologist is preparing a book on the findings. (See related CPC application from NFA.)

CCF requests funding to restore the area disturbed by this archaeological activity and the adjacent areas on this parcel which have been overrun by invasive vegetation. The project purpose is (A) to remove all invasive vegetation and replant with native vegetation to re-create a native habitat and historical landscape on the entire CCF parcel adjacent to the Caleb Nickerson house and encompassing the William Nickerson homestead archaeological site; (B) to restore the wetland on the southern boundary and its buffer zone to restore the habitat and values the area provides; and (C) to construct a pocket park with a walking path leading through the parcel to the area of the archeological dig which, due to flat topography and short length, will be available to many users (though not currently proposed to be technically ADA compliant). This restoration has the added benefit of creating a more aesthetic entrance to the Town of Chatham from the NE along Route 28.

Specific Objectives

Objective A. *Protect and manage open space and vegetation, including valuable trees, on private lands*. This objective supports Chatham HP37: Maintain as open space town property which was acquired for conservation and passive recreation and acquire additional property to preserve green, undeveloped land.

This CPC project will protect and manage the property owned by CCF at 0 Orleans Rd, 9K-3B-C3, Chatham, which was obtained for conservation, and restore it for passive recreation. The property consists of a northern front area adjacent to Route 28 near the NE entrance to Chatham and a southern back area that is the site of the William Nickerson 1664 homestead. The property is adjacent to the NFA property housing the Caleb Nickerson Museum. The entire front portion of the property is in excess of 95% overtaken with invasive species: porcelain berry, shrub honeysuckle and bittersweet. There is also a stand of Japanese knotweed on the adjoining Nickerson property, which will be restored as part of this project. These invasive plants choke out native vegetation that would normally colonize this area and would provide beneficial wildlife habitat. The back portion is an Adjacent Upland Resource Area (AURA) containing a peaceful cedar woodland extensively disturbed by the archaeological dig site. A wetlands area borders the property from the NFA property.

As detailed in Exhibit A: Detailed Restoration Plan, this CPC project will enhance the ecological integrity of the entire property. It will restore the native vegetation of the entire property, ensuring it provides its functions as defined in the Massachusetts Wetlands Protection Act and the Chatham Wetland Protection Regulations, by managing invasive species within the AURA and restoring invasive species management areas with a site-appropriate native plant community. It will thereby improve existing wildlife habitat function and value within the property by managing invasive species that compete with species that provide native habitat to increase habitat diversity and restore appropriate native upland species within the area, which will increase cover, forage and breeding habitat for wildlife.

Objective B. *Protect the archeological and historical resources of Chatham*. This objective supports Chatham HP28: Work with owners of historic properties to obtain agreements or voluntary easements to ensure preservation of recognized historic resources.

This CPC project protects the site of the founding homestead of Chatham, the 1664 home of William Nickerson. It restores the surrounding landscape, removing invasive species.

This CPC project promotes passive recreation for a large user group by unifying the NFA and CCF properties and providing a walking path from the historic Caleb Nickerson House (1827) through restored native habitat leading to the historical archaeological excavation area of the William Nickerson House (1664). It provides for public access to the historic site. It establishes 4'-wide footpaths to accommodate future public access to the open space as a pocket park and to the historic site of the William Nickerson homestead. This will provide foot access from the parking area on the NFA property.

CCF and NFA will add historic markers to make visible the historic house site and related features.

Objective C. *Protect and enhance the traditional rural character and scenic qualities of roadways*. This objective supports Chatham HP: Maintain and reopen views on town properties where unmanaged vegetation has or threatens to obscure views; work with private property owners to promote similar efforts.

This CPC project enhances and beautifies the NE entrance to the Town and to this unique historical resource. It promotes a tranquil landscape reminiscent of how it might have appeared historically through:

1. Removal of invasive species that have taken over the area of the property along Route 28. The property will be replanted with a carefully selected landscape of native plants (see Attachment A: Detailed Restoration Plan). CCF will continue to monitor for invasives and to maintain the landscaping indefinitely with its own funds.

2. Restoration of vegetation disturbed by the archeological excavation to provide an inviting setting for the archeological site. It will, as needed, undertake follow-up planting of replanted areas to ensure success of the restoration of historic areas.

3. Restoration of the degraded adjacent wetland along the southern property boundary and its Buffer Zone areas - transitioning from wet to dry meadow to an upland shrub/tree habitat to provide screening to/from adjacent residential areas.

Which of the Following Goals of CPA does this project address?

☐ XXX The acquisition, creation and preservation of Open Space.

- ☐ XXX The acquisition, preservation, rehabilitation and restoration of Historic Resources.

- ☐ *The creation, preservation and support of Community Housing for individuals and families at 100% or below area median income.*

- ☐ XXX The acquisition, creation, rehabilitation and preservation of Recreational Resources.

- ☐ *Rehabilitation, or restoration of such open space, historic buildings, or community housing that is acquired or created with CPA funds.*

How does this project impact Chatham's citizens and address a current need?

The citizens of the Town of Chatham, as well as those of the Cape Cod region, have a strong interest in the very rich history of our area. This project will provide public access in perpetuity to the unique historical resources including the NFA museum and its gardens, the archaeological area of excavation of the William Nickerson homestead, and the surrounding restored open space, with easy to navigate walking trails and with historical signage.

What is the estimated or target number of people this project will benefit/affect?

This CPC project will benefit thousands of residents and visitors to Chatham. It will integrate the NFA museum site with the new William Nickerson homestead archaeological area. It will provide a scenic pocket park with paths connecting these sites. It will offer signage and museum displays detailing the founding history of Chatham associated with the William Nickerson homestead. It will enhance the scenic quality of the restored property immediately adjacent to Route 28 at the NE entrance to Chatham between Pleasant Bay and Ryder's Cove. The archaeological site was already a popular tourist site this past summer, with its glimpse into the earliest colonial life in Chatham.

How will you measure the success of this project?

Success of the restoration of excavation area and adjacent open space areas will be measured by the viability of planted vegetation after three years. (The goal is to have 95-98% management of invasives and to have the native plant community successfully established.) CCF will also conduct a wildlife inventory at the end of the project. An additional goal is to have more people visiting the site to learn about its ecological and historical value.

Before-and-after pictures of open space areas will document improvement in the aesthetics of this historic area. Likewise pictures taken from Rt. 28 will show an improvement to the roadside landscape.

NFA will keep records of visitors to indicate the expected increase in the number of visits each year.

Projected Action Plan and Timeline, including anticipated completion date. List steps needed to complete the project?

Please see Attachment A: Detailed Restoration Plan.

Beginning in fall of 2019 in the area of the excavation, restoration will begin with management of re-sprouting invasive species using a selective, EPA approved herbicide treatment and hand removal, which will continue over the next three growing seasons. The entire area will then be seeded with a native Grass and Wildflower mix. In fall 2020, this area will be planted with a total of 79 native shrubs.

Restoration of shrubs and vines along the cleared area immediately adjacent to the excavation will also be managed, including in voids created by invasive vegetation removal. These voids will be planted with approximately 27 native shrubs as needed after 80% control of invasive species has been achieved.

Also in 2019, restoration of the adjacent highly invaded, northern portion of the parcel will be restored by removing invasive vegetation by first mowing the area. In late winter 2020, the entire area will be seeded with Grass and Wildflower Mix. A Wetland Mix will be used in the wetland resource area to revegetate the existing footpath. Shrubs and Trees along the northern boundary adjacent to residential areas will be planted in fall 2019 or 2020.

A walking trail with signage will be created throughout the parcel for access to the archaeological excavation area.

Monitoring will occur for three years following restoration to assure 95-98% management of invasives and to ensure natives have survived.

Please provide a full budget including the following information:

Total Amount of Project:

$102,000. (CPC request: $87,000.00). See attached Exhibit B: Cost Breakdown of Restoration, based on Exhibit A: Detailed Restoration Plan.

Other revenue sources including private/public/in-kind:

The CCF Board has authorized matching funds of **$10,000** for this project. The NFA Board has authorized matching funds of **$5,000** for this project.

As a core part of its mission, CCF will maintain and preserve the property and its vegetation after the CPC project is completed. Similarly, NFA will maintain access to its historical resources and will manage the display of artifacts from the William Nickerson homestead site.

Financial sustainability to secure project after the grant:

CCF maintains a budget for land management and trail maintenance, which will be adequate to cover annual costs of on-going maintenance after the grant. Also, prior to the grant, in 2019, restoration of the adjacent highly invaded, northern portion of the parcel will be restored by removing invasive vegetation by first mowing the area. In late winter 2020, the entire area will be seeded with Grass and Wildflower Mix. A Wetland Mix will be used in the wetland resource area to revegetate the existing footpath. This will prepare the property for the restoration efforts under this CPC project.

Annual cost/expenditures once the project is operational, if any?

On-going costs after this initial plan will be incurred by CCF. Mostly, CCF will be mowing the area every year for the first several years after this grant (which includes three years of maintenance) and then every other year, at a cost of approximately $800 per year. Also, CCF would cover any necessary re-seeding or invasive treatment.

Annual cost to the Town once the project is operational, if any:

None.

Potential revenue from project on an annual basis, if any:

None. Access to the property and the archaeological site will be free and open to the public.

<u>What entity will collect and control future revenue</u>? N/A.

<u>What is the basis for your budget? What are the sources of information you used?</u>

Blue Flax Restoration Plan and Estimate of Costs (see Attachment A: Detailed Restoration Plan).

<u>Are there any legal ramifications/impediments to this project</u>? No. We are filing a Notice of Intent with the Chatham Conservation Commission.

<u>Is the project compatible with the Town's Comprehensive Plan?</u> Yes.

<u>Cite specific sections if applicable</u>:

This CPC project is particularly in support of Chatham's Comprehensive Plan for 3. Natural Resources. Specifically, it is compatible with Goals 3.2, 3.3 and 3.4, including NR 35, 36, 37, 38, 43, 44, 45, 46 and 47. Also. see Specific Objectives section above, related to Chatham Historic Preservation goals HP 37, HP28, HP9.

<u>Do you have the authorization of the property owner?</u>

- ○ XXX Yes
- ○ *No*

<u>Do you have a supporting letter from a Town Board, Commission, Committee?</u>

XXX Yes

○ No

<u>What is your assessment of the nature and level of community support for the project?</u>

The history of Chatham is of extremely high interest to both residents and visitors. The archaeological site was already a popular tourist site this past summer, with its glimpse into the earliest colonial life in Chatham. Upon completion of this CPC project, both CCF and NFA will promote interest in the site through press coverage and museum displays. The site is likely to become one of the major tourist sites of Chatham, given its unique ties to early colonial life on Cape Cod.

Upload CPA Documents:

Exhibit A: Detailed Restoration Plan.pdf

Exhibit B: Cost Breakdown of Restoration.pdf

Exhibit C: NFA Letter of Support.pdf

Exhibit D: Historical Commission Letter of Support.pdf

I have mailed the 12 copies to the address listed below. *

○ *Yes*

○ **XXX** No

Attach supporting files using the Browse Button, or mail 12 paper copies to Alix Heilala, Finance Director, Town of Chatham, 549 Main Street, Chatham MA 02633.

Frost Fish Creek Salt Marsh Preservation

Proposal to the Community Preservation Committee (CPC) under the Chatham Community Preservation Act (CCPA)

Application Number: CPA-2020-17

Application Date: January 13, 2020

Project Title: Frost Fish Creek Salt Marsh Preservation

Organization Name: Chatham Conservation Foundation, Inc.

Organization Address: 540 Main Street, Chatham, MA 02633

Email: Gerry@GerryStahl.net

Website: https://ChathamConservationFoundation.org

Names of Governing Board of Trustees:

Robert Lear (President), Paul Chamberlin (Vice President), Gerry Stahl (Treasurer), Edyth Tuxbury (Clerk), Jeanne Branson, David Dougherty, Jack Farrell, Michael Franco, Jane Harris, Roy Meservey, Tony Murphy, Carol Odell, Peter O'Neill, Gary Toenniessen, Cathy Weston.

Federal Tax ID Number (if non-profit): 04-6047692

Submitter or Project Director: Gerry Stahl, Chair of the Salt Marsh Task Force

Contact Phone: (215) 260-7467

Relevant Town Committee (if applicable): N/A

Amount Requested from CPA Funds: $75,000

<u>Project Description</u>:

This project will study how best to preserve an important Chatham salt marsh from ongoing injury, harm and destruction due to development and climate change. The salt marsh is on and surrounded by land owned by the Chatham Conservation Foundation, Inc. (CCF)—see maps below. A preliminary study conducted by APCC in 2018 indicated multiple tidal restrictions and recommended systematic further study to plan for preserving the health of the marsh under likely scenarios of restriction removal, sea-level rise and storm surge.

Recommended studies included: (A) a complete hydraulic and hydrologic modeling; (B) water quality modeling resulting from recommended tidal changes; (C) a ground penetrating radar survey of the bog area to determine sand depth, as needed; (D) a fish and shell fish survey to identify presence/absence of species; (E) expanded vegetation mapping; and (F) establishment of long-term vegetation monitoring transects. Using CPC grant funds, this project will undertake only the first two of these studies (A and B) of the existing marsh and adjacent land onto which the marsh might migrate. The results of the hydraulic and hydrologic study (A) will suggest specific strategies such as potential opening of the existing restrictions, particularly under Route 28 from Bassing Harbor to Frost Fish Creek, to increase flushing without impacting any private property. A water quality modeling study (B) will then consider whether removal of tidal restrictions would result in improved water quality parameters necessary for restoration of salt marsh habitat.

The results of these studies (A and B) may lead CCF to conduct baseline studies (C, D, E and F) as appropriate, using its own funds. *CCF will then be in a position to assess the feasibility of possible scenarios for the preservation of the Frost Fish Creek salt marsh, based on systematic analysis of existing conditions, with potential increased flushing and improved water quality*. The proposed studies will prepare the way for future design, permitting and construction within a comprehensive holistic approach. Preservation of Frost Fish Creek will then be able to encompass a desired combination of the following: improved water quality, salt marsh restoration, reestablishment of fish passage and potential for salt marsh migration—all measureable against baseline data.

Figure 1. Map of CCF properties (dark green) and CRs (light green).

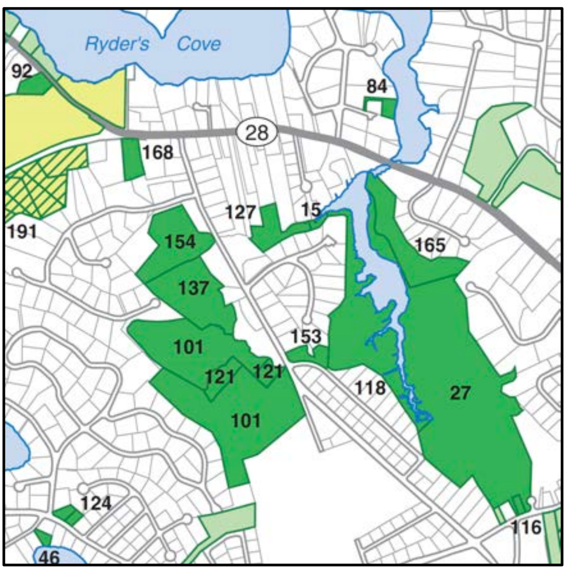


Figure 2. Frost Fish Creek salt marsh: CCF properties #15, 27, 84, 101, 118, 121, 127, 137, 153,154, 165. This is a total of about 90 acres of land surrounding and encompassing the marsh, including land that formerly was part of the marsh or might become part in the future.

CCF is the oldest land trust on Cape Cod, dating to 1962. It owns 620 acres of land in Chatham and manages conservation restrictions (CRs) on another 215 acres of land owned by the Town of Chatham. Of this land, approximately 163 acres of the owned land is salt marsh and 50 acres of the CRs is salt marsh, according to the map below. Additionally, this does not count CCF stewardship of dry land surrounding marsh or land where a salt marsh could migrate in the future with sea-level rise.

A major goal of CCF's 2019-2021 Strategic Plan is to "monitor and maintain health of salt marshes to prevent degradation and/or restore health." In 2019, CCF established a Salt Marsh Task Force to focus efforts on the preservation of the salt marshes in the Town of Chatham. Due to its position at the elbow of Cape Cod, adjoining Pleasant Bay, the Atlantic Ocean and Nantucket Sound, Chatham has a uniquely high percentage of its land covered by or adjoining salt marshes. The preservation of its salt marshes is essential to retaining the health and beauty of Chatham.

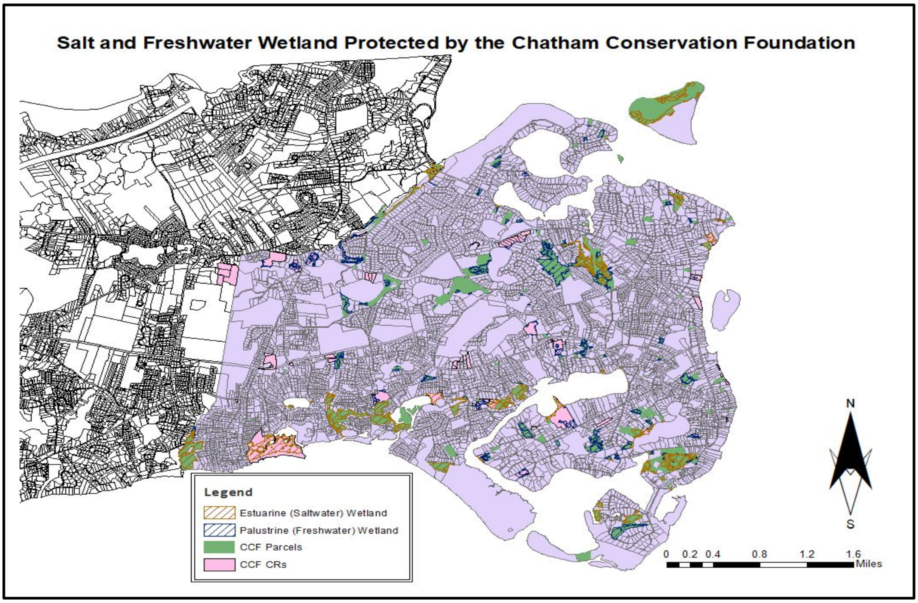


Figure 3. Wetlands protected by CCF.

The mission of CCF is "to preserve land for the benefit of the people, plants, animals and ecosystems of Chatham." Salt marshes have natural rhythms and mechanisms for preserving their ecosystems. These have long been threatened by development, such as roads restricting tidal flows and abutting residences polluting through septic systems and chemical runoffs. Preservation of salt marshes is now additionally threatened by climate change, with, for instance, sea-level rise, extreme storm surges and climate shifts that favor invasive species.

CCF was founded to preserve open space in Chatham in its historical, natural state. It has done this by acquiring about 200 parcels and protecting these and an additional 50 parcels of Town-owned land under perpetual Conservation Restrictions. However, it has become clear that *it is no longer sufficient to simply acquire land*. One must also protect it from the impacts of invasive species, disturbance from surrounding development and escalating climate change.

Protection of salt-marsh resiliency is a subtle matter, requiring careful study of existing conditions and detailed modeling of possible interventions. Salt-marsh preservation has become doubly important in the era of climate change as salt marshes are particularly effective in sequestering carbon and thereby mitigating the *causes* of climate change, as well as mitigating its *effects*, such as sea-level rise and storm surges.

The Frost Fish Creek is CCF's initial salt-marsh preservation target. The following maps of Chatham show wetlands now and projected in a couple decades, with the large bright green area in Figure 4 indicating Frost Fish Creek salt marsh. Figure 5 indicates areas for potential salt marsh migration as tidal restrictions are removed to preserve the original extent of the marsh, and as sea-level rise takes place in the coming years. Note that CCF already owns the areas for probable migration as well as the area surrounding the current wetlands.

The CCF Salt Marsh Task Force is beginning to coordinate with relevant expertise on Cape Cod and in Massachusetts governmental agencies concerned with salt-marsh preservation. The Frost Fish Creek salt marsh has been identified by the Association for the Preservation of Cape Cod (APCC) and other agencies in Massachusetts as a priority for preservation action. In 1987, it was designated by the state as part of the Pleasant Bay Area of Critical Environmental Concern (ACEC). An ACEC is a place in Massachusetts that receives special recognition and protection because of the quality, uniqueness and significance of its natural and cultural resources. The ACEC Program's goal is to preserve, restore and enhance critical environmental resources and resource areas of the Commonwealth of Massachusetts through increased levels of protection, and to facilitate and support the stewardship of these areas. CCF will work closely with Town and state agencies to study and preserve the Frost Fish Creek area.

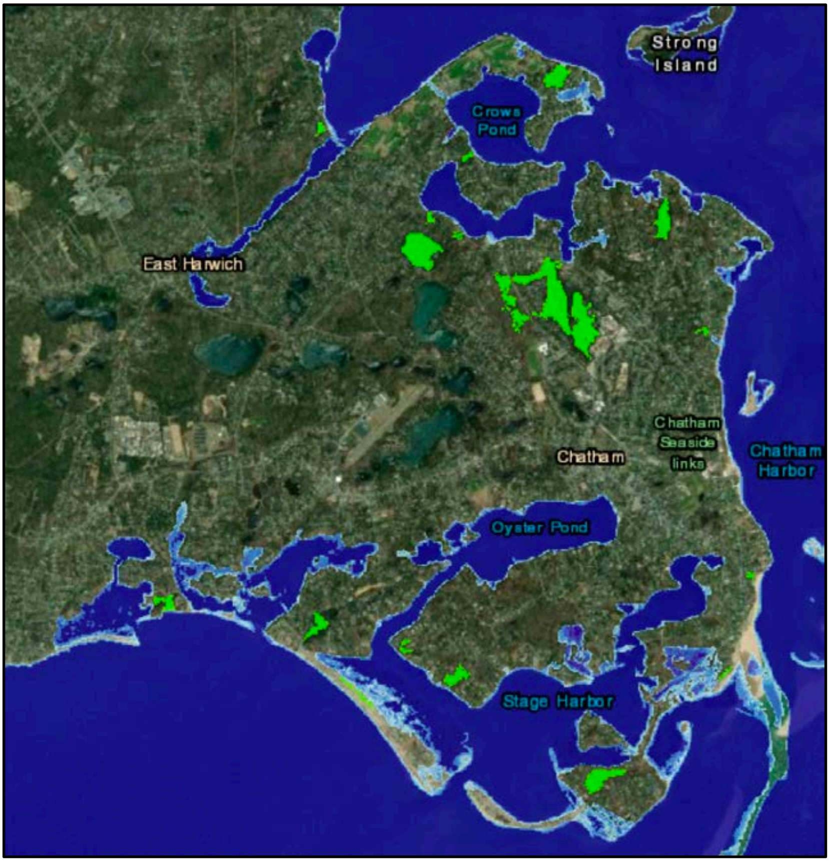


Figure 4. Chatham with future flooding levels shown in light blue and bright green. Source: NOAA's Office for Coastal Management sea level rise viewer at 2 ft. level.

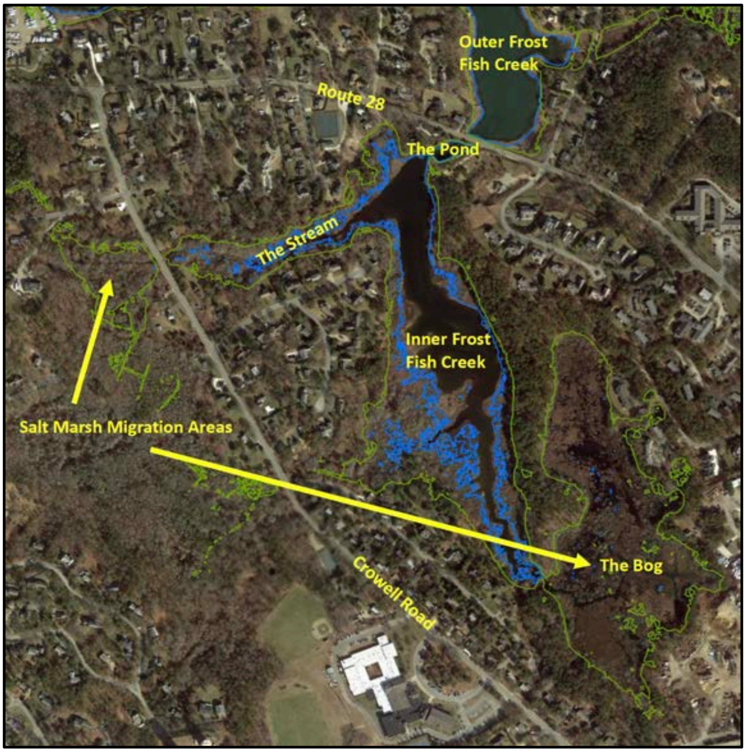


Figure 5. Migration paths of Frost Fish Creek. Blue lines show two-foot flooding and green lines indicate five-foot elevations. Yellow arrows point to areas that were formerly part of the marsh and could be preserved as such in the future.

Frost Fish Creek is a salt marsh owned by CCF. One of CCF's most scenic and most popular trails for public access goes along Frost Fish Creek. In 2018, the CCF Board allocated funds from its operating budget to hire salt-marsh specialists from APCC to undertake an initial study of how to preserve Frost Fish Creek as a healthy salt marsh. (See report in Appendices.)

Since 1968, APCC efforts have led to landmark achievements in water resource protection, land preservation and smart growth, earning APCC the reputation as Cape Cod's most prominent and influential nonprofit environmental organization working to preserve, protect and enhance the natural resources of the Cape. It conducts advocacy, studies and interventions to restore and protect natural landscapes and preserve wildlife habitat.

Working with CCF in 2018, the APCC (i) deployed data loggers at six locations throughout Frost Fish Creek to collect data on water level, temperature and salinity every 10-minutes during a full lunar-driven tidal cycle in October 2018; (ii) conducted an elevation survey throughout the area; and (iii) collected soil samples in an abandoned cranberry bog section of the former marsh. The report made a series of recommendations for further study to determine an optimal plan for preservation of Frost Fish Creek salt marsh. The 2018 APCC study concluded that the traditional tidal access to the Creek was being significantly restricted by Route 28. A culvert under the road to permit tidal flow had deteriorated, restricting flow in both directions, so that too little salt water enters the marsh to maintain its health and too little flow after storms escapes to relieve flooding. The salt marsh is also restricted at other points and is consequently much smaller than it was prior to local development, and is substantially tidally restricted.

The current proposal to the CPC is to take the next set of steps as recommended by the APCC study of Frost Fish Creek to study the feasibility of salt marsh preservation. The purpose of this is to plan how best to preserve this important natural resource from continuing injury, harm or destruction in the next decade. The land owned by CCF surrounding and encompassing Frost Fish Creek is a prized aquifer and watershed land, including forest land, fresh and salt-water marshes and other wetlands, stream and lake frontage, scenic vistas, land for wildlife, nature preserve, and land for recreational use. The current proposal does not include actual implementation of changes to the environment, but provides for the two major studies needed in order to understand the feasibility of alternative implementation approaches. Subsequent implementation would be carried out based on the findings of these studies in close collaboration with Town and state agencies. The proposed studies are necessary preconditions for future statewide funding.

Specific Objectives and Costs

The proposal is to undertake the two concrete studies listed below as project objectives A and B. This is a one-time effort, which will set the stage for a coherent, long-term preservation strategy. These proposed studies will be managed primarily by APCC. The studies will be done within a broader context of planning for Frost Fish Creek and other salt marshes on CCF land in consultation with relevant agencies at the Town of Chatham and the Commonwealth of Massachusetts, as well as other wetlands experts on Cape Cod. The long-term strategy will be implemented using other funding sources, under the direction of CCF, in collaboration with relevant agencies and accompanied by public outreach and education. Public access to trails will be guaranteed through appropriate Town agreements.

Objective A. *Complete hydraulic and hydrologic modeling (H&H)*. This objective will determine options for tidal restoration, culvert sizing/design and expected extent of flooding under different scenarios.

Objective B. *Complete water quality modeling, based on the H&H*. This objective will model changes to water quality (e.g., salinity, nutrients) as a result of changed tidal flows.

Objective C. *Submit a report to the CCF Board, the Town of Chatham and the public, summarizing results and recommendations.* This report shall convey the major findings of each of the studies conducted. It will also outline data-based strategies for preservation of the salt marsh based on these findings.

These proposed studies are largely in response to the findings of the 2018 study, which CCF funded from its own funds and which was conducted by APCC, namely:

- That tidal flow is significantly restricted by the deterioration of the culvert under Route 28. However, if Mass DOT were to suddenly replace the damaged culvert (as could be possible in the near future), the consequences for homes abutting the marsh and for the salt marsh itself would not be sufficiently carefully controlled.
- That a migration path has not yet been determined and prepared for the marsh as sea-level rise impacts the marsh. The upper regions of the wetlands were artificially dammed off for cranberry bogs in the past, and fish corridors were closed off by development.
- That it is important to model the consequences of changing the existing tidal restrictions and to plan for carefully stewarded gradual changes.
- That in order to monitor preservation and restoration, we need to document current conditions, including the current existence of fauna and flora. The marsh is named after a particular fish, but it is not known if the fish currently exists in the marsh. Similarly, we need to know the extent of rare vegetation and of invasive species, as well as the presence of animals.

Following are the budgeted costs of each of the Objectives proposed under this CPC application. Together, these Objectives define the scope of the proposed project and their costs define the proposed budget:

Objective A. *Complete hydraulic and hydrologic modeling (H&H)*. $40,000 for APCC to hire and manage consultant to complete modeling, including up to $35,000 for subcontractor expense.

Objective B. *Complete water-quality modeling based on the H&H.* $35,000 for APCC to hire and manage consultant to complete modeling, including up to $30,000 for subcontractor expense.

Objective C. *Submit a report to the CCF Board, the Town of Chatham and the public, summarizing results and recommendations.* $5,000 for APCC to compile data from the above work into a final report by December 31, 2022.

Total Budget Proposal: $75,000 from CPC, $5,000 from CCF.

* * *

Which of the Following Goals of CPA does this project address?

X The acquisition, creation and **preservation of Open Space**.

How does this project impact Chatham's citizens and address a current need?

Healthy salt marshes are important to the Town of Chatham; to protection of property and infrastructure; to the water quality; to the Town's scenic beauty; to local fauna, sea life and flora; to recreation; to many other eco-systems; and to the climate. Healthy salt marshes sequester greenhouse gases that would otherwise contribute to climate change. They can mitigate flooding and dissipate storm surges. They respond naturally to sea-level rise if not tidally restricted. Degraded and dying salt marshes release dangerous methane gases to the atmosphere, which is significantly more impactful than CO_2. The Frost Fish Creek salt marsh is perhaps the largest salt marsh in Chatham that is most in need of preservation. Preservation of this marsh will provide a working model to guide preservation of other marshes under CCF stewardship.

What is the estimated or target number of people this project will benefit/affect?

This project will benefit the residents of Chatham in general. A preserved marsh will provide recreational opportunities for hundreds of people each year. The proposed studies will allow CCF to make data-based decisions about how best to preserve the marsh.

How will you measure the success of this project?

The proposed studies will capture baseline data concerning the land, water and tidal flows, under different scenarios. As part of the project, in addition to the collection of new measurements, CCF will gather together baseline historic data from previous studies of Frost Fish Creek by various sources and agencies to show changes over time. This will permit future assessment of increased health of the marsh and associated ecology. In particular, potential future spread and migration of the marsh can be periodically measured and compared to the baseline and historic figures.

Projected Action Plan and Timeline, including anticipated completion date. List steps needed to complete the project?

It is anticipated that the studies and report funded as part of this CPC project will be completed within two and a half years from July 2020 through December 2022. Summer of 2020 will be used for project start-up. **Objective A**, the hydraulic and hydrologic modeling (H&H) will be conducted first. Findings from this will feed into **Objective B**, *the water quality modeling*. **Objective C**, *the final project report* detailing findings and recommendations will be completed by December 2022.

Please provide a full budget including the following information:

Full Project Budget	
Objective A - H&H modeling	
APCC - Restoration Ecologist	$2,400.00
APCC - Restoration Technician	$1,750.00
APCC - Grant/Contract Administrator	$795.00
Subcontractor	$35,000.00
Travel (130 miles) for 2 meetings	$75.00
Task 1 - Subtotal	***$40,020.00***
Objective B - Water quality modeling	
APCC - Restoration Ecologist	$2,400.00
APCC - Restoration Technician	$1,750.00
APCC - Grant/Contract Administrator	$795.00
Subcontractor	$30,000.00
Travel (65 miles) for 1 meeting	$35.00
Task 2 - Subtotal	***$34,980.00***

Objective C - Final Report	
APCC - Restoration Ecologist	$2,100.00
APCC - Restoration Technician	$1,070.00
APCC - Grant/Contract Administrator	$795.00
Subcontractor	$1,000.00
Travel (65 miles) for 1 meeting	$35.00
Task 3 - Subtotal	***$5,000.00***
TOTAL	**$80,000.00**

Total Amount of Project: $80,000.

Other revenue sources including private/public/in-kind:

CCF paid APCC $5,000 in 2018 to conduct a first phase of this preservation study. These funds came from CCF's operating budget.

CCF will provide volunteer services to assist with this CPC project.

CCF will contribute $5,000 to pay for Objective C, the final report.

Financial sustainability to secure project after the grant:

The project will be complete at the end of the grant period. Possible future design, permitting and construction suggested by the findings of this project would involve state-wide funding with Town collaboration, proposed using data from this study, and would not be part of this grant. Until the studies are conducted and new decisions made based on the findings, there are no additional costs planned after the grant.

Annual cost/expenditures once the project is operational, if any?

There will be no special on-going costs, other than the normal maintenance of the land and trails, which is covered by CCF's staff, volunteers and operational budget.

Annual cost to the Town once the project is operational, if any: None.

Potential revenue from project on an annual basis, if any:

None. Access to the trail will be free and open to the public. CCF is prepared to enter into a restriction or agreement with the Town to guarantee permanent public access to the trail.

What entity will collect and control future revenue? N/A.

What is the basis for your budget? What are the sources of information you used?

The budget was prepared with the assistance of the APCC salt-marsh staff, based on their experience conducting similar studies. APCC staff conferred with both Horsley Witten and the Woods Hole Group concerning reasonable costs for the two major studies.

Are there any legal ramifications/impediments to this project? Not for the studies in this project. Any potential legal issues associated with future implementation steps will be identified and addressed as part of the planning process based on the findings of this project.

Is the project compatible with the Town's Comprehensive Plan? Yes.

Cite specific sections if applicable:

This CPC project is particularly in support of Chatham's Comprehensive Plan 3: Natural Resources. Specifically, it is compatible with Goal 3-1: Protecting the quality of our air and water resources. The preservation of salt marshes like Frost Fish Creek contributes to Water Quality Protection, the control of Storm Water and the natural protection of Coastal Resources. It is also supportive of Goal 3-2: Protection of Vegetation and Wildlife Habitat. In addition, the trail along Frost Fish Creek supports Chatham's Comprehensive Plan 4: Open Space and Recreation.

Do you have the authorization of the property owner?

X Yes

<u>Do you have a supporting letter from a Town Board, Commission, Committee?</u>

X Yes

We have supporting letters from Dr. Robert Duncanson of the Town of Chatham and from the Pleasant Bay Alliance.

<u>What is your assessment of the nature and level of community support for the project?</u>

The Chatham community is highly supportive of the work of CCF in preserving the land of Chatham, including the fresh-water ponds and salt-water marshes. CCF trails, kayak trips and guided tours are very popular. In addition, Chatham residents are increasingly concerned about climate change—especially sea-level rise and storm surges. They are looking for ways to mitigate these and are strongly supportive of CCF efforts to preserve healthy salt marshes. As CCF proceeds with exploring strategies to preserve healthy salt marshes in Chatham, public education about its importance will be a central component of the effort.

<u>Upload CPA Documents:</u>

2018 Report on Tidal Study of Frost Fish Creek by APCC.pdf

Frost Fish Creek Restoration Project Application to DER Priority Projects

Applicant Information	
i. **Applicant's Name:** Chatham Conservation Foundation, Inc. (Contact: Gerry Stahl, Treasurer; President: Robert Lear; Executive Director: Dorothy Bassett)	ii. **Email/Phone:** Gerry@GerryStahl.net 1-(215)-260-7467
iii. **Project Name:** Frost Fish Creek Restoration Project	
iv. **Restoration Project Category:** *Check all that apply.* ☐ Cranberry Bog Wetland Restoration ☐ Dam Removal and River Restoration	

1. Site & Restoration Information Please use as much space as needed. The boxes will expand as you fill them.
I. Project Location and Setting: Describe the project site and general location. What natural features are present, such as streams, wetlands, and forests? What kind of buildings, roadways, or other human-built features are nearby?
Frost Fish Creek is a 90-acre conservation area and Critical Natural Landscape in North Chatham with a variety of natural features. In 1987, it was designated by the state as part of the Pleasant Bay Area of Critical Environmental Concern (ACEC).[1] The Creek is a tidally influenced tidal wetland system directly connected to Ryder's Cove, Bassing Harbor, Pleasant Bay and the Atlantic.

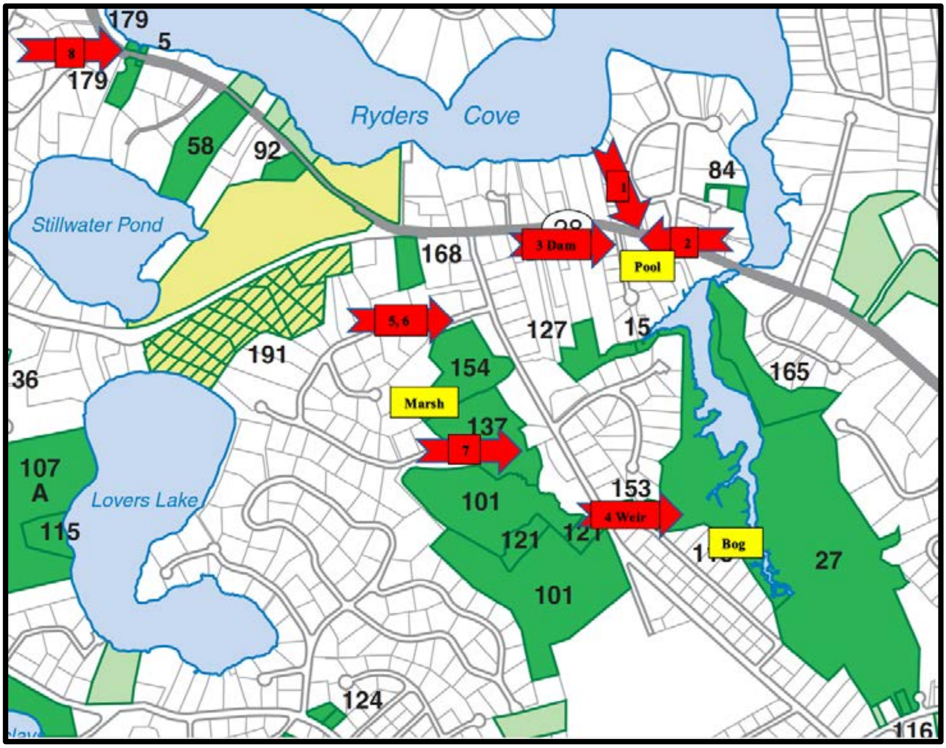
[1] The ACEC includes the entire project area plus Lovers Lake and Stillwater Pond, which were connected to it by a herring run.

There is a major tidal restriction at Route 28, which is slated for replacement. There are other tidal restrictions that historically supported agriculture, especially cranberry bogs. The Creek is fed from a large wetland (the "Bog" in *Map 1*, below), which collects runoff from residential and small-industry neighborhoods, as well as from a forested wetland (the "Marsh" in *Map 1*—currently wooded swamp, shrub swamp and upland, but potentially a salt marsh migration site), which historically included a herring run to Lovers Lake and Stillwater Pond. The tidal restrictions and other anthropogenic activities have harmed the health of the salt marsh system, as indicated by phragmites, reduced extent of salt marsh and poor water quality. With restoration of ecological functions, the salt marsh in the Creek area could potentially migrate to the Bog and Marsh areas in response to sea-level rise.

The project site is owned by the project applicant, the Chatham Conservation Foundation, Inc., Cape Cod's oldest land trust. The project aims to evaluate and, where indicated, restore routine tidal action and healthy stream flow to extensive estuarine habitats as well as associated brackish and freshwater wetlands for the benefit of the people, plants, animals and ecosystems of Chatham, as well as to sequester coastal blue carbon, restore fish runs, improve natural habitats and increase recreational opportunities.

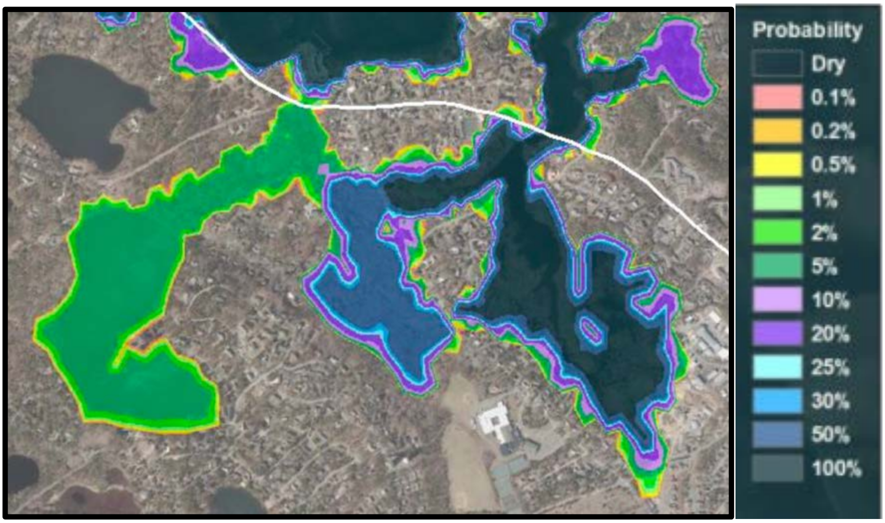
The following paragraphs detail the major sites within the project area. Three maps describe the extent, ownership and major features of the project area, overlaid on the Town of Chatham assessor's map.

Map 1 shows the project area with numbered arrows corresponding to existing culverts. A photographic site visit with pictures taken at the numbered sites can be downloaded at: https://gerrystahl.net/SMTF/ffc_site_visit.pdf. Certain sections of the project area are labelled for the sake of reference in this application.



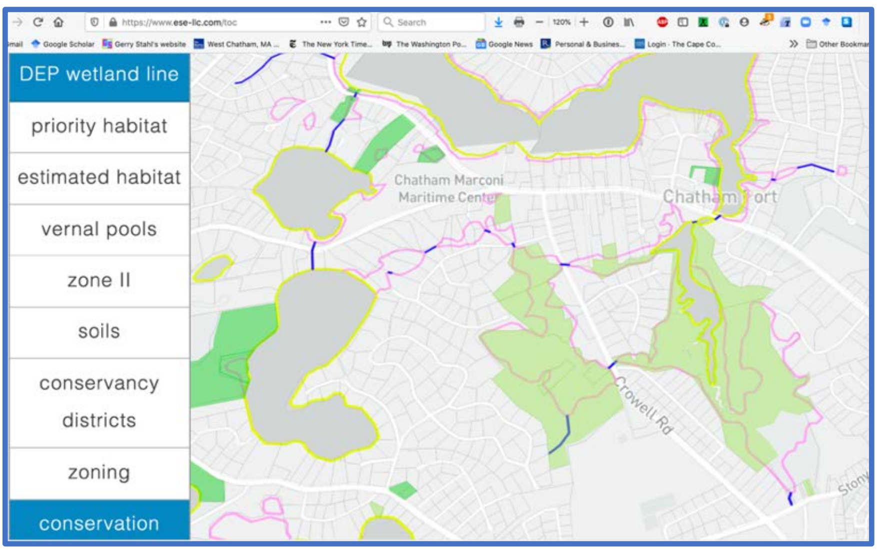
Map 1. Parcels near Frost Fish and Stillwell Pond owned by CCF (green) and the Town (yellow). Existing culverts (red arrows; numbers correspond to photo sites).

Map 2 is a projection of future flooding areas, showing how the areas marked “Bog” and “Marsh” on *Map 1* are likely migration paths for the salt marsh to be formed around Frost Fish Creek if the tidal restrictions at sites 1, 2 and 3 are removed. This would provide floodplain connectivity, supporting a natural flow regime under projected effects of climate change.



Map 2. Projection by The Woods Hole Group of flood probabilities in 2070.

Map 3 shows wetland lines connecting Frost Fish Creek to Lovers Lake and Stillwater Pond—historic and potentially future herring runs.



Map 3. DEP wetlands map showing CCF conservation parcels: herring runs connecting FFC and Stillwell Pond.

Much of the land in the project area owned by Chatham Conservation Foundation (CCF) is currently forested. CCF’s most popular public trail goes along the entire length of the east side of Frost Fish Creek. The area marked “Bog” is a former cranberry bog and is partially flooded and maintained at a water level about two feet higher than the Creek. The area marked “Marsh” is currently partially forested swamp and includes two vernal pools that CCF maintains for use by the local school.

The photographic site visit (https://gerrystahl.net/SMTF/ffc_site_visit.pdf) begins at *site #1*, immediately downstream of a deteriorated culvert under Route 28. *Site #2* is immediately upstream of that culvert. Currently, two flows of water pass through this culvert. There is a metal pipe visible at both ends, partially below low-tide level. There is a smaller flow of water, whose entrance and exit are invisible below low-tide level. This culvert is not on CCF property. However, CCF is partnering with MassDOT to replace that culvert in order to restore optimal tidal flow to Frost Fish Creek. MassDOT may submit a separate application to DER for the culvert replacement project and CCF would support that application. The current application -- CCF’s Frost Fish Creek Restoration Project -- is focused on managing the consequences of that restored tidal flow to create a healthy ecology throughout the project area. CCF is cooperating with MassDOT and other agencies in the design and replacement of the culvert under Route 28, including modeling of the CCF project area. CCF will also collaborate with the Town of Chatham and other partners on associated public relations.

Site #3 is a small earthen dam across Frost Fish Creek approximately 60 meters upstream of the Route 28 culvert (labelled “Dam”). The Dam has a deteriorating culvert. The Dam restricts tidal flow from the small area marked “Pool” to the CCF project area. The Dam is primarily on CCF property and marks the beginning of CCF’s project area. A first decision of the proposed project will be whether or not to remove the dam and the timing for doing so.

Between Site #3 and Site #4 is the current extent of Frost Fish Creek. It is a scenic area that supports a variety of wildlife, including a diversity of birds. A number of private residences are perched uphill along the west side of the Creek. The further one goes upstream, the more phragmites dominate, as little saltwater reaches there.

Site #4 is the transition from the Creek to the Bog. The culvert there is a Weir with an adjustable height. For many years, the height has been set at about two feet higher than the Creek. Considerable watershed runoff from the surrounding residential and small-industrial neighborhood enters the Bog. Once MassDOT's modelling of the area is completed, CCF plans to undertake further H&H studies, particularly of the Bog and Marsh, as well as water-quality studies of the entire project area. These will inform a decision about what to do about the Weir. One possibility would be to encourage tidal flow up the Creek and into the Bog by eventually gradually removing the Weir restriction. This could establish a migration path into the Bog for healthy salt marsh as sea level rises in the future.

Sites #5 and #6 are two sides of an existing culvert under Crowell Road near Northgate Rd. *Site #7* is another existing culvert under Crowell Road near Meadowbrook Rd. These culverts allow small streams from the Marsh to flow into Frost Fish Creek. An issue for the project is to determine the highest use for the Marsh area, given the results of studies and projections of potential water flow and flooding in this area over the next decades.

Site #8 is a culvert under Route 28 near Stillwater Pond that MassDOT will be replacing. This is not part of the CCF proposed project. (However, CCF owns the land on both sides of this culvert and will be cooperating with MassDOT on their effort there.) As shown in the third map, this culvert leads to Stillwater Pond, which is connected to Lovers Lake, which is connected to the CCF Marsh. Thus, there is a potential to reopen a system of fish runs that used to exist.

II. Project Background: Describe the history of the site to the best of your knowledge, including your own involvement. What about the site's current condition suggests that restoration actions are needed? Please also describe how the site currently impacts the nearby environment and/or community (such as blocking fish passage, creating a public safety hazard, flooding, etc.)

Frost Fish Creek was home to indigenous tribes and formed a boundary of Chatham when the Town land was initially purchased from the Wampanoag by William Nickerson in 1656. CCF's 1.1-mile walking trail meanders along the eastern edge of Frost Fish Creek offering walkers glimpses of an old cranberry operation, which has reverted into open wetlands. Along the high trail, borrow pits for sanding the bogs appear on either side of the path. With its outlooks of the wetland observed from upland Pine/Oak woodlands, this area offers the most varied views and numerous opportunities to experience seasonal bird and mammal life in Chatham. A 9-minute video on the Creek and the proposed project was publicly aired at the CCF 2020 Annual Meeting and is now available on the CCF website at: https://www.chathamconservationfoundation.org/trailguide (scroll halfway down). The video documents the history of the area, discusses and illustrates some of the wildlife, and briefly describes the proposed restoration project.

As Chatham's land trust, CCF has acquired parcels since the 1960s in order to preserve open space in the face of development. It has established charitable trust restrictions on the Frost Fish Creek parcels that they "be held in an open and natural condition exclusively for conservation purposes forever."

Recently, CCF has committed to taking increased action to restore parcels that are threatened by invasive species and climate change. For instance, CCF is currently using a CPA grant to restore land on Route 28 about a mile northwest of Frost Fish Creek at the homestead site of the founder of Chatham, creating a public path and native planting landscape at the historic site. Salt marshes are a particular focus of restoration due to their role in climate change and to the fact that much of CCF's land is associated with salt marshes. CCF formed a Salt Marsh Task Force in 2019 and targeted Frost Fish Creek as its first site for salt-marsh restoration. (It has recently added a large marsh complex in West Chatham as a second focus for study, but that is not part of the present application.)

See *2019 APCC Study* (downloadable at: https://gerrystahl.net/SMTF/FFC_Restoration_Report_2019.pdf.)
In 2018, CCF contracted with APCC (Association to Preserve Cape Cod) to conduct a preliminary study of Frost Fish Creek. This study showed the extent of tidal restriction due to the culvert at Route 28. It also pointed to the Dam (Site #3) and the Weir (Site #4) as further restrictions. It recommended further detailed

studies. (The data from this study has been forwarded to MassDOT for their modelling effort.)

The study found human-induced degradation of the ecological system, including impaired water quality, loss of salt marsh, reduced salinity, limited habitat connectivity and fish passage, presence of invasive common reed, and reduced recreational access. It suggested that these factors could be improved by restoring tidal flow to the system.

The time-series monitoring of tidal hydrology completed by APCC indicated overall restriction by the culverts and upstream water-control structures resulting not only in reduced tidal flow and flushing contributing to decline in salinity and poor water quality, but also elevated water levels at low tide and increased residence time of water after storm events, increasing flood risk upstream of Route 28.

While the study called for further modeling, its initial elevation survey indicated minimal to no expected impact on structures (homes) on low-lying properties. One concern when starting this project was proximity to the existing Acme Laundry spill containment and potential for tidal restoration to impact the site. However, the elevation survey along with tidal hydrology indicated that the berm and containment area are located beyond the extent of potential flooding. Thus, this initial assessment would suggest there would be minimal to no impact of a full or partial tidal restoration on structures on neighboring properties or contamination from this contained spill.

The vegetation survey completed by APCC indicated some loss and degradation of salt marsh, presence of invasive *Phragmites*, and shallowing of the creek. Restoration of tidal flow would increase tidal prism and salinity supporting salt-marsh health and potentially expansion/migration in the bog area while reducing the presence and extent of *Phragmites*, a salt-intolerant species. Increased flushing and tidal exchange would likely also improve sediment movement reducing the problem of creek shallowing due to impoundment of sediment behind the restrictions. However, reduction in *Phragmites* and improvement to salt marsh should be weighed against expected loss of other salt intolerant habitats or species like *Typha* when setting goals and objectives for preservation or restoration of Frost Fish Creek. While fish and wildlife were not surveyed by APCC, restoration of this site could also provide opportunity for restoration of species like the tomcod ("frost fish"). Improved water quality and habitat would also provide enhanced recreational opportunities for the community.

See CCF's *CPC Proposal* (downloadable at: https://gerrystahl.net/SMTF/FCC_CPC_application_2020.pdf).
In 2020, CCF submitted a grant proposal to the Chatham Community Preservation Committee for CPA funds to conduct two new detailed studies recommended by the APCC study: an H&H (hydraulic and hydrologic modeling) study of the entire project area, including the Creek, Bog and Marsh, as well as a water-quality study of the bodies of water throughout the project area. This proposal was approved by the CPC, Town officials and Selectmen. It is currently pending approval at Town Meeting, which has been repeatedly delayed due to the pandemic. Approval is expected this summer.

The project area historically supported commercial cranberry bogs, resulting in changes in land use and water flow. The old herring runs have been closed. Water quality in the Creek has deteriorated due to limitations on tidal flushing.

CCF acquired parcels in the project area over several decades. CCF maintains a scenic public trail along the Creek and over some of the adjacent forested hills. CCF is currently installing identification signs on some of the trees and plants along the trail. CCF periodically conducts group hikes along the trail and produced a video of the history of the area (see https://www.chathamconservationfoundation.org/trailguide). CCF has begun public education efforts about the importance of salt-marsh restoration during climate change (see cover article on Frost Fish Creek in the *CCF Bulletin Spring 2021* at: https://gerrystahl.net/SMTF/ccf_bulletin_spring2021.pdf).

III. Project Goals: Describe what the proposed project will accomplish.

The goal of the project is to restore the project area, including the fresh and saltwater wetlands, to a natural state that will be resilient to climate change and to local development over the next 20-to-50-year timeframe. This includes assessment and redesign of the tidal restrictions at Route 28, at the Dam, at the Weir and along Crowell Rd – to be followed by permitting and construction. Decisions on how to address the existing tidal restrictions require hydrologic and water-quality studies. The output of these studies will inform goals and objectives for final design, permitting, installation and resources monitoring. These decisions will be made in collaboration with project partners and in consultation with Town residents, especially abutters.

In line with CCF's mission, the project purpose is to "preserve land for the benefit of the people, plants, animals and ecosystems of Chatham." This includes improving water quality, providing expanded recreational opportunities in nature, and addressing the impacts of climate change by restoring, extending and managing salt marshes to increase carbon sequestration, reduce flooding and protect land from coastal storms.

The desired outcome of this project is to optimize ecosystem benefits of tidal restoration as defined by the design decisions for the culverts and other tidal restrictions within the system. The details of the project will derive from those design decisions, including how best to foster a healthy natural state of each sub-area in accordance with its highest use.

Design and replacement of the culvert at Route 28. This goal will be pursued primarily by MassDOT, its consultants and its partners. CCF will collaborate on this effort and support it. This work will result initially in a hydrologic model of Frost Fish Creek corresponding to a redesign of the culvert. The redesign will have major consequences for CCF's proposed coastal wetlands restoration project, and the model will provide initial guidance to CCF. The MassDOT effort will include permitting and construction of the redesigned culvert and roadway along Route 28.

Probable removal of the Dam. It is likely that the Dam with its culvert will be removed to allow the new tidal flow from the Route 28 culvert to be restored up Frost Fish Creek. A project goal is to plan for such a removal, including coordinating its timing with the replacement of the Route 28 culvert. The consequences of removing the Dam will have to be discussed in detail with abutting residents. The CCF project will include permitting and construction for the probable removal of the Dam.

Potential lowering of the Weir. A more complex decision will be whether to gradually lower and/or eventually remove the Weir. This will involve additional studies of hydrology and water quality in the Bog, such as those planned with the expected CPA grant to CCF. The Bog collects considerable water and pollution from the surrounding watershed—and more will be added by a new Town storm drain. Assessment will be required concerning the consequences of tidal flow into the Bog area from the Creek and freshwater flow into the Creek from the Bog. Any change may have to be made over a period of years, taking into account sea-level rise and changing flood plains. A conversion into salt marsh or into a site for salt-marsh migration may be necessary. This will involve consultation with abutters, permitting, soil testing and possible amendment, and construction to define Bog boundaries.

Improvements to connecting streams. The two culverts under Crowell Road may be sound and adequate. Planning and model projections will be needed to see if interventions are needed to the stream beds connecting the Creek to the Marsh as well as the former herring run to Lovers Lake. The project may need to engage in permitting and construction to improve these stream beds. Acquisition by CCF of some small parcels of wetland may be useful and collaboration with abutters will in any case be important.

IV. Project Scope: Describe the proposed project. What work will be involved with your project? Has any work been completed to date? (such as site visits, technical analyses, conceptual plans, permits, etc.)?

CCF has done substantial background work for the project:

- CCF has maintained parts of the project area for six decades. It has a small trailhead off Route 28 for a well-established trail it maintains along the Creek and through upland forest. In recent years, it opened another access to the other end of the trail from Meadowbrook Rd. CCF is currently adding tree and plant identifiers for public education. It maintains two vernal pools in the Marsh area for science education at the adjacent middle school. CCF is currently developing an ecology curriculum involving hands-on experiences for distribution to schools and has already organized school events at the project area. CCF holds periodic public education events about ecology and Frost Fish Creek.
- CCF hired APCC to do an initial study in 2018/19 (*APCC Study 2019*, downloadable at https://gerrystahl.net/SMTF/FFC_Restoration_Report_2019.pdf), taking account of previous studies of the area and conducting a series of new studies.
- The present proposed project is a follow-up to the recommendations of that 2019 study. An informal photographic site visit to the various relevant culverts (downloadable at: https://gerrystahl.net/SMTF/ffc_site_visit.pdf) provides visuals.
- CCF submitted a grant application (*CPA Grant Proposal*, downloadable at: https://gerrystahl.net/SMTF/FCC_CPC_application_2020.pdf) in January 2020 to the Chatham Community Preservation Committee for a CPA grant to fund more detailed studies of the hydrology and water-quality of Frost Fish Creek. The proposal was approved by the CPC and the Selectmen, as well as receiving letters of support from Dr. Robert Duncanson of the Town of Chatham, from the Pleasant Bay Alliance and from APCC. Final approval by Town Meeting is expected this summer. This grant will pay for studies to extend the APCC and MassDOT studies.
- Recently, CCF learned of MassDOT's project to replace the culvert under Route 28 leading into Frost Fish Creek. The CCF Salt Marsh Task Force had anticipated that such a project would be necessary at some time, given the deterioration of that culvert. However, the timing of the MassDOT project, their subcontracting of a new hydrologic modeling of the area and their willingness to collaborate with CCF on this project were fortunate and timely.

Once MassDOT has finalized the design of the culvert under Route 28, the associated modeling results are available, and the results of the CPA-funded studies are known, it will be time to plan the rest of the proposed project in more detail.

- Decisions about redesign or removal of the Dam and the Weir will come first.
- Restoration of each body of water (Creek, Pool, Bog and Marsh) will have to be planned based on the details of the tidal-restriction removals. For instance, a decision to convert the Bog to salt marsh over time will have to consider the soil composition and the possible need to remove or add soil.
- The streams through the Crowell Rd culverts and the herring run connection to Lovers Lake will need to be investigated to see if the culverts will be adequate over time and if the stream beds need upgrading.
- Based on decisions about the various culverts, permitting will have to be arranged and construction work contracted and supervised.

Assessment of current levels of invasive plants in the bodies of water and census of varieties of fish and shellfish will be needed as a basis for ecological interventions and on-going monitoring. The project will conduct comprehensive functional assessment of the site's baseline conditions.

The scope of the project will incorporate the following tasks:

Task 1. Feasibility studies and modeling

The DOT studies and modeling are already underway. CCF will undertake further H&H and water quality studies funded by its CPA grant, probably in Fall 2021, to extend the range of the MassDOT modelling. This will further assess effects of different tidal restoration scenarios to best understand potential positive and negative impacts on private landowners, natural habitat areas and infrastructure. Combined with the 2019 APCC study, this should provide a basis for deciding among project options.

Task 2. Public outreach

Public engagement will be an integral part of this project through all tasks and phases of the work. Already, CCF has begun public education about the importance of salt marshes to the resilience of Chatham and to the preservation of the local ecology with public lectures, publications in local newspapers and in the *CCF Bulletin*, and a video on Frost Fish Creek. For instance, CCF will be participating in an event on “protecting natural resilience” by project partner C-CAN on May 22, 2021.

Outreach to Chatham residents generally and to abutters in particular will begin in earnest once the studies and modeling have been completed and options are clearer. Over 700 individuals and households in Chatham have become paid members of CCF during the past three years; they receive periodic *CCF Bulletins* (such as the one at: https://gerrystahl.net/SMTF/ccf_bulletin_spring2021.pdf, which highlights plans for Frost Fish Creek).

CCF will work closely with the Town of Chatham to inform the public about restoration plans, including through articles in the widely circulated *Cape Cod Chronicle* and through special public meetings to solicit community input into the plans. Abutters to Frost Fish Creek will be contacted individually to discuss proposed changes.

Task 3. Design

Based on the feasibility studies and extensive review with the project team and the public, design development could advance from concept designs to 25% and 75% level designs. This would primarily concern plans for the Dam, the Weir, the Bog, the Marsh, the connecting streams and extended trails. Implementation steps will have to be planned as part of the proposed project, based on the findings of the feasibility studies. Implementation design will include drafting of a project budget. The budget for the replacement of the Route 28 culvert will be the responsibility of MassDOT and its partners. The costs of the CCF follow-up hydrology and water-quality studies will be covered by the CPA grant. Other budget considerations will be incorporated in connection with the design of further project activities.

Task 4. Permitting and Final Design

Permitting and final design of the replacement of the Route 28 culvert will be primarily the responsibility of MassDOT and its partners. Permitting for any changes at the Dam and the Weir or elsewhere will be conducted as part of CCF’s project. The 75% design (permit-ready) plans will be submitted for permitting, with modifications integrated into final design. Different aspects of the project (e.g., the Dam, the Weir, the Bog, the Marsh and the connecting streams) might be staggered to allow the ecology to adjust to different changes. This could involve multiple permitting processes.

Task 5. Construction

Construction bid packages will be developed and the project components bid out to contractors for construction. Construction activities will need to be carefully specified with the assistance of DER, and qualified contractors hired and supervised. Coordination will be completed with DOT to integrate work on the Route 28 culverts with work upstream within the project area. Construction is anticipated to include replacement of the Route 28 culverts, removal of the small Dam immediately upstream of Route 28, as well as potential removal of the bog Weir and restoration of the Bog and/or Marsh to natural wetlands. Again, construction of different aspects of the project will likely be staggered. In particular, the Marsh may be targeted as a migration path for the salt marsh over the coming decades; preparations for that would not be an early priority of the project. Fundraising was begun with the CPA grant application. Further fundraising will involve state and federal agencies—potentially with DER, NRCS and/or CCCD involvement. CCF could also consider doing community fundraising among Chatham residents interested in donating to specific aspects of the project.

Task 6. Monitoring

Pre- and post-restoration monitoring will at minimum incorporate vegetation sampling and deployment of data loggers to measure changes in tidal hydrology and salinity as a result of restoration. This monitoring is envisioned to mirror the pre-restoration assessment completed by APCC in 2019, with additional monitoring to be completed to measure the success at achieving the goals of this project. Monitoring of many aspects of this restoration project (e.g., water quality, tidal flushing and fish presence) will be central to quality control and public accountability. CCF will continue to monitor water flow, water quality, salt-marsh extent, ecosystem health, fish presence and animal presence during and after the project period to help evaluate and document project success. CCF will also continue to provide public education and to develop further recreation services beyond the DER Priority Project period.

V. Has any funding been identified or spent for this project? **Yes ☒ No ☐**
If yes, describe:

CCF paid for the 2018 APCC study of Frost Fish Creek (report downloadable at: https://gerrystahl.net/SMTF/FFC_Restoration_Report_2019.pdf).

CCF anticipates final approval of a $75,000 CPA grant to conduct H&H and water-quality studies to extend the APCC and MassDOT studies.

The CCF annual operating budget includes a line item for the Salt Marsh Task Force. The CCF Board can also allocate special project funding from time to time at its discretion. CCF could also solicit donations from members and the public to support specific aspects of the restoration project.

2. ANTICIPATED BENEFITS

Please use as much space as needed. The boxes will expand as you fill them.

I. Ecological Benefits: What are the expected environmental benefits of your project? For instance, what positive changes do you expect to see in the natural areas within and near your project site? This could include improving the flow of water, reconnecting sections of waterway so fish can access them, improving water quality, etc.

The most obvious benefit will be improving the flow of water by removing tidal restrictions.

The considerable increase in flushing should dramatically improve water quality, as bodies of water have recently been confined. The 2006 MEP report states that "culverts restricting tidal flow under Route 28 have had a negative influence on water quality in Frost Fish Creek." The expected result of tidal restoration may also offer a significant benefit to adjacent landowners in terms of mitigation of flood waters that back-up at the current flow restrictions.

Reconnecting sections of waterway will allow fish to access the bodies of water, and to move back and forth among them and in and out of the ocean. A historic herring run loop could be re-established through the Creek, Marsh, Lovers Lake, Stillwater Pond and back to Ryder's Cove.

The project will include monitoring the fish, sea-life, birds and mammals, both before and after restoration. CCF already maintains an outdoor camera to capture photos of animals, such as river otter and deer. Over 150 species of birds have been identified at Frost Fish Creek. It is not known if frost fish (*Microgadus* tomcod) are still present in the Creek. A restored Creek could improve shellfish potential and even create nursery habitat for commercial fish species.

Over time, there is potential for extensive improvement and recovery of salt marsh and freshwater wetland with healthy marsh grasses and cedar swamp habitat. The restoration of tidal flow to the existing fringing marsh will improve the health of this resource area, providing improved habitat for fish, shellfish, birds and other wildlife. Reconnection of tidal flow and restoration of the bogs has the potential to allow for long-term salt-marsh migration with near-term benefits for improvements to these wetlands to a freshwater or brackish system. Restoration of wetlands in this manner will aid in sequestration of carbon and prevent the release of greenhouse gases from the underlying peat and soils.

With sea-level rise, water flow between the Creek and the Bog or Marsh could provide migration paths for the salt marsh around the Creek.

Other benefits to wetland functions and ecosystem services are hard to predict in detail at this point. They will likely include: nutrient/toxicant/sediment retention in the areas that become salt marsh; short and long-term flood storage capacity during extreme weather; surface water erosion reductions; habitat for anadromous fish runs; better habitat for birds; improved organic carbon export to the estuaries; increased nursery stock for the coastal fisheries economy; improved birding opportunities for tourists; improved local aesthetic value for residents and hikers; and educational opportunities for local students.

As part of the project, we will survey conditions as a baseline for monitoring benefits and other changes – e.g., the planned water-quality study.

II. Community Benefits: To the best of your ability, describe how your project is expected to benefit the local community and economy. This could include creating outdoor recreational space, addressing flooding or safety issues, improving climate resiliency, etc.

Climate projections indicate considerable flood potential in the project area as well as certain surrounding residential or industrial areas. Optimal tidal flushing will allow flood waters to drain out to sea. In the other direction, incoming storm surges on Chatham's coastline can be mitigated by partial absorption into the Creek system, with its connections open to additional holding areas. It will be important to undertake flexible planning and on-going monitoring to minimize negative community consequences and to maximize resiliency.

Improved water quality and increased fish access will have direct benefits for community recreation, such as kayaking and fishing. It could also benefit local commercial fishing by supporting the life cycle of herring and their role in fish ecology.

III. Landowner Information

Please use as much space as needed. The boxes will expand as you fill them.

I. Who is the landowner(s) of the project site?

The Chatham Conservation Foundation, Inc., a 501(C)3 non-profit organization, is the landowner of the project site. As a land trust, CCF acquired the following parcels between 1966 and 1999:

CCF #	Date Acquired	Grantor	Acres	Registry Book/ Land Court Certificate	Registry Page/ Land Court Document	Plan Book/ Page; Lot(s)	CR overlay or CT Deed from Compact	Address	Assemblage Name	FY 19 Town Map No.	FY 19 Town Pcl. No.
15	7/20/1966	Moye	5.40	1375	1050	no plan	27238/340	Frost Fish Hill	Frost Fish Creek	13I-8	1B
27	12/31/1967	Nanly Homes -Lynch	36.00	1387	615	93/53	27238/340	Stepping Stones Rd	Frost Fish Creek	13H-0	1
101	12/23/1983	Marden	20.70	3969	253	338/4	27238/340	Crowell Rd	Frost Fish Creek	12H	17-2
116	8/13/1987	Burlin	0.36					Stony Hill Rd	Frost Fish Creek	13G-62	2
118	6/16/1988	Nickerson		6307	22	no plan	27238/340	Stepping Stones Rd	Frost Fish Creek	13H-0	1
121	5/10/1988	Nickerson	0.62	6957	55	no plan	27238/340	Crowell Rd	Frost Fish Creek	12H-19	3
127	12/29/1990	Robertson	1.50	7399	170	no plan	27238/340	Crowell Rd	Frost Fish Creek	12I-13	19

13 7	7/3/199 2	Yasun a	10. 20	811 1	1	200/3 3	27238/3 40	Crowell Rd	Frost Fish Creek	12I-2	17
15 3	12/22/1 995	Walthe r	0.9 7	998 6	146	520/1 4: Lot 8B	27238/3 40	Court St	Frost Fish Creek	12H-24HB	H8 B
15 4	8/28/19 96	Gregor ian	5.0 1	103 97	74	527/7 6: Lot 2	27238/3 40	Crowell Rd	Frost Fish Creek	11I-3	6
16 5	6/8/199 9	Frost Fish Realty Trst	5.4 3	123 25	284	541/8 6: Lot 15	27238/3 40	Frost Fish Hill	Frost Fish Creek	13I-8	1B

See *Map 1* near start of application for location of these parcels on the Assessor's map of Town parcels, with CCF # shown. These parcels appear on the DFG BioMap2[2] as Conservation Openspace and as Critical Natural Landscape.

II. Is the current or future landowner committed to the proposed restoration work? Is a sale pending on the current restoration-minded entity? (Landowner Agreement must be attached in writing and/or copy of Purchase and Sale Agreement provided). **Yes ☒ No ☐**

CCF is committed to the proposed restoration work. Through the Compact of Cape Cod Conservation Trusts, the parcels are covered by Charitable Trust restrictions that require they "be held in an open and natural condition exclusively for conservation purposes forever."

III. Landowners are generally expected to sign permit applications and hold construction contracts, typically with assistance from DER and others. In some cases, landowners will work with project partners who will serve as the lead on permits and/or construction contract.

A. Please indicate who is anticipated to be the applicant on any necessary permit applications:

CCF will be the applicant on some permit applications. However, CCCD and/or MassDOT and its contractors will be the applicant on permits involved in the culvert replacement under Route 28. Furthermore, the Town of Chatham or other project partners may be the applicant on certain other permits related to this project.

[2] https://maps.massgis.state.ma.us/dfg/biomap2.htm

B. Please indicate who is anticipated to be the contract holder for implementation of the restoration work:

CCF will be the contract holder for some implementation work. However, CCCD and/or MassDOT and its contractors will be the contract holder for work involved in the culvert replacement under Route 28. Furthermore, the Town of Chatham or other project partners may be the contract holder for certain other work related to this project.

IV. Applicant and Partner Information

Please use as much space as needed. The boxes will expand as you fill them.

I. If different from the applicant, please name the Lead Project Sponsor for this project (see definition on pages 2-3 of the RFR).

Same.

II. Please describe the qualifications/experience of the applicant to help lead a restoration project.

The Chatham Conservation Foundation (CCF) is the oldest land trust on Cape Cod. It currently owns 191 parcels in the Town of Chatham, covering 628 acres. Since 1966, it has been steward of this land. Most of this land is either forested, salt marsh or fresh-water pond. In addition, CCF manages the Conservation Restrictions on 45 parcels of Town and privately owned land totaling 214 acres. CCF has a staff Land Steward and several experienced volunteers and Trustees who maintain trails, monitor vegetation and maintain the land. CCF manages contracts with professionals and manages grants for special projects.

Several Trustees have served many years on the Chatham Conservation Commission and/or bring relevant training and experience.

CCF contracts with APCC to assist in restoration efforts, including planning, conducting studies and supervising subcontracts.

The Chair of the CCF Salt Marsh Task Force, Dr. Stahl, has experience in project management. As a professor of information science, he directed an internationally renowned research project with over $8 million in NSF grants over a 10-year period. Earlier, he was a neighborhood planner for community revitalization and energy conservation in Philadelphia for 7 years, with about $4 million in foundation, city and federal grants he raised. As CCF Treasurer, he developed online systems for CCF's management of land stewardship, finances (including grant management), donor tracking and record keeping.

CCF has a paid staff including Executive Director and Land Steward. It has a working Board of Trustees and a number of regular volunteers, as well as an assigned AmeriCorps Cape Cod Member.

III. Have any other restoration partners (actual or potential) been identified? Yes ☒ No ☐

If yes, please identify them here and describe their qualifications/experience and role in relation to the project.

The proposed project will form a Working Group of project partners. The Working Group will meet at least quarterly online to review findings and decide on next steps. (At CCF's suggestion, MassDOT already convened a number of the partners to discuss the modelling and design of the culvert under Route 28.) Statements of support for the proposed project from many of the partners are attached (*Appendix 3. Statements of Support*). Restoration partners include:

- **Department of Transportation (MassDOT)** (David White, Timothy Dexter and Liana Dinunzio), which has contracted with Stantec (Jennifer Ducey) and The Woods Hole Group (Matt Schulz). Dexter, Supervisor of Wetland Resources & Wildlife Unit has been with MassDOT for 13 years and has worked on a variety of initiatives and programs involving stream and wetland restoration, and wildlife habitat. Dexter has been instrumental in several culvert restoration and replacement projects and is an author of MassDOT's *Stream Crossing Design Guide*, contributor to the fluvial geomorphology approach, and developed MassDOT's Rivers and Roads training program. White, Deputy Director of Environmental Services has been with MassDOT for 24 years and has been involved in a wide array of projects and program initiatives including Resiliency and Adaptation to address sea-level rise and extreme-weather events. White is presently working on the development of MassDOT's Culvert Assessment and Management Program, a statewide initiative to standardize the assessment of potentially vulnerable culverts and identify culverts that need maintenance or upgrade for safety and resiliency.

Dinunzio is with Environmental Services, Wetland Resources & Wildlife Unit of MassDOT.

- **Cape Cod Conservation District (CCCD)** (Richard DeVergilio). DeVergilio is looking to include costs of the Route 28 culvert replacement and the larger Frost Fish Creek tidal restoration in an upcoming CCWRRP funding request. The CCCD through the CCWRRP is particularly concerned about restoration of tidal restrictions and fish runs.
- **National Resources Conservation Service (NRCS)** (Stephen Spear). NRCS has been involved in restoration projects all over the Cape such as this one – providing planning, technical, and financial support for assessment, design, and construction.
- **Association for the Preservation of Cape Cod (APCC)** (April Wobst). APCC has worked with Cape Cod communities to identify more than 150 restoration projects aimed at restoring impaired salt marshes, fish runs and shellfish beds, as well as improving water quality through stormwater remediation. As APCC's Restoration Ecologist, Wobst provides technical, planning, permitting and management support to communities interested in completing restoration projects. APCC will work with the CCF and project team to support planning, design, implementation, outreach and monitoring for this project. APCC has experience and expertise in project management and public engagement for restoration projects of this scope and scale, including the current partnership working with the Falmouth Rod and Gun Club to restore the Upper Childs River stream channel and bogs.
- **Town of Chatham** (Robert Duncanson). Dr. Duncanson is Director, Natural Resources Department, Town of Chatham. The CCF, NRCS and the CCCD have been working closely with the Town during scoping and planning for this project. The Town has been supportive of the project and ranks it as a priority for restoration. The CCF anticipates approval of Chatham CPC funds to support further modeling and feasibility studies in 2021.
- **Pleasant Bay Alliance (PBA)** (Carole Ridley). Ridley is the Director of PBA, which conducts research and projects in the Pleasant Bay AECA in the following areas: watershed planning, coastal processes and structures, wetlands protection, water quality monitoring and waterways.
- **Chatham Climate Action Network (C-CAN)** (Jane Harris). Harris has degrees in biology and resource management and 20 years of experience as Conservation Administrator in 3 MA towns. She has served on the boards of CCF, PBA, C-CAN, FCW, APCC, Mass Assoc. of

Conservation Commissions, AmeriCorps of Cape Cod, Chatham Land Bank.

- **Friends of Chatham Waterways (FCW)** (Jeff Mason). Mason is Director of FCW and is a Professional Wetland Scientist (PWS) and a Certified Environmental Restoration Practitioner (CERP) with expertise in wetland/riverine/estuarine ecology; project management; regulatory support and permitting; mitigation/restoration site design, implementation and monitoring; and remote sensing/GIS analyses of aquatic ecosystems.

IV. Describe any community support or community involvement in the project. To what degree have supporters have been involved in the project to date?

CCF is a well-established community-based organization with broad community support. CCF's Trustees are all Chatham residents. Over 700 Chatham residents and households have been dues-paying members of CCF during the past three years.

As Cape Cod's oldest land trust, CCF has preserved land in Chatham since the 1960s, through donations of land and purchases funded by Chatham residents. CCF now owns 191 parcels, preserving over 600 acres of land in a natural state. It also manages the Conservation Restrictions on 45 Town-owned parcels totaling over 200 additional acres. Many local volunteers assist in watching over these parcels and maintaining trails on these lands.

The Chatham Community Preservation Committee approved CCF's application for a CPA grant to conduct further detailed studied of the hydrology and water quality of Frost Fish Creek. This application was supported by the Chatham Select Board and is expected to be approved at Town Meeting this summer.

V. Anticipated Role for DER

Please use as much space as needed. The boxes will expand as you fill them.

I. Describe the role you see DER playing as part of the Project Team and what project needs you see DER supporting (be as specific as possible):

Coastal Wetland Restoration. Once tidal flow is restored through the redesigned Route 28 culvert, tidal flushing, restoration of water flow throughout the project area, increased water quality, salt marsh vegetation and fish population will need to be fostered. DER could provide guidance, technical assistance and funding to support this.

Dam Removal and River Restoration. It is likely that the restriction at the Dam and eventually the restriction at the Weir will need to be removed. DER could provide guidance in making this decision, planning the process, applying for permits, contracting for construction and raising funds to pay the associated expenses. In addition, the streams connecting the Creek to the Marsh and from there to Lovers Lake may need some restoration; DER could similarly support this.

Cranberry Bog Wetland Restoration. The restoration of the Bog will be a major undertaking. It was historically a cranberry bog and now collects watershed run-off. DER guidance and technical assistance in restoring this area would be valuable.

The proposed project covers a project area with diverse characteristics and needs. DER's experience would be invaluable in highlighting issues and helping to coordinate decisions, plans and actions. Each of the project stages listed under Section IV, Project Scope, will benefit from DER staff technical assistance, technical services by qualified DER contractors, and/or direct DER grant funding.

ATTACHMENTS:

A. REQUIRED :

1. Letter of commitment from property owner (*if owner is not Applicant*), or if applicable a copy of Purchase and Sale Agreement and Letter of Commitment by purchaser (if not the Applicant). **Applicant is owner**.
2. Copy of the latest Assessor's Map showing the parcel(s) on which restoration work might take place and the ownership information for the lot. **Appendix 1. Assessor Map**. See also *Map 1* at start of Application.
3. At least one photograph of the project site. For multi-site projects, at least one labeled photograph of each site must be submitted. **Appendix 2. Project Photo.**

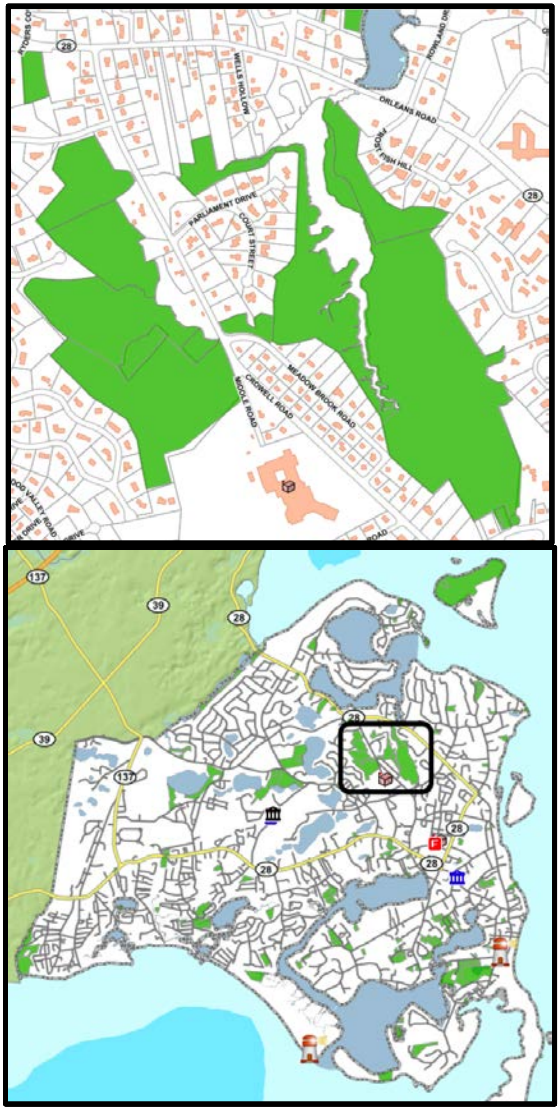
B. OPTIONAL:

- Additional photographs. Download at: https://gerrystahl.net/SMTF/ffc_site_visit.pdf.
- Locus map. **Appendix 1. Assessor Map.**
- Design plans (*if completed*). For example, completed conceptual or engineering designs.
- Letters of support from the community, e.g., letters from selectmen, abutters, local organizations. **Appendix 3. Statements of Support.**
- Project budget and timeline (*if available*). Please indicate any matching funds that have been secured.
- Permits, if obtained.
- Press and media coverage (e.g., newspaper clippings, articles, links). **CCF Bulletin Spring 2021** at: https://gerrystahl.net/SMTF/ccf_bulletin_spring2021.pdf.

SIGNATURES	
By signing below, I acknowledge the terms and specifications contained within this RFR.	
Applicant Signature: Gerry Stahl	**Date: May 10, 2001**
☐ **X** By checking this box, you confirm that all supporting materials such as project plans, reports and/or documents are included with this application.	

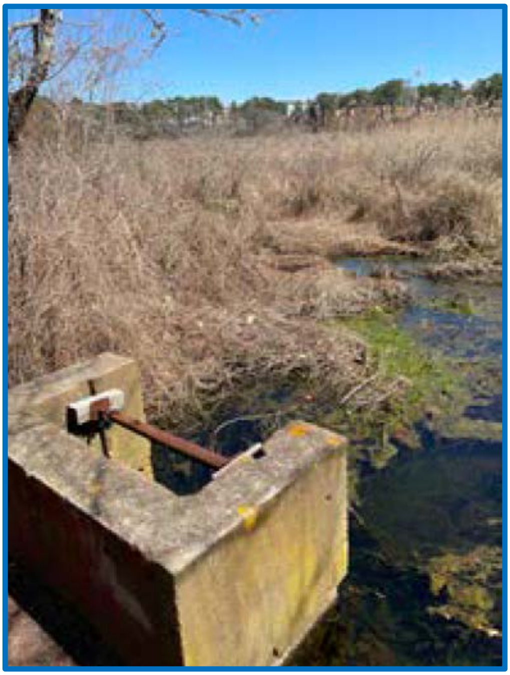
Appendices:

Appendix 1. Assessor Map



Assessor map and locus map. From https://www.mapsonline.net/chathamma.

Appendix 2. Project Photo



Project photo of weir culvert at Frost Fish Creek.

Appendix 3. Statements of Support.

Statements of support for the "Frost Fish Creek Restoration Project" from project partners.

MassDOT (David White, Timothy Dexter and Liana Dinunzio), which has contracted with Stantec (Jennifer Ducey) and Woods Hole Group (Matt Schulz)

On Tue, May 4, 2021 at 8:54 AM White, David J. (DOT) <david.white@state.ma.us> wrote:

I am writing to express MassDOT's continued support of the Chatham Conservation Foundation's wetland and ecological restoration project of Frost Fish Creek. We recognize that your efforts to remove weir structures and berms within Frost Fish Creek will provide improved flow and water quality that will help restore the wetland functions of Frost Fish Creek. As part of MassDOT's Culvert Assessment and Management Program we are actively pursuing a feasibility analysis and design of the Route 28 Culverts at Frost Fish Creek and Ryders Cove to ensure highway system safety and reliability as well as improve the crossing for sea level rise and connectivity.

We look forward to working with you on this important project.

David White

MassDOT

Deputy Director, Environmental Services

CCCD (Richard Devergilio)

On Fri, Apr 30, 2021 at 7:55 PM Rick Devergilio <rdevergilio@comcast.net> wrote:

The Cape Cod Conservation District is happy to support this effort with the Chatham Conservation Foundation. Frost Fish Creek has been identified by the CCWRRP as a priority project that works to restore natural tidal flow to the FFC Wetland System while also restoring the rte 28- infrastructure for long term coastal resilience. The CCWRRP is partnering with MA-DOT and the town of Chatham to secure design and installation funding for the effort.

Rick DeVergilio

Project Manager

Cape Cod Conservation District

NRCS (Stephen Spear)

On Mon, May 3, 2021 at 3:38 PM Spear, Stephen - NRCS, West Yarmouth, MA <stephen.spear@usda.gov> wrote:

NRCS supports the Chatham Conservation Foundation's effort to restore the Frost Creek salt and fresh water wetland system. This location has been identified in The Cape Cod Water Resources Restoration Project as a candidate for restoration. We are willing to assist the Foundation and all other partners in this effort.

Steve Spear

Conservation Planner - Cape Cod Water Resources Restoration Project

USDA Natural Resources Conservation Service

APCC (April Wobst)

On Wed, May 5, 2021 at 3:37 PM April Wobst <awobst@apcc.org> wrote:

APCC will work with the CCF and project team to support planning, design, implementation, outreach and monitoring for this project.

April Wobst

Restoration Ecologist

Association for the Preservation of Cape Cod

Town of Chatham (Robert Duncanson)

On January 24, 2020, Robert A. Duncanson, Ph.D., Dir. of Health & Natural Resources, Town of Chatham, wrote:

I had the opportunity to review the CPA application entitled "Frost Fish Creek Salt Marsh Preservation" submitted by the Chatham Conservation Foundation, Inc (CCF).

Frost Fish Creek has been monitored intermittently over the decades by the Town, local school classes, CCF, and others. The work proposed in the application will be a comprehensive evaluation of the Creeks ecology, including hydrodynamics, water quality, and marsh health as impacted by surrounding development and culvert restrictions under Route 28. Based on experience gained in the Muddy Creek restoration project this type of holistic evaluation is necessary to understand conditions in Frost Fish Creek, associated wetlands, and develop appropriate long-term mitigation measures.

Therefore, I ask your support of the application by the Chatham Conservation Foundation, Inc. for Frost Fish Creek.

Robert A. Duncanson, Ph.D.

Dir. of Health & Natural Resources

Town of Chatham

Pleasant Bay Alliance (Carole Ridley)

On Thu, May 6, 2021 at 10:59 AM Carole Ridley <cr@ridleyandassociates.com> wrote:

On May 4, the Pleasant Bay Alliance Steering Committee voted the Alliance's support of the Foundation's Frost Fish Creek Restoration Project proposal to MassDER and willingness for me as the Alliance representative to serve as a partner on the project working group.

Carole Ridley

Coordinator, Pleasant Bay Alliance

Ridley & Associates, Inc.

Chatham Climate Action Network (C-CAN) (Jane Harris)

On Fri, May 7, 2021 at 7:02 PM Janet Williams <janet.williams27@gmail.com> wrote:

The Chatham Climate Action Network (CCAN) strongly supports and endorses the Chatham Conservation Foundation's application that Frost Fish Creek be designated as a Restoration Priority Project by the Mass Department of Ecological Restoration.
Restoration Improvements of this important natural resource has the potential to reduce roadway flooding, provide storage for floodwaters as a result of anticipated increases in sea level, and promote water quality to improve the health of adjacent marsh resources to provide climate resilience to the Town of Chatham.

If you have any questions, please feel free to contact me. Thank you!

Janet Williams

Chair, Chatham Climate Action Network

Friends of Chatham Waterways (Jeff Mason)

On Tue, Apr 27, 2021 at 9:24 AM Jeff Mason <masonjeffreya@gmail.com> wrote:

I support the application of CCF for the Frost Fish Creek Restoration Project designation of a DER Priority Project. FCW can be particularly helpful in assessing water quality issues.

Jeffrey A. Mason, PWS, CERP

President, Friends of Chatham Waterways

Part I: Grants Awarded at Drexel University

DR K-12: Computer-Supported Math Discourse Among Teachers and Students

This full research-and-development project designs, develops and tests an interrelated system of technological, pedagogical and analytic components to provide a range of opportunities for middle- and high-school students to engage in significant mathematical discourse (DR K-12 challenge 2); it catalyzes and supports these opportunities by enhancing the ability of in-service teachers to engage in, appreciate and foster math-problem-exploration and math-discourse skills in their students (DR K-12 challenge 3). The project addresses the core STEM discipline of mathematics by motivating the identification, comprehension and enjoyment of mathematical discourse skills through socially interactive, collaborative learning experiences involving pedagogically organized series of stimulating, skill-appropriate problems using computer-based visualization/exploration and small-group math-problem discussion.

The project's design-based-research approach crafts a socio-technical *educational model* to provide a comprehensive, practical package of tools and techniques for classroom teachers and students, which integrates and refines a number of mutually supportive components: (a) *Innovative technology*: A custom, open-source virtual learning environment that integrates synchronous and asynchronous media with the first multi-user dynamic-math-visualization application. (b) *Curricular resources*: Problem-based learning topics in specific areas of mathematics designed to help teachers tune rich math problems to local texts or curriculum and to guide student exploration. (c) *In-service teacher professional development*: Practicing teachers in online masters programs are mentored to understand and model the innovative technologies and pedagogies by doing collaborative problem posing/exploring/solving and engaging in collaborative reflection on the math discourse in their logged interactions. (d) *Middle- and high-school students:* The teachers introduce the model, technology and resources into their classrooms.

The project builds on and integrates previous work of the PIs, including: the discourse-analysis-based theory of group cognition (Stahl, 2006); the Virtual Math Teams learning environment developed, analyzed and evaluated in (Stahl, 2009b); curricular materials and dynamic math visualization software of GeoGebra, adapted to flexible multi-user collaborative learning; online professional development and online mentoring of in-service math teachers at the Math Forum and at the Drexel and Rutgers-Newark schools of education; and the adaptation of conversation analysis to text-based chat interaction analysis, designed to highlight how collaborative problem solving or group knowledge building takes place. The project adapts components that have been explored, prototyped, or piloted by the PIs to classroom use. Project key personnel and Advisory Committee members bring expertise and experience in educational software R&D; math problem-set adaptation, dissemination and mentoring; in-service math teacher training; online math resources, collaborative learning, problem-based learning and dynamic math; design-based educational research management and evaluation; theory of knowledge building in small groups and in online communities. They also bring opportunities for national deployment and scaling up.

Intellectual merit. This project integrates leading-edge cyber-learning-environment technology incorporating innovative collaborative math exploration tools with educational approaches based on current directions in the learning sciences. It approaches this through a systematic iterative process of co-evolving the technology and curricular resources in the context of engaging, reflective collaborative-learning experiences of significant mathematical discourse by in-service teachers and their students. It thereby advances theory, technology and practice within real-world educational settings to forge a coherent research-based approach to math education appropriate to today's challenges and potentials.

Broader impact. The project designs, tests, integrates, evaluates and disseminates technology, curricular resources, pedagogical methods and analytic tools for use in math-teacher professional-development programs, classrooms of math students, home-schooling networks, online schools and the Math Forum community (over three million visits per month). Project results will support the use of math exploration technology within collaborative math-discourse approaches at diverse schools nationally through their spread to in-service teacher-training programs and services—bringing practical cyber-learning of math to at-risk and isolated math students. It documents the potential impact on both teachers and students of this computer-supported math-discourse approach quantitatively and qualitatively.

Project Description

Mathematics education in the future faces enormous opportunities from the availability of ubiquitous digital networks, from innovative educational approaches based on theories of collaborative learning and from rich resources for interactive, online, dynamic math exploration. The fact that more and more teachers and students are learning online—with distance education, online masters programs, home schooling, online high schools, etc.—makes the incorporation of virtual collaborative learning environments a natural trend. A major issue in realizing these opportunities on a broad scale in schools is empowering teachers to appreciate and engage in the new approaches, and supporting them with appropriate tools, models and resources for practical instructional usage.

This project therefore proposes to develop a model of professional development and a suite of supports for math teachers. It will design, test, evaluate and refine a virtual learning environment that integrates synchronous and asynchronous media with an innovative multi-user version of a dynamic math visualization and exploration toolbox. Online teams of in-service teachers will be introduced to the collaborative exploration of Common Core State Standards-based math topics in this environment. They will then be guided in reflection on their own team's discourse with the use of chat-replaying tools. As they become familiar with the use of the technology and with the nature of collaborative math discourse, some of the trained teachers will mentor other teachers through a similar process of engagement. Also, they will introduce their students—primarily in diverse urban schools—to experiences of mathematical exploration and to reflection on math-team discourse. The model of math teacher professional development and of student collaborative math learning centers on the *production of significant math discourse*.

Theoretical Framework: Math Cognition as Math Discourse

To mathematicians since Euclid, math represents the paradigm of creative intellectual activity. Its methods set the standard throughout Western civilization for rigorous thought, problem solving and argumentation. Many of us teach math in part to instill in students a sense of deductive reasoning. Yet, too many students—and even some math teachers—end up saying that they "hate math" and that "math is boring" or that they are "not good at math" (Boaler, 2008; Lockhart, 2009). They have somehow missed the intellectual math experience—and this may limit their lifelong interest in science, engineering and technology. According to a recent "cognitive history" of the origin of deduction in Greek mathematics (Netz, 1999), the primordial math experience in 5th and 4th Century BC was based on the confluence of labeled geometric diagrams (*shared visualizations*) and a language of written mathematics (*asynchronous collaborative discourse*), which supported the rapid evolution of math cognition in a small community of math discourse around the Mediterranean, profoundly extending mathematics and Western thinking.

The vision behind our project is to foster *communities of math discourse* in networks of math teachers, in classrooms of K-12 math students and in online communities associated with the Math Forum. We want to leverage the potential of networked computers and dynamic math applications to catalyze groups of people exploring math and experiencing the intellectual excitement that Euclid's colleagues felt—refining and testing emerging 21st Century media of *collaborative math discourse* and *shared math visualization* to support math discourse in both formal and informal settings and groupings. Those members of the project team who teach math teachers masters-level courses and professional-development workshops—and others—have found that many people teaching K-12 math have had little experience themselves participating in processes of mathematical exploration and discovery (Krause, 1986; Livingston, 1999; Silverman & Thompson, 2008). This project is designed to provide teachers with first-hand experiences and to mentor them in guiding their students to engage in rich math discourses that go beyond generating numeric answers to supply math reasoning and to draw conceptual connections (Briedenbach et al., 1992; Carlson, 1998; Carlson et al., 2002; Monk, 1992; Thompson, 1994).

The learning sciences have transformed our vision of education in the future (Sawyer, 2006; Stahl, Koschmann & Suthers, 2006). New theories of mathematical cognition (Bransford, Brown & Cocking, 1999; Brown & Campione, 1994; Greeno & Goldman, 1998; Hall & Stevens, 1995; Lakatos, 1976; Lemke, 1993; Livingston, 1999) and math education (Boaler, 2008; Cobb, Yackel & McClain, 2000; Lockhart, 2009; Moss & Beatty, 2006), in particular, stress collaborative knowledge building (Bereiter, 2002; Scardamalia & Bereiter, 1996; Schwarz, 1997), problem-based learning (Barrows, 1994; Koschmann, Glenn & Conlee, 1997), dialogicality (Wegerif, 2007), argumentation (Andriessen, Baker & Suthers, 2003), accountable talk (Michaels, O'Connor & Resnick, 2008), group cognition (Stahl, 2006) and engagement in math discourse (Sfard, 2008; Stahl, 2008). These approaches place the focus on problem solving, problem posing, exploration of alternative strategies, inter-animation of perspectives, verbal articulation, argumentation, deductive reasoning and heuristics as features of *significant math discourse* (Maher, Powell & Uptegrove, 2010; Powell, Francisco & Maher, 2003; Powell & López, 1989).

To learn math is to participate in a mathematical discourse community (Lave & Wenger, 1991; Sfard, 2008; Vygotsky, 1930/1978) that includes people literate in and conversant with topics in mathematics beyond basic arithmetic. Learning to "speak math" is best done by sharing and discussing rich math experiences within a supportive math discourse community (Papert, 1980; van Aalst, 2009). By articulating thinking and learning in text, students make their cognition public and visible. This calls for a reorientation of the teaching profession to facilitate dialogical student practices as well as requiring content and resources to guide and support the student discourses. Teachers and students must learn to adopt, appreciate and take advantage of the visible nature of collaborative learning. The emphasis on text-based collaborative learning can be well supported by computers with appropriate computer-supported collaborative learning (CSCL) software, such as that prototyped in the Virtual Math Teams (VMT) Project (Stahl, 2009b).

Research Project Goal, Hypothesis and Components

Project Goal

> *To incrementally refine a research-based, classroom-tested model of computer-supported, resource-supported* ***math education*** *through* ***shared visualizations*** *and* ***collaborative discourse*** *by groups of mentored* ***teachers*** *and groups of their* ***students***—by designing, developing and testing: (i) a **discourse-based model** of math-teacher professional development and mentoring support; (ii) customized **technology** for computer support of **shared math visualization** and **joint exploration**; and (iii) adaptable, standards-based math-content teaching **resources** for middle-school and high-school students, guidelines for group **collaboration** and **accountable talk,** tools for **reflection** on discourse and networks of on-going **mentoring** relationships for math teachers.

Research Hypothesis

The project is based on an hypothesis, which it will test, concerning how to *increase the quality and quantity of significant math discourse* among math teachers and K-12 students:

> Indicators of math learning (by groups of teachers and groups of their students)—such as group discussion of math content, problem posing/exploring/solving, explanation of math moves, visualization or investigation of multiple representations, and reflexive analysis of group math work—can be increased through (i) a math-discourse-based **model of in-service teacher professional development** supported by and integrated with use of (ii) a multi-user version of **dynamic mathematics technology** integrated in a rich online learning environment to support shared visualization and joint exploration of mathematical topics and (iii) **mentoring relationships, collaboration and accountable talk guidelines, and curricular resources** for online professional-development courses, K-12 classes and formal and informal online math communities.

This hypothesis is intended to guide iterative cycles of trial and analysis in design-based research (design, develop and test—not to prove efficacy and effectiveness). It will assess the effect of the combination of project components—because in such a socio-technical system the effect of introducing the technology is highly dependent upon the mentoring and the use of appropriate resources.

The hypothesis centers on measurements of *group* math discourse rather than on assessment of *individual* learning of math content—in accordance with the socio-cultural theory that effective individual math learning can be an indirect product of *participation* in group math discourse (Lave & Wenger, 1991; Sfard, 1998; 2008; Stahl, 2006; Vygotsky, 1930/1978). Vygotsky's notion of the *zone of proximal development* suggests that students may be able to engage in mathematical work within groups at a level that they will not be able to engage in for a couple years as individuals—and that such group work can be essential for the individual development in the long run (Vygotsky, 1930/1978, pp. 84-91). As a result, there is a need to assess the educational effectiveness of group interactions as such, beyond pre/post tests of the individuals. In addition, the striking finding within CSCL research of *productive failure* (Barron, 2003; Kapur & Kinzer, 2009; Patak et al., 2011; Schwartz, 1995) shows that there can be a paradoxical inverse relationship between measures of successful learning by small groups versus by the individual members of those groups because of group processes that reveal deep mathematical relationships but that do not lead immediately to high test scores of the individuals. For these reasons, *the project evaluates its goal in terms of the quantity and quality of the math discourse* that takes place during the small-group problem-solving interactions, looking for hypothesized increases for groups as they participate and in successive project years as the model, technology and resources are iteratively developed.

(i) Model of Math Education

The proposed project will design, develop and test a ***model*** of math education through collaborative math problem proposing/exploring/solving, by involving in-service teachers in first-hand mathematical experiences and helping them to reflect on their own learning experiences. Then they will try out the model with their students, while receiving mentoring and support from the project. The collaborative model of math education stresses math discourse. In this project, groups of teachers and groups of students will do math problem solving collaboratively and then reflect on the logs of their discourse to identify key moves. We propose using teachers' and their students' original mathematical conversations as "didactic objects" (Thompson, 2002) designed to support "decentering" (Wolvin & Coakley,

1993) and "collective reflection" (Cobb et al., 1997) on particular aspects of their math discussion. The discourse-centered model of math education will structure learners in small teams and will provide mentoring to guide the team's mathematical exploration, discourse and learning. Math Forum staff and other project team members will provide initial mentoring to the first cohorts of teachers, who will in turn mentor subsequent cohorts of teachers as well as students in their own classes. A permanent support network will be established to provide sustainability of project accomplishments. The teachers who are trained in this project will be encouraged—initially by paying them—to participate in teacher networks, including national and international networks of teachers, supporting broadening dissemination of the discourse model of math education.

(ii) Online Math Collaborative Learning Environment

The proposed project will design, develop and test two forms of ***technology*** to support math learning with collaborative and interactive tools for cyberlearning: (a) computer-supported collaborative learning (CSCL) software and (b) dynamic mathematics (software that allows users to manipulate geometric diagrams, equations, etc.). (a) CSCL provides virtual learning environments in which teams of students can interact synchronously and asynchronously to build knowledge together. This student-centered approach has many advantages, including increased motivation, sharing of skills, engaging in significant discourse and practicing teamwork. This project will adapt and extend the Virtual Math Teams (VMT) environment already prototyped and tested by the PIs (Stahl, 2009b). (b) Dynamic math (such as Geometer's Sketchpad, Mathematica, Cabri or GeoGebra) has already profoundly impacted math education (Goldenberg, 1995; Hoyles & Noss, 1994; King & Schattschneider, 1997; Laborde, 1998; Myers, 2009; Scher, 2002), with Geometer's Sketchpad and GeoGebra used in many US classrooms and globally. Yet, research on math education has not analyzed how students use dynamic math tools in sufficient detail (compare Çakır, Zemel & Stahl, 2009; Stahl, 2009b). GeoGebra (http://www.geogebra.org) is an open-source system for dynamic geometry, algebra and beginning calculus—including trigonometry, conics, matrices, graphing and Euclidean constructions. It offers multiple representations of objects in its graphics, algebra and spreadsheet views that are all dynamically linked, making GeoGebra a particularly flexible tool for exploration. Working with the developers of GeoGebra, this project will provide the first multi-user version of dynamic math, so that teacher teams and student teams can explore math collaboratively; it will integrate this into the larger VMT virtual collaborative-learning environment with text chat and wiki to support persistent discourses about math—that can be shared, reflected on and researched.[3]

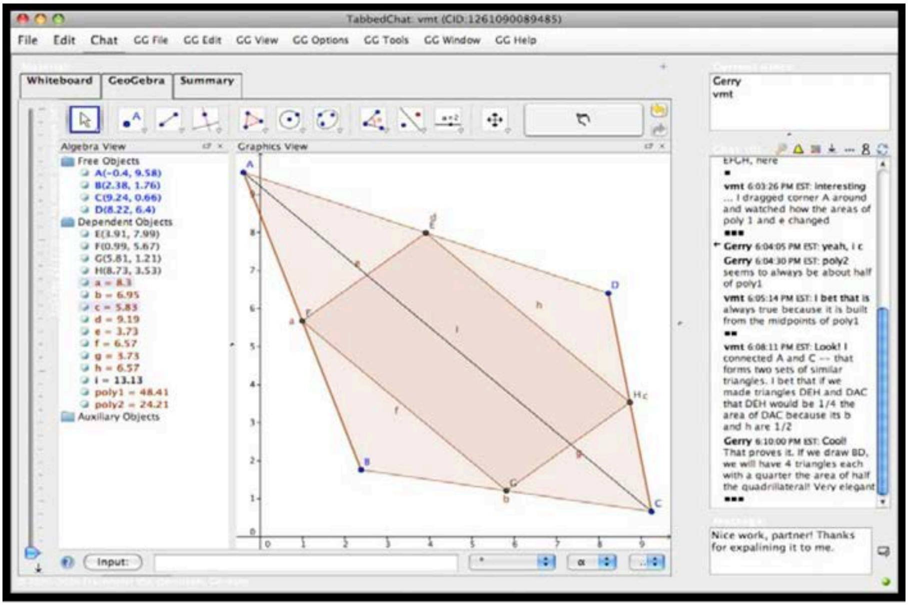


Figure 1. A demo (not real student interaction data) GeoGebra construction created and discussed collaboratively in a proof-of-concept multi-user prototype of the project's learning environment, based on the VMT system. The VMT system includes (not shown here): a Lobby with social networking and tools for teachers, integration with a wiki, and Web browsers.

(iii) Curricular Resources

The proposed project will design, develop and test ***resources*** to support teachers and students in their interactive explorations of rich math problems (e.g., open-ended problems with multiple possible solution approaches and many potential extensions to explore). Three kinds of resources are: (1) Curriculum packages in domains of K-12 math, building on existing NSF-funded and community-based sources (see http://dynamicgeometry.com, http://keypress.com/x5582.xml and

[3] For a demo of the prototype system, go to http://vmt.mathforum.org/VMTLobby. Log in as "guest" with password "guest". The Lobby should open showing the List of All Rooms. Select Project "VMT Research". Click on "Apply filters". Open "Geometry". Open "Polygons". Click on "GeoGebra Demo Room" Eventually a JavaWebStart chat room should open. Explore its different tabs and functions.

http://geogebra.org/en/wiki). The curriculum will be based largely on classroom-tested problems using dynamic-math software and integrated with popular math textbooks (e.g., *Everyday Mathematics, Investigations in Number, Data and Space, Mathematics in Context, Connected Mathematics, Interactive Mathematics Program, Core-Plus Mathematics, Simms Integrated Mathematics* and textbooks from McDougal Littell or Glencoe), but adjusted by experienced Math Forum staff for collaborative online usage. It will be aligned with the recommendations of the *Common Core State Standards for Mathematics* and the new NCTM volumes, *Focus in High School Mathematics: Reasoning and Sense Making in Algebra/Geometry*. Teachers will be mentored in adapting the content of their local curriculum to collaborative online student exploration, whether using GeoGebra or not. (2) Guidelines, suggestions and examples for collaborative learning, knowledge building and math exploration will be published. This will feature "accountable talk" guidelines for math discourse. (3) Training resources in understanding online math discourse will be developed to help teachers and students identify examples of productive inquiry moves, etc., to foster reflection on logs of their math discourses. These broad categories of resources will encapsulate the expertise of the project team in problem design, collaboration mentoring and discourse analysis, producing documents that can be used by a gradually growing community of math teachers and students. The content of these resources will build on experience at the Math Forum, the VMT Project, the teacher professional-development programs at Drexel and Rutgers and the related research literature. The content will be elaborated, tested, evaluated and refined—and then published as project deliverables.

Results from Prior NSF Support

The proposed project grows out of the successful Virtual Math Teams (VMT) Project. This is a several-year NSF project (awards DUE-0333493, IERI-0325447, SBE-0518477, DRL-0723580) that developed an open-source virtual learning environment for math students. The system integrated a social-networking portal, synchronous text chat, a shared whiteboard, an asynchronous wiki, a referencing tool, mathML expressions and a web browser. Student actions and chat postings are automatically logged to be replayed for analysis. Over a thousand student-hours of piloted usage were logged. A qualitative micro-analytic approach to interaction analysis was developed based on ethnomethodologically inspired conversation analysis (Garfinkel, 1967; Sacks, 1962/1995; Stahl, 2009a; 2009c; Zemel, Çakir & Stahl, 2009). A large number of publications have appeared from the project (see http://GerryStahl.net/vmt/pubs.html), including 2 books (Stahl, 2006; 2009b) and 6 doctoral dissertations (Çakir, 2009; Litz, 2007; Mühlpfordt, 2008; Sarmiento-Klapper, 2009; Wee, 2009; Zhou, 2010).

The VMT Project pioneered the study of online collaborative math discourse—both its nature and modes of computer support for it. The 28 studies in (Stahl, 2009b) present some of the most important of the 169 publications related to the project. They include a number of dissertation-level case studies of interactions in the VMT environment by middle-school, high-school and junior-college students, which analyze: how math problem solving can be effectively conducted collaboratively among students who have never met face-to-face; how the structure of text chat interaction differs from spoken conversation; how the media of graphical diagrams, textual narratives and symbolic representations can be intimately interwoven to build deep math understanding; how deictic referencing is important to establishing shared understanding; how students co-construct a joint problem space; how collaborative meaning making and knowledge building are accomplished in detail; how online math discourse can be supported by a software environment that integrates synchronous and asynchronous media with specialized math tools; and how a methodology based on interaction analysis can be used for a science of group cognition.

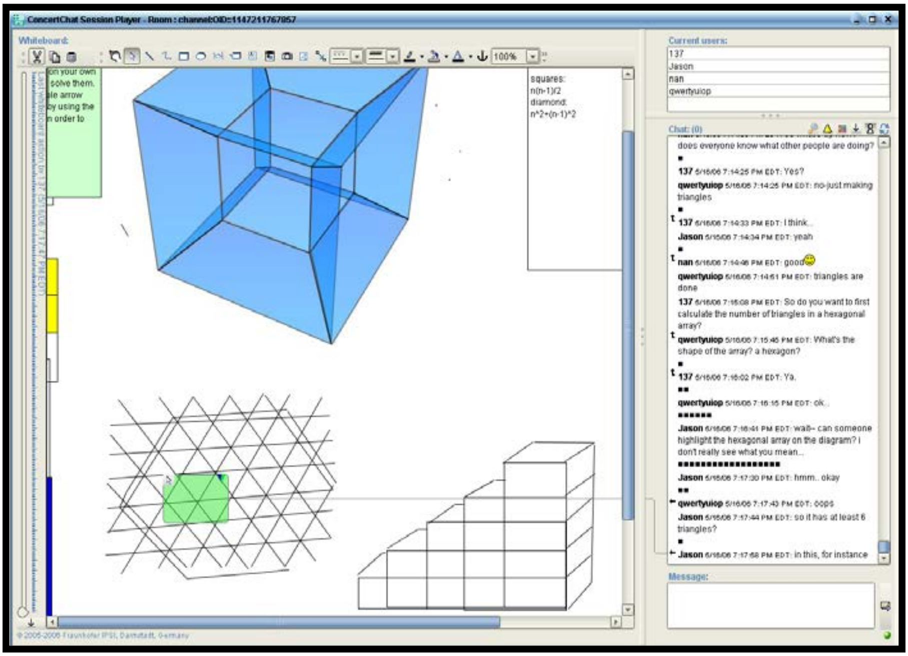
The VMT Project was structured as design-based research, with the technology, research and theory co-evolving through dozens of iterations. The VMT Project demonstrated both the practicality of the proposed project and the need for it. While the VMT Project prototyped a rich cyber-learning environment and studied student interaction, it did not develop the range of supports that we know are needed for classroom use: robust software, problem sets, guidelines, etc. Furthermore, it did not include a dynamic-math component. The VMT Project provides a solid starting point for the proposed project and documents the need for further technological development, enhanced support for dynamic math, curricular models and training of in-service teachers. The design, development and testing of these logical next steps are needed to enable a powerful and innovative form of math education to be offered in a practical form to K-12 schools through education schools and to the public through the Math Forum.

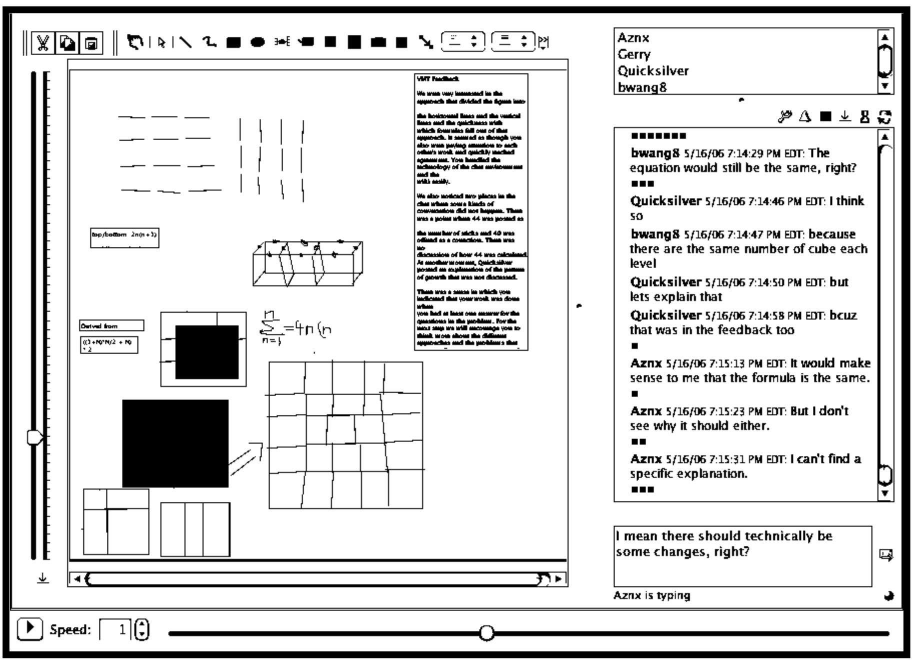
Prior NSF support of the Math Forum has developed a successful approach to online mentoring of math teachers and their students. Since 1993, the Math Forum has mentored over 100,000 students, conducting hundreds of workshops, summer institutes and school-improvement contracts. Recently, it has successfully completed the Virtual Fieldwork, Online Mentoring, and Teacher Workshop Model projects (NSF DUE-**0717732,** DUE-0127516 and DUE-0532796). Mixed-methods studies of these have shown the surprising result that the online mentoring of K-12 pre- and in-service teachers had a more positive effect for teachers with low math self-efficacy (Renninger et al., in press). This is due to the non-linear and flexible format of online discussion—suggesting that online collaboration may well help at-risk math students at least as much as those with higher math self-efficacy. Math Forum approaches are making inroads with a population of people who most would think will not change (Renninger et al., 2010). In the proposed project, Math Forum workshops for teachers will complement and feed teachers into the courses at Rutgers and Drexel. The workshops will also train mentors and seed the on-going teacher network.

Research and Development Design

The proposed project adopts an iterative design-based-research approach to design, develop and test innovative curriculum materials, technologies, teaching methods and models for teacher in-service professional development and K-12 student instruction. The project develops a socio-technical educational model that evolves and integrates a number of mutually supportive components, each of which has previously been explored in a preliminary way by one or more of the PIs. However, the components have not previously been integrated into a scalable model of math education. The proposed project brings together the PIs, other necessary senior staff and advisors with the resources to begin to systematically test, refine, validate and disseminate the integrated model. There are several areas of work:

(a) A model of math education as computer-supported math discourse. The model incorporates: (b) innovative technology for collaborative math discourse, (c) support for shared mathematical visualizations and (d) curricular materials to stimulate and guide math discourse. The model includes three successive project targets: (e) in-service teacher professional development, (f) middle- and high-school math education and (g) broader virtual math-discourse communities.



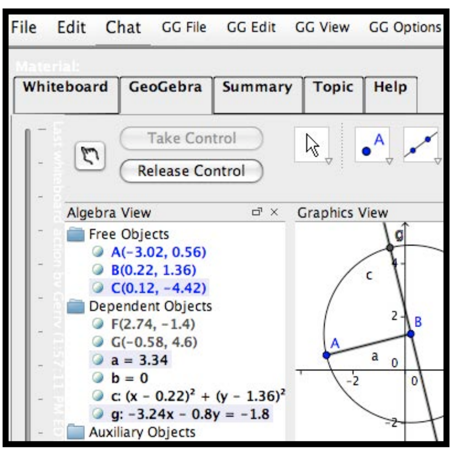


Figures 2 and 3. Images of actual student online collaborative work on patterns. In Figure 2, a student points from a chat message to a smallest hexagon pattern composed of 6 triangles illustrating VMT's unique integration of chat and whiteboard with its deictic reference tool. Figure 3 shows the Replayer tool interface across the bottom.

(b) Innovative technology for collaborative math discourse. The VMT Project developed a research prototype of a custom, open-source virtual learning environment that integrates synchronous (text chat, shared whiteboard, dynamic math exploration, shared web-browser) and asynchronous (a community wiki, a social-networking portal) media to support math visualization and collaborative discourse by virtual math teams. This prototype was adequate for extensive testing in multiple iterations, as well as limited use by select teachers in their classrooms as part of research trials. As part of the proposed project, we will implement, test and refine new interfaces for teachers, mentors and administrators. These will allow *teachers* to register a number of students at once, set up multiple copies of interaction rooms for multiple small groups of students, monitor activity in rooms, respond to problem behavior online and review reports of student activity. New functionality will also make it easier for *students* to document their online work (e.g., in the project wiki or in Word documents, Excel spreadsheets and PowerPoint slides) with log excerpts and images of constructions. Support for *researchers* will facilitate researchers in the project as well as colleagues outside the project to easily replay sessions of student interaction.

The VMT Project was widely recognized as an important example of synchronous support for online collaboration and was studied by several international researchers (GerryStahl.net/vmt/pubs.html); it is expected that the proposed project will be of even more interest, particularly within the math education research community. The VMT Replayer allows complete replay of a user session, including all actions and system notices, as though the session was digitally video-recorded. The researcher’s view is guaranteed to be identical to the user’s view since it is generated from the same data as sent to a client computer. The log information will be made available in convenient textual formats for student reflection and reporting as well as for researcher analysis. New functionality to be explored includes automated feedback agents and displays, increased integration so math objects can be moved easily from the synchronous tabs (chat, whiteboard, summary, GeoGebra, web browsers) to asynchronous components (wiki pages, email, documents), as well as refinement of the interface. The system will be released as open source on SourceForge so that others can deploy it on their own servers or extend the software to meet their own educational needs. The Math Forum will maintain the system as a permanent service, so that users can easily create topics for chat rooms and invite other users to collaborate.

(c) Support for shared mathematical visualizations. The project will port GeoGebra—a comprehensive and well established application for dynamic-math exploration—to the virtual learning environment described above. It will make the application fully multi-user. It will integrate the application in a tab of the environment (see Figure 1 above). As previously described, GeoGebra is a particularly appropriate dynamic-math application for this project because its source code is freely available as open source, there is an active international development community to support on-going development, the lead developer and the founder are committed to consult on this project, the application supports a wide range of math from algebra and geometry construction to calculus and 3-D, GeoGebra has won international prizes, it has been translated into about 50 languages and it has received on-going NSF support. Like all other dynamic-math applications, GeoGebra currently exists only as a single-user application. While users can send their static constructions to each other, display screen images, or awkwardly include a view of the GeoGebra application within other environments through screen sharing (e.g., in Blackboard, Moodle, Elluminate, etc.), only one person can dynamically manipulate the construction. Our port converted GeoGebra to a client-server architecture, allowing multiple distributed users to manipulate constructions and to all observe everyone's actions in real time. Every action in the GeoGebra tab will be immediately broadcast by the server to all collaborating clients (and logged in detail for replay and research). We have been exploring turn-taking mechanisms (see Figure 4) to avoid conflicts in the construction and modification of GeoGebra drawings; although it is important in synchronous chat to allow multiple users to type simultaneously, we have found that it is natural for a group to allow one member at a time to change a graphical construction and for group members to take turns editing and rearranging.



Incorporation of GeoGebra in the VMT environment framework allows users to engage in text chat while manipulating the construction. Importantly, users can graphically point from a chat posting to an area of the construction that they want to index (see Figure 2)—an important support for math discourse that is unique to VMT. They can also scroll back and forth through the history of the GeoGebra construction, animating its evolution—a powerful way to explore many mathematical relationships. In addition, a complete record of the collaborative construction is available to the participants, their teachers and project researchers, allowing them all to analyze and reflect upon the complete interaction, including the construction actions synchronized with the chat. We have already completed a prototype port of GeoGebra to VMT in order to confirm its feasibility. It provides an exciting collaborative experience. The port now needs to be engineered in a robust way, incorporating all of the GeoGebra functionality (including import and export compatible with standard GeoGebra and Geometer's Sketchpad to facilitate sharing of constructions, and a full menu system to support learning by new users). In Year II of the project, we will incorporate the extended GeoGebra 4.0 functionality that will be released by then, including support for inequalities and CAS (computer algebra system like Mathematica, Maple, or the TI-Nspire CAS calculator). The project will produce a refined and tested multi-user version of GeoGebra and will release it as open source.

(d) Curricular materials to stimulate and guide math discourse. Problem-based learning (PBL) materials in areas of mathematics like algebra, combinatorics and geometry will be adapted from existing high quality curricula and piloted. These materials will define challenging math problems for collaborative online group exploration and help teachers to tune them to local student capabilities. The materials will allow students to explore rich but accessible problems taken from topic domains covered in their textbooks and in the Common Core State Standards. The PBL approach involves mentors who are trained to guide student exploration and to steer collaborative student groups to address their joint learning issues (Barrows, 1994; Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2008; Koschmann, Glenn & Conlee, 2000). Project team members and others have developed some model math problems (Krause, 1986; Math Forum & Wolk-Stanley, 2003a; 2003b; 2004a; 2004b; Powell, Lai & O'Hara, 2009). The Math Forum has years of Problems-of-the-Week in several areas of school mathematics, which can be adapted to online group collaboration. Much curriculum has been developed with NSF funding for dynamic-math applications like GeoGebra and Geometer's Sketchpad, including lessons tied to state standards and intended to support popular textbooks through student hands-on exploration. The project will facilitate classroom teacher use of such resources in this new learning context. The team has already prototyped a series of problems that consecutively explore issues of combinatorics; along with the problems, a teachers' guide contains concrete suggestions on how to adapt the problems for different kinds of student teams (Powell, Lai & O'Hara, 2009). The problems in this document were tested in the VMT Project and in high-school classrooms of teachers studying at Rutgers. Sets of problems correlated to textbooks and to the Common Core State Standards will be compiled, some taking advantage of GeoGebra. Additional resources will be developed to train teachers and students in mentoring techniques, in collaboration skills and in math-discourse skills. All these resources will be tested and produced in publically available online documents as project deliverables. These and other math problems will be incorporated in the VMT Lobby's library of Topics, to be available to students in home-schooling and informal-learning situations.

(e) In-service teacher professional development. To effectively change education in schools, teachers must be prepared to understand and to learn how to model use of the innovative technologies and pedagogies. Practicing teachers rarely find time to engage in learning processes capable of transforming their teaching practice and they seldom are able to introduce major new approaches in their highly constrained curricula. This project therefore involves in-service teachers when they have scheduled time to pursue masters-level professional-development courses. It starts by involving them during their regular courses (taken online) in online collaborative problem solving using the project's software technology and curricular approach—(a), (b) and (c) above. Later course work involves them trying out what they have learned back in their own classrooms, within the context of their current curriculum; the project provides mentoring and resources to support this effort.

Both Drexel and Rutgers-Newark offer masters-level teacher-professional-development programs and courses in math education in online modes. The fact that these teachers will already be studying together online creates an ideal setting for the use of an online learning environment with dynamic-math support. These graduate programs have been designed, taught and directed by project co-PIs Silverman and Powell. The proposed project will allow these programs to develop, test and adopt the educational model of computer-supported math discourse. This model will be pioneered at these two schools of education, providing a collaborative interaction that will produce a more generalized result than would development at a single institution. It will also permit extended utilization of the online medium by, for instance, having teachers from both institutions working together on math topics in small groups and having them mentor teachers from each other's institution. In the later years of the project, this model will be disseminated to other schools of education, partially through Advisory Committee members. The Math Forum has effectively implemented a similar model, incorporating its Online Mentoring Project modules into teacher education programs around the country.

The initial plan at *Drexel University* is to build on the existing MS in Mathematics Learning and Teaching (MS-MLT) program, which is already exclusively offered online. This program in math education was originally developed by co-PI Silverman and is taught primarily by him and Math Forum staff. For the first cohort of students under this project, Drexel will offer MTED775, "Special Topics: Supporting Math Learning through Computer-Supported Collaborative Discourse." This course will be one required math-education elective for MS-MLT students and an elective for other professional-development students. Then two new education courses will be developed to make this model a part of the regular course offerings of the School of Education: MTED 651 (which will focus on teachers personally engaging in computer-supported, resource-supported collaborative discourse and reflection on both their activity and their learning) and MTED 652 (which will focus on supporting teachers to incorporate computer-supported, resource-supported collaborative discourse in their classes). MTED 652 will include resource development for teachers' classroom implementations. Each of these courses—which have been approved at Drexel pending funding of this project—will carry 3 quarter-credits.

The initial plan at *Rutgers-Newark* is to engage two cohorts each year of practicing teachers in a revised version of the online course in "Mathematics and Instructional Technology" taught by co-PI Powell. The goals of the course are three-fold: (1) to familiarize in-service teachers with the mathematical problem-solving and problem-posing activities of the online problem-exploration units in which their students will engage; (2) to deepen in-service teachers' thinking about the effects of the collaborative environment on their own and their students' thinking about mathematics (math objects, relations among objects and dynamics among relations), math reasoning and problem-solving heuristics; (3) to focus in-service teachers' instructional attention on understanding and facilitating students' discourse in mathematics. To accomplish these goals, the course will engage in-service teachers in a sequence of tasks, beginning with familiarizing them with the project online environment through involving them in mathematical activities using it, then engaging them in reviewing their session logs and finally having them plan how they will implement the model in their teaching.

(f) Middle- and high-school math education. The in-service teachers will introduce the technology and curricular resources that they used in their university classes into the classes they teach, often mixing students from different schools or cities in online teams to take advantage of being part of an online discourse community and to motivate the use of online media by students in face-to-face classrooms. The teachers will take the logs of their students' interactions back to their professional-development sessions for on-going group analysis. They also will engage their students in reflection on their own logs, discussing how the math discourse surfaces mathematical insights and conceptual connections.

The curricular resources adapted by the project are designed to support classroom math activities by enhancing and reinforcing the core objectives covered in textbook readings and instructor-led activities. Resources include adaptation options and guidelines to help teachers tune problem sets to complement their core activities. For instance, the research-based textbooks, *Mathematics in Context* and *Discovering Geometry*, which are used in the Philadelphia public school system, stress student investigation in order to construct conceptual understanding of key math concepts and the *Common Core State Standards for Mathematics* recommend that "students consider the available tools [such as] dynamic geometry software…to explore and deepen their understanding of concepts" (p.7). The project model builds on this approach, providing opportunities for students to explore and discuss topics online with peers from their own or other schools. The model provides: tools for dynamic, multi-user, graphical exploration; visual and numeric feedback on quantitative and qualitative changes during exploration; and a record of the exploration and accompanying discourse, which students can replay, reflect on and incorporate in reports—e.g., pasting log excerpts or screen images in their documents.

Reflection on interaction logs by teachers and students primarily involves trying to follow the problem-solving path of participants and to notice critical collaboration moves. They will be encouraged to look for examples of accountability to the group, to standards of math reasoning and to the characteristics of their math objects. They will look for instances where someone poses a productive inquiry that initiates effective group exploration—or where the group fails to come up with a useful proposal or fails to take up a proffered proposal. Examples will be culled and shared on the project wiki.

Although many project activities center on teacher professional development, the ultimate goal is to *increase the quality and quantity of both teacher and student mathematical discourse*. Therefore, teacher professional development will be oriented to improving the math discourse of their students. While the primary indicator of project success will be the identification of desirable mathematical discourse moves during problem solving by teachers and students, the project will also be concerned with changing student conceptions of math. It will survey a sample of teachers and students before and after their involvement in the project to compare self-reports of attitudes about math and about approaches to math instruction. In addition, some teachers and students will be asked as a final part of their course work to compose a brief reflection paper on their learning experience.

Most of the in-service teachers in the project come from the Philadelphia, Camden, Newark, New Brunswick and New York City areas. Thus, many of the classrooms that will be involved in the program are inner-city K-12 schools with high proportions of educationally at-risk and economically disadvantaged students; others are from near-by suburban and private schools with contrasting student populations. The project educational model will therefore be tested in diverse, real-world settings.

Because teacher and student work on math problems will all take place in the online software environment, complete detailed logs will be available to the project staff, as well as to the students and teachers themselves. The logs can be reviewed and studied in detail with the Replayer software, as well as with various formats of log printouts. This will not only facilitate reflection by students and teachers on their own work, but also permit the documentation of interesting cases for teacher instruction and detailed analysis for project evaluation. The project will compile a portfolio of instructive case studies.

(g) Broader math-discourse communities. Once teachers studying at Drexel or Rutgers and their students become involved in online collaborative dynamic geometry and math discourse, teams will be set up that involve students from online schools, home-schooling networks or the Math Forum virtual community. This will yield data for generalizing project findings as well as stimulate the spontaneous generation of self-organizing communities of math discourse. This will primarily take place through contacts and presentations by project staff and the teachers who have been trained, as well as through the Math Forum and its large user community (3 million visits/month. The project technology and resources will be made publically available as an integral part of the Math Forum services in Years IV and V of the project. The VMT software environment is designed to support the viral spread of user communities across the Internet; the proposed project is intended to form a critical mass of users and topics to catalyze that process. The model of computer-supported math discourse will become institutionalized at Drexel and Rutgers, will be taken to other schools of education through Advisory Committee members and personal contacts of project staff, through Math Forum outreach, through the extensive active GeoGebra user community and through presentations at educational conferences and in related journals.

(h) Group cognition theory. When small groups engage in collaborative problem posing, exploring and solving, they can accomplish cognitive tasks interactively or transactively as a group. The project will analyze logs of student math work, shared visualizations and reflective discourse, using conversational analysis and statistical methods to study how students build on each other's utterances, constructions and actions to accomplish mathematical cognition. Building on past work on group cognition (Çakır, Zemel & Stahl, 2009; Koschmann, Stahl & Zemel, 2009; Stahl, 2006; 2010a; 2010b), this will provide a contribution to theory of situated and distributed cognition. In particular, analysis of the use of GeoGebra in a fully logged multi-user online environment with guidance in math discourse moves will pioneer in the development of theory of cognition in groups using dynamic-math tools, providing insight into math learning generally. Case studies and other findings with theoretical implications will be published.

	Year 1	Year 2	Year 3	Year 4	Year 5
Model	Design, development, testing of courses for teachers	Integrate technology and resources fully in courses	Refine model based on formative evaluation	Publish articles about model	Disseminate model to other schools of education, etc.
Techno-logy	Debug VMT; multi-user GeoGebra 3.3; menu system; implement full logging	New VMT functionality; multi-user GeoGebra 4.0; teacher admin & monitoring supports	Release VMT as a Math Forum service; automate statistical analysis	Support VMT Open Source; develop feedback of analysis to participants	Disseminate VMT servers
Resources	Pilot teacher resources; develop student resources	Test teacher and student resources	Evaluate use of resources	Publish resources	Disseminate resources
Curricular materials	Review existing materials for GeoGebra and Geometer's Sketchpad	Compile problem sets aligned with standards and textbooks	Evaluate use of materials	Publish materials in formats for teachers, home schooling, distributed schooling	Disseminate materials
Teachers	Pilot model with 10 teachers in Drexel and Rutgers courses and 20 teachers in Math Forum workshops	Implement model with 35 teachers in Drexel and Rutgers courses and 40 teachers in Math	Evaluate model with 50 teachers in Drexel and Rutgers courses and 40 teachers in Math	Continue training with 60 teachers in Drexel and Rutgers courses and 40 teachers in Math	Evaluate teacher training in Drexel and Rutgers courses; continue training 40 teachers in Math Forum workshops

		Forum workshops	Forum workshops	Forum workshops	
Students	Pilot with 25 students	Involve 750 students of teachers in courses and workshops; log series of sessions by student small groups	Involve 750 students of teachers in courses and workshops; log series of sessions by student small groups	Involve 750 students of teachers in courses and workshops; log series of sessions by student small groups	Evaluate changes in significant math discourse of student groups over time: within group and across cohorts
Mentoring	Prepare mentoring materials based on previous Math Forum mentoring projects	Pilot mentoring of teachers with 2 outstanding teachers	Increase to 5 teacher mentors	Increase to 10 teacher mentors	Increase to 15 teacher mentors
Theory	Validate coding scheme	Analyze discourse moves in logs	Conduct in-depth case studies and interviews	Compile best practices case studies	Develop theory of math group discourse

Project Phases, Milestones, Deliverables

Evaluation

Formative evaluation is a constant process built into the design of the project. As a design-based research effort, the over-riding research hypothesis listed at the start of this project description will be addressed by designing and exploring an iteratively refined solution—and by documenting its impact on the quantity and quality of math discourse by teachers and students. The interlocking components of the project will be reviewed at weekly project team meetings. Team meetings will include interaction analysis data sessions (Jordan & Henderson, 1995; Stahl, 2010a), in which the group collaboratively discusses new data from logs of teachers or students—and makes design decisions for refining the co-evolving components. The project team will discuss what seems to be working and what does not. It will decide what to modify for the next iteration. The project is complex, with many dependencies among its components and many shifting contextualities. A flexible approach like design-based research is needed to respond to a continuous formative evaluation and on-going project modification.

The explicit evaluation effort will include semi-annual formative-assessment reports documenting: (a) project progress, (b) improvements in project outcomes and (c) plans for the next half year. The external Advisory Committee (AC) will review, discuss and respond to each report. The AC will meet annually to discuss project progress with the project team. The AC has expertise in mathematics education, research evaluation, teacher training, problem-based learning, conversation analysis, CSCL and virtual communities. Most AC members have been PIs on successful NSF grants in the learning sciences. The AC includes: **Sharon Derry** (Wisconsin), **Cindy Hmelo-Silver** (Rutgers-New Brunswick), **Christopher Hoadley** (NYU), **Timothy Koschmann** (Southern Illinois), **Mary Marlino** (UCAR), **Kay McClain** (Arizona State), **K. Ann Renninger** (Swarthmore), **Lauren B. Resnick** (LRDC, CMU), **Carolyn Penstein Rosé** (CMU), **Anna Sfard** (Haifa & Michigan State), **Wesley Shumar** (Drexel), **Tamara Sumner** (Colorado), **Daniel D. Suthers** (Hawaii), **Alan Zemel** (SUNY Albany). The external evaluator is **Sukey Blanc** (Senior Research Associate with Research for Action), who has led evaluations on projects such as the Metro Math MSP.

As discussed above, the research hypothesis focuses on the quantity and quality of math discourse at the group unit of analysis. Theories of the zone of proximal development, productive failure and group cognition argue that learning-related processes and phenomena at the group level may be different from those at the individual level. Other research has documented the efficacy of dynamic-math visualization tools for *individual learning*; for instance, a study of geometry students in eleven Florida schools revealed a significant difference in the FCAT mathematics scores of students who were taught geometry using Geometer's Sketchpad compared to those who used the traditional method—regardless of differences based on SES or gender (Myers, 2009). The proposed project has a different focus. The PI and colleagues have developed coding schemes and analysis approaches oriented to the *group unit of analysis* based on conversation analysis of adjacency pairs and longer sequences (Sacks, 1962/1995; Schegloff, 2007; Stahl, 2009b, Chs. 20, 22, 23, 26; 2011b; Stahl et al., 2011). This approach serves both quantitative and qualitative analysis, by simultaneously specifying the structure of meaningful discourse moves and providing countable categories of group interaction units, in order to document changes over time—comparing discourse characteristics in selected time slices within teams or across cohorts.

The project will automatically produce raw data in the form of log files of participant online interactions. The log files are anonymous, but allow tracking of individual users through consistent login handles. The VMT environment is instrumented to capture all user actions in the chat and whiteboard—this will be extended to multi-user GeoGebra. A database of all sessions is automatically maintained and provides spreadsheet logs in handy formats and Replayer files. Software tools will be used for automated and manual log analysis of discourse measures and their evolution during training. While low-level group processes (e.g., number, length and rate of chat postings and drawing actions in different time slices) can be tracked automatically and analyzed statistically, higher-level math-discourse processes have to be interpreted manually. The PI has on-going, NSF-supported collaborations with Carolyn Rosé of Carnegie-Mellon University's intelligent tutoring group, exploring software agents in the VMT environment to provide student guidance and also investigating computer support for coding discourse moves in text chat, to aid and supplement manual analysis. Raw and coded logs will be maintained in a database to facilitate analysis of changes over time for groups across sessions and across successive cohorts of participants.

Quantitative analysis—based largely on the coding of discourse moves in teacher and student VMT logs—will track changes in key measures of significant math discourse. The project hypothesis will be operationalized as predicting an increase in specific measures as a given group works in the VMT environment during time slices across an academic term. Logs of the following groups involved in the project will be evaluated: (a) in-service teachers participating in Math Forum workshops, (b) teachers working together as part of teacher professional development course work, (c) students guided by their teachers, (d) students working with other students as part of school classes and (e) students interacting with others informally at other schools or globally.

Discourse will be coded and measured along the following dimensions: (1) volume of discourse and level of participation, (2) percentage of on-task math discourse, (3) use of representations, (4) integration of chat and drawing, (5) use of accountable talk moves, (6) adoption of socio-mathematical norms and practices, (7) speaking meaningfully with explanation and argumentation, (8) involvement in posing, exploring and solving problems and (9) additional dimensions to be developed based on project experience. The theory of math learning through participation in math discourse (Sfard, 2008) specifies important mathematical discourse moves, such as encapsulation, reification, saming, routines, deeds, explorations and rituals. The theory of accountable talk (Michaels, O'Connor & Resnick, 2008; Resnick, 1988) specifies discourse moves that promote accountability to the group, to standards of math reasoning and to the characteristics of the math objects. Speaking meaningfully in math discourse "implies that responses are conceptually based, conclusions are supported by a mathematical argument and explanations include reference to the quantities in the problem context [as opposed to a focus on merely] describing the procedures and calculations used to determine the answer" (Clark, Moore & Carlson, 2008, p.298). Socio-mathematical norms include what counts as an acceptable, a justifiable, an easy, a clear, a different, an efficient, an elegant and a sophisticated explanation (Yackel, 1995; Yackel & Cobb, 1996). Mathematical practices emerge from interaction, are taken up by participants and are applied repeatedly (Medina, Suthers & Vatrapu, 2009; Stahl, 2011a). These dimensions of significant math discourse are associated with typical sentences and discourse moves that can be identified by coders. A coding scheme will be validated with acceptable inter-rater reliability, as in (Stahl, 2009b, Chs. 22, 23; 2011b).

Detailed interaction analysis of selected cases will show *how* the math discourse actually evolves. Quantitative analysis can establish the statistical significance of changes in learning outcomes, but it generally does not provide much insight into the mechanisms of change; these mechanisms will become visible in detailed case studies in which the specifics of the interactions can be studied. By combining quantitative and qualitative analysis of discourse transformations, the project evaluation will determine how the online interaction involves engagement in significant mathematical discourse. This will help researchers to determine what to try in subsequent cycles of research and will allow evaluators to judge project progress.

Summative evaluation will assess the degree to which the discourse of teams of teachers and of students reveals—through the quantity and quality of their math discourse—increased understanding and improved practice of mathematics. It will make sure that project products (software, mentoring guides, problem sets, masters courses, analysis tools, best practices case library and analyses of case studies from the data corpus) have been produced and made publicly available. It will assess the effectiveness of these products based on the analyses of their use by teachers and students as logged in the data corpus, using quantity and quality of the facilitated math discourse as a measure of success.

In addition to the quantitative and qualitative analysis of changes in significant mathematical discourse by groups of teachers and students involved in the project, there will be ethnographic observations of participants. The observations—including pre/post surveys, open-ended interviews and reflection reports—will be primarily conducted by co-PI Khoo and External Evaluator Blanc, both trained cultural anthropologists. The goal of these observations will be to establish—as much as possible from the user perspective of the project participants—the effectiveness of project interventions (the pedagogical model, the technology, the resources). Interviews with students and teachers will explore their changed attitudes toward mathematics and their insights into the nature of mathematical reasoning. This will be triangulated with the analysis of the math discourse of the same participants in specific time slices. Ethnographic observation of teachers will additionally explore to what extent they have come to feel that teaching math-discourse skills is key to fostering student math learning; to what extent they try to use the project model, technology and resources in their regular teaching; to what extent they intend to stay involved in support networks. The summative evaluation will report on these issues as well as the timely accomplishment of project tasks, training levels, dissemination efforts and project deliverables.

Dissemination

The primary avenues of dissemination will be: (a) through the Math Forum, (b) through Schools of Education, (c) through teacher professional associations, (d) through GeoGebra and dynamic math user communities and (e) through virtual learning communities, including home schooling and online schools.

(a) By the end of the project, the technology and the resources developed through the project will be publicly available as services of the Math Forum. The Math Forum has been the premier online resource for mathematics teaching and learning for over 16 years. It has three million visits to the site each month; its digital library contains over a million web pages, mostly user generated (as a forerunner of the Web 2.0 philosophy). Public services (which typically started from NSF-supported research projects) have been made sustainable through support from Drexel University, fee-for-service programs and teacher training contracts. The Problem-of-the-Week (PoW) is the Math Forum's core service and is subscribed to by many school districts. It is primarily oriented toward problem solving of challenging math problems by *individual* students. The result of the proposed project would be to extend this service with open-ended math problems for *groups* of students to explore collaboratively online. Teachers using the PoW service would be encouraged to involve their students in the new service, initially interacting with classmates, but eventually joining cross-school, national and international virtual math teams. Math Forum services typically support both formal and informal mathematics learning by teachers and students (Renninger & Farra, 2003; Renninger & Shumar, 2002b; 2004; Shumar & Renninger, 2002).

(b) Several of the co-PIs and Advisory Committee members (e.g., Powell, Silverman, Derry, Hmelo-Silver, Hoadley, Koschmann, McClain, Renninger and Sfard) teach at schools of education across the country—and are in contact with math educators at many more. The project accomplishments will influence the teacher professional-development programs in these centers. Teachers who are involved in the teacher professional-development components of this project will also spread project findings as early adopters at their graduate programs and K-12 schools. Ready access to project resources, models and technology at the Math Forum will facilitate general dissemination of innovative math education—including through the popular teacher discussion forums on the Math Forum website—to additional teacher professional development programs.

(c) The PIs and Math Forum are active in NCTM, AERA, PME, and PMENA and will present project findings at the annual conference for teachers of mathematics. Additionally, project researchers are prominent in the learning science communities around the ICLS, CSCL and other academic conferences and publish prolifically in academic and practitioner journals, books and conferences.

(d) Because it provides the first multi-user version of a dynamic-mathematics application, the project will be well known within the worldwide communities of GeoGebra and Geometer's Sketchpad users. The project technology will all be available as open source, so that other researchers and developers can build on it, modify it and install versions on their own servers. (The project technology is built on VMT and GeoGebra, both already available as open source at SourceForge.) Teachers, trainers and researchers who do not have the technical expertise to do this, can simply use the environment that is on the Math Forum servers; they can develop their own curriculum for it and can readily access detailed user logs from it. Features for administration of chat rooms will be built in to support local administration.

(e) For the sake of sustainability beyond the proposed project and to support further scale-up, it is important to establish an on-going network of teachers in the form of self-organizing communities (Renninger & Shumar, 2002a). As discussed above, this will begin with mentoring relationships between cohorts of teachers going through the project professional development. The mentoring relationship will grow into a mutual support network, in which teachers from the programs at both Drexel and Rutgers will share questions, case studies, best practices, curriculum, etc. Later in the project, this growing local network will connect with national and international teacher networks, such as Tapped-In (http://tappedin.org), the Knowledge Building Teacher Network (Chan, van Aalst & Law, 2009) and the Institute for Knowledge

Innovation and Technology (http://ikit.org). These networks will disseminate use of the project services widely. We are aware of the issues in trying to build sustainable virtual learning communities (Barab, Kling & Gray, 2004) and will use an iterative approach. In addition, dissemination efforts will target organizations, consortia and networks of home schooling and of online schools.

Expertise

The proposed project brings together an interdisciplinary team of researchers, led by the PIs:

PI, Gerry Stahl: PI on the VMT Project. Author of *Group cognition: Computer support for building collaborative knowledge* and *Studying virtual math teams*. Founding editor of *International Journal of Computer-Supported Collaborative Learning*. He will have overall responsibility for the project.

PI, Arthur Powell: Chair of the Department of Urban Education at Rutgers-Newark and Associate Director of the Robert B. Davis Institute for Learning at Rutgers-New Brunswick. Specializes in problem solving, deductive reasoning and heuristics in math education. Expertise in analysis of learning in digital video. Primary responsibility for teacher professional development at Rutgers.

Co-PI, Jason Silverman: Faculty member at the School of Education, Drexel University. Developed and teaches the online masters degree program in Mathematics Learning and Teaching at Drexel. Primary responsibility for teacher professional development at Drexel.

Co-PI, Stephen Weimar: Director of the Math Forum since 1994. Established track record as PI on multiple successful NSF grants. Responsible for integration with Math Forum services.

Co-PI, Sean Goggins: Brings a decade of collaborative and social software design and development team leadership. He will be primarily responsible for automated and statistical data analysis.

Co-PI, Michael Khoo: Trained in anthropology, he evaluated components of NSF NSDL digital libraries. He will coordinate the internal formative evaluation component of this project.

Annie Fetter: Co-founder of the Math Forum. Directs the Problem-of-the-Week. Has done professional development and written curriculum for the Geometer's Sketchpad software since it was created. She will be involved in training and mentoring the teachers and coordinating the classroom usage.

Sukey Blanc: Trained in urban anthropology, she studies mathematics and science education, educational equity and school reform. She is Senior Research Associate with Research in Action, a Philadelphia-based non-profit organization engaged in education research and evaluation, which since 1992 has worked with public school districts, educational institutions and community organizations to improve educational opportunities for those traditionally disadvantaged. She will work with the Advisory Committee and will be responsible for external formative and summative evaluation.

The Math Forum. This well established math education site, MathForum.org, has its office at Drexel University with program and technical staff to run services and to maintain the Internet technology. The staff has extensive experience in mentoring math teachers, training new mentors, designing math resources and supporting a huge user community. Most of the program staff are experienced classroom math teachers. The technical staff will be responsible for software development during the project and then for maintaining the project software during and beyond the lifetime of the project.

The Advisory Committee. The AC brings expertise in math education; educational psychology; quantitative analysis of learning outcomes, motivation and attitudes; problem-based learning theory and analysis; CSCL; and online communities of learners. (See attached letters.)

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ONR: Theories and Models of Group Cognition

Statement of Work

This project brings a broad range of theoretical approaches, mixed-method analyses and computational models to bear on a rich data set of team interaction. The data provides a complete record of eight hours of intense synchronous problem solving by two virtual math teams. The data was collected in 2006 under IRB-approved protocols; the data is completely anonymous online chat data.

Within the project, the data will be analyzed in three primary ways: (i) through manual qualitative conversation analysis, (ii) through leading-edge techniques of natural language automated processing and (iii) through mixed methods of qualitative and quantitative analysis, data mining, cluster analysis, statistical analysis and network analysis.

The findings from the original analyses described above will be compared with a range of relevant previous literature. This includes the following sources: (i) previous work of the PIs themselves, (ii) related work by other researchers in the ONR CKI program, (iii) coding schemes developed in the field of computer-supported collaborative learning (CSCL), and (iv) seminal works on distributed cognition, situated cognition, activity theory, mediated cognition, situated learning, knowledge building, ethnomethodology, actor network theory, dialogics, small-group theory and social theory.

In addition to publishing project findings in white papers, conference papers and journal articles, the PIs will organize workshops to: (i) compare different coding schemes and analysis methods and to discuss potentials for synthesis and mixed methods combinations, (ii) analyze the data set for this project from different methodological perspectives from other CKI and CSCL projects, and (iii) consider different theories and models of macrocognition as applied to the data set for this project.

The goals of the project will be: (i) to identify the nature of group cognition processes (macrocognition) in ad hoc problem-solving teams, (ii) to clarify terminology, (iii) to distinguish related theories, (iv) to validate or expand theory, and (v) to contribute to computational models and other tools, coding schemes and metrics for analyzing macrocognition.

Introduction

This project brings a broad range of theoretical approaches, mixed-method analyses and computational models to bear on a rich data set of team interaction. The data provides a complete record of eight hours of intense synchronous problem solving by two virtual math teams. The data will be made available in a number of formats convenient for analysis. Within the project, the data will be analyzed in three primary ways:

- Using an adaptation of conversation analysis applied to text chat, the interactions will be analyzed to identify methods of group cognition or macrocognition, whereby the group constructs new knowledge that emerges through the group interaction and that none of the participants previously possessed.
- Using techniques of natural language processing, the interactions will be automatically coded using coding schemes that identify key moves and utterances that are associated with collaborative knowledge building or macrocognition.
- Using mixed methods of qualitative and quantitative analysis, data mining, cluster analysis, statistical analysis and network analysis, the two approaches above will be bridged, identifying measures that connect the qualitative manual conversation analysis results and the quantitative automated coding analysis results.

The findings from the original analyses described above will be compared with a range of relevant previous literature. This includes the following sources:

- The previous work of the PIs themselves, including the analyses in Stahl's *Group Cognition* and *Studying Virtual Math Teams*, and the past work by Rosé on language analysis and coding of knowledge building.
- Related work in the CKI program, including publications from projects funded by CKI, such as Cooke's and Warner's analyses of interaction data.
- Other coding schemes for collaborative knowledge building developed in the field of computer-supported collaborative learning (CSCL).
- Seminal works on distributed cognition, situated cognition, activity theory, mediated cognition, situated learning, knowledge building, ethnomethodology, actor network theory, dialogics, small-group theory and social theory.

The project leads (Stahl and Rosé) are both leaders in the international CSCL research community. The project will leverage their connections in the CSCL and

CKI communities to involve other researchers in collaboratively pursuing the project investigations and in disseminating the emerging results. In addition to publishing project findings in white papers, conference papers and journal articles, the PIs will organize the following kinds of events:

- A workshop at which researchers with different methodological perspectives from other CKI and CSCL projects gather to compare different coding schemes and analysis methods and to discuss potentials for synthesis and mixed methods combinations.
- A workshop at which researchers with different methodological perspectives from other CKI and CSCL projects gather to analyze the data set for this project.
- A workshop at which researchers representing different theoretical perspectives gather to consider different theories and models of macrocognition as applied to the data set for this project.

The goal of the project will be to identify the nature of group cognition processes in ad hoc problem-solving teams, to clarify terminology, to distinguish related theories, to validate or expand theory and to contribute to computational models and other tools, coding schemes and metrics for analyzing macrocognition.

Impact of Proposed Work

The proposed project will result in the design, development and testing of analysis methods, automated tools, dynamic models and empirically grounded theory for the understanding of group processes of macrocognition (aka group cognition) in ad hoc teams confronted by non-standard problems.

Future Naval Relevance

The proposed project is directly responsive to the ONR CKI Program focus on analyzing group processes involved in team decision making in tactical teams. The project develops tools for analyzing, theorizing and modeling group processes involved in team decision making in small ad hoc groups collaborating on complex problem exploration, analysis and solving.

Management Approach

Gerry Stahl will coordinate work at Drexel and Carolyn Rosé will coordinate work at CMU. They will stay in weekly contact to coordinate the overall project. Drexel will act as lead on the grant and 50% of the grant is subcontracted by Drexel to CMU.

All human data to be used is strictly anonymous online chat data recovered from Math Forum server logs. The data was created in Spring 2006 under protocol approved by the Drexel IRB, which is certified under Human Subject Assurance Number FWA0001852. CMU's IRB is also certified.

Technical Approach

Outline of Proposed Work

In each of the project's three years, there will be six types of tasks, including (1) corpus definition, (2) manual analysis, (3) coding scheme design, (4) automated coding, (5) data analysis and (6) theory building:

1. *Corpus Definition*: In each year of the proposed work, we will work with a different existing corpus of interaction data so that by the end of the project, we will be able to engage in theory building that generalizes across multiple tasks under multiple configurations. By the end of the project, we will be in a good position to derive generalizations that have substance and generalizability. We will apply both the transactivity-based coding scheme and coding schemes from the CKI and CSCL communities to the same data.
2. *Hand Analysis*: For each of our corpora we will analyze up to half of the data by hand and then use automatic coding technology to code the rest. This hand analysis will be based upon interaction analysis of the corpus. Although the hand analysis will attempt to uncover structures to guide the design of the coding scheme, it will more generally seek to discover the full range of macrocognitive processes that take place in the data at the group unit of analysis.
3. *Coding Scheme Design*: Our work will be focused on a transactivity-style analysis, however we expect to have to make adjustments to the category definitions for each corpus we work with in order to be true to the nuances of the discussions going on there while maintaining high reliability and without changing the spirit of the codes. Additionally, we will be working with coding

schemes from the CSCL and CKI communities, beginning with Cooke and Gorman's (2009) work on interaction-based measures of cognitive systems, especially measures of communication flow, which allow for analyses of influence and stability within group discussions.

4. *Automated Coding*: As in our prior work, we will make heavy use of automated coding technology in this proposed work. In our experience, the technology is still new enough that each corpus we work with raises new challenges for this technology. However, as we address those challenges, we produce new knowledge in the area of text mining and text classification, which generates additional insights and publications.
5. *Data Analysis*: One major goal of our data analysis across all three corpora is to validate the transactivity framework by correlating occurrences of subsets of codes with important outcome measures. But we'll also be exploring correlations between occurrences of transactivity-related events with those of the types of analysis schemes explored previously in the CKI and CSCL communities. In general, the data analysis will explore diverse methods and mixed-method combinations to specify data points and group interaction methods (macrocognitive processes) as discovered in the data by both hand analysis and automated coding, in order to test and refine theories and models of team decision making in ad hoc groups.
6. *Theory Building*: The ultimate goal of our theory building will be to stimulate exchange of ideas and findings between the CKI community and the CSCL community through workshops, symposia and publications at the International Conference of the Learning Sciences, the Computer-Supported Collaborative Learning conference and the *International Journal of Computer-Supported Collaborative Learning*.

Detailed Description of Project

1. Corpus Definition

Data that captures interesting examples of collaborative knowledge building is hard to find. The Group Cognition Lab worked for six years to generate good data for analysis (Stahl, 2006). It defined an online environment in which groups can meet and everything that group participants share interactionally is captured by the computer logs. We defined tasks and facilitated sessions to realize ad hoc, complex, one-of-a-kind team problem-solving scenarios. We led the groups to focus on building and processing new knowledge for their problem solving.

Moreover, we recruited students at a stage where they were just learning the fundamentals of abstract thinking, so that we could observe the emergence of new individual and group skills in concert with each other. The lab developed technologies for instrumenting the online environment and for replaying the interactions in ways that support detailed analysis by researchers. In addition, we explored alternative analysis methods and developed our own approach to interaction analysis.

The core data set selected for this project was generated as part of the Math Forum's VMT Spring Fest 2006 in May of 2006. The student participants were normal users of the Math Forum online services; their identities were completely anonymous, signified only by a self-selected login chat handle. The best examples of group cognition can be found in the logs of Team B and Team C. These logs reveal rich examples of cognitive processes accomplished interactively by the groups. Each Team engaged in four hour-long sessions during a two-week period. There are dramatic signs of longitudinal development at both the individual and group level as they learned new communication and problem-solving skills and methods appropriate to their socio-technical and goal-oriented situation.

The log for the two teams together consists of about 3,000 chat postings and 3,000 other actions. This is a sizable corpus for manual and automated analysis. We already have considerable experience analyzing brief excerpts from this corpus. These excerpts form the core of two exceptional PhD dissertations that have already been completed (Çakir, 2009a; Sarmiento-Klapper, 2009a). Other excerpts have been analyzed by colleagues from other labs internationally, as reflected in chapters of *Studying Virtual Math Teams* (Stahl, 2009b) and in symposia on VMT data at the CSCL 2007 and 2009 conferences (Koschmann & Stahl, 2009; Stahl, 2007).

The core data set is being made available as open source through an international CSCL data archive. This will not only make it globally available to researchers for making comparisons, but it will format it in a common XML-based scheme, making it susceptible to being displayed in various templates. This is part of an on-going effort within the CSCL community to enhance comparability of different methodological approaches. The proposed project will be part of this international effort in a number of ways.

The selected data corpus will be analyzed in detail within the proposed project through three phases:

- Year I: Session 4 of Team B. This is probably the session with the most examples of collaborative knowledge building. Therefore it will provide a rich source for initial development of a coding scheme that identifies and classifies instances of effective macrocognition.

- Year II: Team C Sessions 1 and 4. This is data involving the same web-based technology and the same problem-solving task as in Year I, but conducted by a different group of participants. The inclusion of the team's first and last session offers data with a longitudinal contrast, as well as some comparison with the year I data. It therefore provides a solid basis for testing and generalizing the year I coding.
- Year III: The complete combined corpus of Team B and C data (all sessions). This provides an extensive data corpus of over 6,000 events. It includes many group interactions. It provides a rich source for statistical comparisons among interactions.

2, Hand Analysis

The VMT Project at the Group Cognition Lab at Drexel University has developed an ethnomethodologically-informed approach to interaction analysis of synchronous online interaction data (Zemel, Xhafa & Çakir, 2009). This approach is defined and described in Chapter 28 of *Studying Virtual Math Teams* (Stahl, 2009c). It is illustrated especially in Chapters 6, 7, 8 and 9 of that volume (Çakir, 2009b; Sarmiento-Klapper, 2009b; Toledo, 2009; Zhou, 2009). The method involves data sessions using the VMT Replayer to engage a group of experienced researchers in the conversation analysis of an excerpt from an online session to define the linguistic, visual and indexical work being carried out by the group and the group cognition thereby accomplished. The method is rigorous, generalizable and reliable, as discussed in Chapter 28.

As described in Chapter 28 on "*Toward a Science of Group Cognition*" (Stahl, 2009c), the analysis of group cognition explores how small groups engage as a group (i.e., at the group unit of analysis) in the accomplishment of cognitive tasks. These include such tasks as: intersubjective meaning making, interpersonal trains of thought, shared understandings of diagrams, joint problem conceptualizations, common references, coordination of problem-solving efforts, planning, deducing, designing, describing, problem solving, explaining, defining, generalizing, representing, remembering and reflecting. Groups develop general methods of doing these things, always adapted to the situations in which they are engaged and the media and other resources that are at their disposal (Stahl, 2009a).

3. Coding Scheme Design

Machine-learning algorithms can learn mappings between a set of input features and a set of output categories. They do this by using statistical techniques to find characteristics of hand-coded "training examples" that exemplify each of the output categories. The goal of the algorithm is to learn rules by generalizing from these examples in such a way that the rules can be applied effectively to new examples. In order for this to work well, the set of input features provided must be sufficiently expressive, and the training examples must be representative. Typically, machine-learning researchers design a set of input features that they suspect will be expressive enough (Strijbos, 2009). At the most superficial level, these input features are simply the words in a document. But many other features are routinely used in a wide range of text-processing applications, such as word collocations and simple patterns involving part of speech tags and low-level lexical features; we will draw from this prior work.

Once candidate input features have been identified, analysts typically hand code a large number of training examples. The previously developed TagHelper tool set (Rosé et al., 2008) has the capability of allowing users to define how texts will be represented and processed by making selections on the GUI interface. In addition to basic text-processing tools such as part-of-speech taggers and stemmers that are used to construct a representation of the text that machine-learning algorithms can work with, a variety of algorithms from toolkits such as Weka (Witten & Frank, 2005) are included in order to provide many alternative machine-learning algorithms to map between the input features and the output categories. Based on their understanding of the classification problem, machine-learning practitioners typically pick an algorithm that they expect to perform well. Often this is an iterative process of applying an algorithm, seeing where the trained classifier makes mistakes, and then adding additional input features, removing extraneous input features, or experimenting with algorithms.

Applying this iterative process requires insight and skill in the areas of linguistics and machine learning that the social scientists conducting corpus analysis are unlikely to possess. TagHelper tools support this interactive processes by making it easy to define different processing configurations through the GUI and then providing reports about how the configuration worked and where the process may have broken down. The goal of our tool development is to make this process easier for social scientists. In particular, the process of identifying where the process has broken down and how the configuration can be tuned in order to improve the performance requires more expertise than typical social scientists would possess. Thus, the bulk of our development work will be in developing the machinery to bridge the gap between the natural structure of the input texts and the behaviors that social scientists are interested in cataloguing and coding, using bootstrapping approaches.

In our recent corpus-based experiments (Josh & Rosé, 2009; Arora, Joshi, & Rosé, 2009) we have explored the usage of alternative types of syntactically motivated features on text classification performance. Our methodology is extensively discussed in our recent journal article in the *International Journal of Computer-Supported Collaborative Learning*, investigating the use of text classification technology for automatic collaborative learning process analysis (Rosé et al., 2008).

Advancing Beyond the Capabilities of Keyword-Based Approaches. Linguistic Inquiry and Word Count (Pennebaker, 2003) is a paradigm case of keyword-based approaches to analysis of verbal data, that is very commonly used in social psychology, especially but not solely in work related to health communication. LIWC indicators that are designed to measure latent characteristics of authors such as emotional or psychological state based on vocabulary usage have been successfully calibrated with a wide range of behaviors over multiple types of studies. Nevertheless, they have limitations that must be taken into account methodologically. LIWC indicators have typically been used in studies where the external variables of interest are health outcomes or health related behavior. In studies where consistent stories based on calibrations of LIWC indicators with external variables are reported, the corpora used were created under very controlled circumstances, always only within the experimental condition of a study in which the genre and topic of the writing were determined by the experimental manipulation. When these tight constraints are removed, the story becomes much less clear. For example, Pennebaker and Francis (1996) present results from a study with two different conditions. The experimental variation lay in the change of the topic participants wrote about. In this study, the LIWC indicators made opposite predictions about behavioral outcomes and emotional states in the experimental condition in comparison to the control condition. Discrepancies like this occur because there are many linguistic factors besides the emotional state of the author or speaker that affect the frequencies of word usage. For example, many words have multiple meanings and only convey negative emotion in some contexts and not in others. For example, the words “bake” and “roast” used while talking about the weather convey a feeling of discomfort, whereas in the context of a discussion about cooking, they do not. Base frequencies of terms also vary between topics. Thus, a difference in frequency of a term may either indicate a difference in the emotional state of the author or simply a difference in topic. If LIWC predictors were truly indicative of emotional state independent of topic, and fluctuations in emotional state predict corresponding fluctuations in health and behavior outcomes, it is difficult to reconcile the difference in the direction of predictions between conditions reported in that paper. Nevertheless, if one accepts that LIWC indicators are merely proxies that can be used for estimating measurement of psychological state within very narrowly constrained contexts, then the pattern makes sense. However, this limitation has strong negative implications for the applicability of LIWC indicators within naturalistic communication settings in which there is a wide variation in the communicative goals motivating individual contributions, such as in naturalistic on-line learning environments where students may interact about a wide range of topics in connection with a variety of activities over time.

Analysis of collaborative learning interactions have demonstrated that what happens on the process level is important for predicting what cognitive benefits participants in a conversation take away from it (e.g., King 2007). More complex learning is supposed to occur in "spirals of reciprocity," where learners are intensely engaged with one another (Salomon and Perkins 1998). In particular, learners can attain new levels of understanding during interactions where more complex cognitive activities occur, such as analytical thinking, integration of ideas and reasoning. These include activities such as elaborating on content (e.g., Webb 1989), explaining ideas and concepts (e.g., Chi et al. 1994), asking thought-provoking questions (e.g., King 1998, 1999), argumentation (e.g., Kuhn 1991), resolving conceptual discrepancies (e.g., Piaget 1985) and modeling one another's cognitive states. These activities may not be adequately represented by patterns of individual turns taken out of context. Modeling these processes instead requires categorical coding schemes building on precise definitions of categories (see Chi et al. 1994). Trained human coders are able to consistently apply well-defined coding schemes across multiple contexts. However, we acknowledge that applying coding schemes like this by hand is extremely tedious. And effectively writing rules by hand to reliably match against complex patterns, which is an option provided by some corpus analysis environments, is difficult as well.

When human coders apply categorical coding schemes, they bring insights with them from their human intellect. Human language is highly complex, encoding meaning on multiple levels, and carrying very subtle nuances that are difficult to formally capture with a rule based model. Interpretation of language involves using cultural sensitivity to style and lexical choice, applying world knowledge, integrating meaning across spans of text, and often making inferences about what is implied in addition to what is literally stated. In contrast, regardless of approach, machine coding will always be based on rigid rules that are necessarily an over-simplification of the reasoning processes that humans rely on for their interpretation. Note that word counting approaches such as LIWC, which were discussed earlier, are an extreme case of this over-simplification. This simplification threatens the face validity of the coding that can be accomplished automatically because this word based approach may not be measuring what it is purported to be measuring. Using an example from our own work, we have used

LIWC to examine the language behavior of five different tutors who participated in a series of calculus problem solving studies (Gweon et al. 2006). We evaluated tutor effectiveness by comparing them with respect to the average learning gains of the students they tutored. Based on this analysis, we determined that the more effective tutors scored higher on LIWC's confidence scale. When we examined which words from the tutors' contributions the associated LIWC word list was matching against, the most frequent word was "factor", which came up inside discussions about algebra. Thus, the LIWC confidence scale was not ranking tutors based on their confidence at all, but rather their tendency to supplement their calculus tutoring with basic algebra concepts such as factoring. Thus, word-counting approaches like LIWC that make their assessment based on individual words taken out of context should be used with caution. We see from our calculus example that they are not guaranteed to reflect accurately the mental states they were designed to assess.

Machine learning based approaches can transcend the limitations of keyword-based approaches because they allow for more complex representations of text beyond simply keywords. In our recent work, for example, using more complex grammar and context oriented features in addition to word level features, we have demonstrated significant improvements in analysis accuracy over simple word based representations of text for tasks such as collaborative learning process analysis (Rosé et al., 2008), sentiment analysis (Joshi & Rosé, 2009; Arora, Joshi, & Rosé, 2009), and text compression (Chaudhuri, Gupta, Smith, & Rosé, 2009; Gupta, Chaudhuri, & Rosé, 2009).

Advancing Beyond the Capabilities of LSA. Latent semantic analysis (LSA) is well known as a practical method for representing words in terms of classes of words that share a similar distribution in terms of the "neighborhoods" or words they occur with. One can think of it as a way of identifying groups of semantically related words (Landauer et al., 1998). We would expect that methods that offer a way of generalizing over alternative phrasings of the same or similar ideas would be useful in tracking initiation-reply links that form the elementary units of knowledge building processes in conversation.

In the typical method for applying LSA, we first construct a term-by-document matrix. Next, LSA applies singular value decomposition to the matrix, and reduces the dimension of the feature space of terms to a 300-dimensional concept space. We can then represent a term vector, whether it is a simple term vector or an expanded term vector, in terms of this LSA space by averaging across the LSA representation for each word in the text within that 300 dimensional space. Text vectors that have been transformed in this way can then be compared using cosine similarity.

However, for the purpose of tracing the knowledge-building process of students, there is a major limitation of LSA as it is typically applied that must be taken into account. Note that not all words carry equal weight within the vector that results from the averaging process in constructing an LSA vector for a text. Words that are closer to the "semantic prototypes" represented by each of the 300 dimensions of the reduced vector space will have vectors with longer lengths than words that are less close to any single one of those prototypes within that space. Thus, those words that are closer to those prototypes will have more of an effect on the direction that the resulting vector will have within the space. Thus, they will have more of an effect on the comparison with other texts. However, one should note that in a running discussion, it is the unusual content, the noteworthy ideas, that often form the links between initiation and responses, rather than the common concepts that form the background for the ongoing discussion. And thus, one major limitation of LSA as it is typically applied is that it de-emphasizes the contribution of precisely those words that are most important for making the textual links in the discussions that we would like to identify.

Recently we have developed a new approach to applying LSA that overcomes this limitation. For the task of identifying initiation-reply links in a conversational thread recovery task, it significantly outperformed the typical method for applying LSA as well as other baseline approaches making use of lexical resources such as Wordnet. Further work along these lines will be a major focus of the technical component of this proposed research.

4. Automated Coding

Many of the fundamental activities in on-line organizations, such as brainstorming, decision-making and training, require communication. This underlying conversation both furthers the goals of a team and reflects the underlying structure of interactions and relationships within social institutions (Zimmerman & Boden, 1991). Several decades of research in Computer Mediated Communication (CMC) have examined how the use of media affect team communication processes (e.g., Hall, 1976; Li, 1999; Setlock & Fussell, 2007). However, progress in this research community is hampered by how time consuming it is to do this analysis by hand. For example, one recently published study of the effects of culture on negotiation processes required over a year to collect the data, refine the coding scheme, and code and analyze the data. The outcome of this work is a better understanding of one of many communication processes in virtual teams performing one of many different tasks. To extend such work to the full domain of teams, tasks and communicative activities would take decades. As a basic part of our approach, we propose to use a traditional approach to using analysis of corpora by hand in order to increase understanding of virtual teams on a small to medium scale and then use the automatic analysis to expand to a dramatically larger scale.

In our prior work, we have made substantial progress towards detecting properties of conversation that are specifically associated with quality of collaboration. We have focused on a property known as *transactivity* (Rosé et al., 2008; Wang, Rosé, & Joshi, 2007; Joshi & Rosé, 2007), an important property of collaborative discourse. Participants in a collaborative setting are said to have transactive discussions when they elaborate, build upon, question or argue against the ideas presented by their partners in the process of working towards a common understanding of the task and reaching a shared solution. This process of understanding the partners' ideas, comparing them to one's own understanding, arguing and forming a common ground upon which a solution can be built collaboratively has been shown as important for learning (Teasley, 1997; Azmitia & Montgomery, 1993).

The idea of transactivity has its roots in educational psychology with Piaget's model of assimilation/accommodation and Vygotsky's socio-cultural theory of learning. Piaget's model is a particularly key component of the theoretical underpinnings of our proposed work since it provides a framework for characterizing the difference between simply managing existing pieces of knowledge, as one might characterize work so far on macrocognition in the CKI community, and more major cognitive restructuring that can occur at certain points within an assimilation/accommodation cycle.

Digging into the details a little more deeply, at the heart of Piaget's theory of learning is the assimilation-accommodation cycle in which students encounter stimuli in the world that provide data either in support of or in conflict with their own internal model of the world. During assimilation, a student imposes his own model on the stimuli he sees, interpreting everything in that light, and rejecting what does not fit. During accommodation, a student is open to considering a model of the world that may be imposed from the outside. When these processes are in balance, the conditions are most favorable for a student to notice a gap or deeper flaw in his own mental model. When a student becomes aware that stimuli from the world reveal a gap, that student may then choose to search for a revised model of the world that accounts for the new data, which may even require a dramatic paradigm shift or major reorganization of knowledge.

It is important to note that an important ingredient in Piaget's theory is the equality of power or partnership between students working together that is important for creating an environment in which assimilation and accommodation are in balance. Note that equal power does not imply equality in knowledge. Based on Piaget's foundational work (Piaget 1985), one can argue that a major cognitive benefit of collaborative learning is that when students bring differing perspectives to a problem-solving situation, the interaction causes the participants to consider questions that might not have occurred to them otherwise. This stimulus could cause them to identify gaps in their understanding, which they would then be in a position to address. This type of cognitive conflict has the potential to lead to productive shifts in student understanding. Examining the discourse between students in a collaborative-learning setting can reveal evidence of the power relationship between students, the exchange of views and evidence of the opportunity for cognitive conflict in the socio-cognitive conflict that is manifested in the argumentation that occurs between students. The impact of socio-cognitive conflict on learning has been noted especially in connection with difficult-to-learn content (Azimitia & Montgomery, 2005; Russell, 2005). And the important connection between relationship development and socio-cognitive conflict has also been documented (Azimitia & Montgomery, 1993). Examining the discourse between students can also reveal where an imbalance in a power relationship can hinder participation and learning. For example, Elbers & de Hann (2004) provide a qualitative analysis from a socio-cultural perspective on how racial stereotypes affect the power/authoring relationship between students, which may hinder collaborative discussion.

Vygotsky's theory argues for similar patterns of discussion from another angle. While Piaget's theory focuses on equal power but difference in knowledge, Vygotsky focuses more directly on differences in knowledge, but also argues in favor of relationship development and the social nature of knowledge construction. Based on Vygotsky's seminal work (Vygotsky 1978), we know that when students who have different strengths and weaknesses work together, they can provide support for each other that allows them to solve problems that would be just beyond their reach if they were working alone. This makes it possible for them to participate in a wider range of hands-on learning experiences. In our own work, we have observed evidence of helping behavior as a socio-cognitive variable that mediates learning (Gweon et al., 2006; Gweon et al., 2007). Social aspects of group functioning as they relate to and result from patterns of interaction are unquestionably key consideration for groups that will interact with one another over a long period of time. However, one could argue that they are even more essential in ad hoc teams with a critical purpose since any subtle incident that might harm trust or hinder the flow of information might interfere with the success of the encounter.

Surveying the field of computer-supported collaborative learning for frameworks for analyzing group conversations, one might conclude that there are a plethora of different approaches. Nevertheless, one might also consider it not a giant leap to consider that the topic of what makes group discussions productive for learning and community building has been explored with very similar findings, perhaps with subtle distinctions, and under different names such as *transactivity*

(Berkowitz & Gibbs, 1983; Teasley, 1997; Weinberger & Fischer, 2006) in the cognitive learning community and *uptake* (Suthers, 2006), *group cognition* (Stahl, 2006) or *productive agency* (Schwartz, 1998) in the socio-cultural learning community. Despite differences in orientation between the cognitive and socio-cultural learning communities, the conversational behaviors that have been identified as valuable are very similar. Building on these common findings, the field of Computer-Supported Collaborative Learning has emerged where support for collaborative learning has been developed that addresses observed weaknesses in conversational behavior related to this phenomenon.

5. Data Analysis

To complement the ethnomethodologically informed interaction analysis and the machine-learning algorithms for automated coding (Strijbos, 2009), we will also analyze the three corpora using content analysis (Krippendorf, 2004) and network analysis (Wasserman and Faust, 1994). The content analysis will be performed on the 3,000 chat postings and the network analysis will be performed on the 6,000 chat and drawing actions.

The content analysis will be executed using two rubrics (Goggins & Laffey, forthcoming). The unit of analysis for this work will be a complete unit of conversation (Krippendorf, 2004). The first rubric will evaluate the development of group identity within the small groups, using Tajfel's (1978, 1979, 1982) description of group communication as inter-group, inter-personal, intra-group and inter-individual. Inter-group communication is communication across groups, and only rarely occurs in this data set. Inter-personal communication takes place between two individuals. Intra-group communication is within the group, where all members participate in the dialogue. An utterance addressing individual members in the presence of the whole group as an aside is coded as inter-individual communication.

The second rubric will evaluate the corpus of data for knowledge co-construction using a rubric developed by Gunawardena et al (1997). Two raters will score the conversations on these rubrics and measure inter-rater reliability using Krippendorf's alpha (2004). This type of analysis is performed by Goggins, Laffey & Gaylen (forthcoming) on asynchronous communication records, and the contrast with the results from synchronous chat data will provide a helpful contrast of synchronous and asynchronous knowledge co-construction in small groups.

Social network analysis will be performed on the 3,000 chat postings and 3,000 other actions in order to determine if there are patterns of networked interaction that correspond with the development of group identity or the co-construction of knowledge. The resulting networks will be bi-partite (users and objects) and regular. Since the networks in our corpora are closed and small, we will focus our analysis on small network evolution and elaborating semantically meaningful measures of tie strength.

Tracking longitudinal evolution will involve developing a time-series set of network views, possibly addressing the state of the network as a feature that contributes to other forms of analysis. We will also explore the advantages of deriving measures of tie strength from the results of machine-learning algorithms, response-time lag and length of sustained interaction between pairs of group members.

These quantitative analyses will not be performed in isolation from the interaction analysis or the automated coding. Decisions about the granularity in both network analysis and content analysis will take the findings and approaches from these other two methods into consideration. The findings of all these mixed-method analyses will inform the design of computational models (Wee & Looi, 2009) and supply a basis for calibrating the models of macrocognition.

6. Theory Building

The findings of the analyses described above will be synthesized into a theoretical framework of group cognition / macrocognition. This theory will be compared to competing theories in current research literature, such as: distributed cognition (Hutchins), situated cognition (Suchman), activity theory (Engeström), mediated cognition (Vygotsky), situated learning (Lave), knowledge building (Scardamalia & Bereiter), ethnomethodology (Garfinkel), actor network theory (Latour), dialogics (Wegerif), small-group theory (Weick, 2005) and social theory (Giddens, 1984). The comparison will aim to determine areas of overlap, respective limitations, potential conflicts and possibilities for synthesis.

Project Schedule, Milestones and Reports

As detailed above, in each of the three years, there will be six types of tasks, including (1) corpus definition, (2) coding scheme design, (3) hand analysis, (4) automated coding, (5) data analysis, and (6) theory building. These six types of activities are broken down into tasks associated with target dates within the three years of the proposed work in the table below.

Deliverables for this project include 5 coding manuals, 3 coded corpora (all of which are coded with two different frameworks, one transactivity based and one based on Nancy Cooke's work), and publications (at least 2 submissions per year, which include both conference papers and a journal article and include technological innovation as well as theory building). Extensions to automatic coding technology will be integrated with the already publically available text mining toolkits, TagHelper tools and SIDE, which have been developed in PI Rosé's prior work and are already in broad distributions (for example, TagHelper has over 1000 users in 57 countries).

FY2010

- Chapter on linguistic analysis of collaboration for the *International Handbook of Collaborative Learning* (already in progress)
- Workshop at Alpine Rendezvous on coding schemes for collaborative knowledge building
- Workshop at International Conference on the Learning Sciences on coding schemes for collaborative knowledge building
- Coding manual for Corpus 1
- Coded corpus 1
- Conference paper with automatic analysis results on coded corpus 1
- Quarterly Technical and Financial Progress Reports

FY2011

- Coding manuals for corpus 2
- Coded Corpus 2
- Workshop at GROUP on mixed methods for analyzing collaborative knowledge building
- Workshop at CSCL on theories related to macrocognition
- White paper on theories related to macrocognition
- Possible conference paper (ACL or AIED) related to automatic analysis
- CSCL 2011 paper introducing the CKI framework to the CSCL community, with theory building analysis from year 1 on corpus 1
- Quarterly and Annual Technical and Financial Progress Reports

FY2012

- Coding manuals for corpus 3
- Coded Corpus 3
- Publication of book on interaction analysis of Corpus 3 by MIT Press
- ICLS paper submission on results from study 1/Corpus 2
- CHI paper submission for study 2/Corpus 3
- Journal article submission synthesizing findings across all corpus analysis projects for this grant
- Quarterly Technical and Financial Progress Reports
- Final Report

Qualifications of the Principal Investigators

The Group Cognition Lab at Drexel

The Group Cognition Lab conducts basic research on phenomena of distributed cognition that take place distinctively at the small-group level of description, such as collaborative knowledge building, joint decision making, group problem solving, shared meaning making, co-construction of knowledge representations. It is located at Drexel University in Philadelphia and is a joint project of the iSchool (College of Information Science and Technology) and the Math Forum. It is directed by Gerry Stahl, Sean Goggins and Stephen Weimar.

The Lab specializes in studies that make visible the development of group cognitive processes by generating, capturing and analyzing naturalistic episodes of computer-mediated interaction by novices, such as teams of students just learning to problem solve together online. The microanalysis of these episodes reveals characteristics of group process that contribute to an empirically grounded theory of group cognition, which is emerging from the lab.

The Lab is a flexible collaboration of researchers who bring complementary skills and interests to the multidisciplinary mission of the Lab. This includes information scientists interested in small-group cognitive processes, educators interested in how to promote learning of group-cognitive skills, qualitative and quantitative analysts interested in adapting social science research tools to the analysis of group cognition, software designers interested in developing online environments to support effective collaboration, and theorists interested in elaborating the theory of group cognition.

The following major activities are integrated within the Lab:

- Developing the Virtual Math Teams (VMT) service at the Math Forum for generating real-world data on small groups of students learning to engage in online problem solving of open-ended ill-structured and wicked math problems.
- Working with schools of education and math-teacher-training programs to involve teachers and students in exploring the potentials of the VMT service.
- Conducting collaborative data sessions of researchers to analyze the group interactions taking place in logs of online group work.
- Developing case studies and quantitative analyses of the data from logs of online group work to describe characteristics of group cognition.
- Designing new features for the VMT environment to support group-cognitive accomplishments, based on the microanalysis of interesting cases of usage.
- Extending the theory of group cognition, including building graphical and computational models, clarifying terminology, defining specific concepts, and relating to cognate theories.

The Lab has been recognized as a leading center for research on group cognition based on its work from September 2003 to August 2009. It has gone through many cycles of design-based research using a prototype VMT environment at the Math Forum, including Spring Fests in 2005, 2006 and 2007, in which student groups from around the world met for sequences of four hour-long sessions. This produced 2,000 student-hours of data, which was reported in about 200 academic publications. In addition, two major books were published: *Group Cognition* (Stahl, 2006, MIT Press) assembled studies of online collaboration that motivated the work of the Lab and the VMT service; *Studying Virtual Math Teams* (Stahl, 2009, Springer Press) includes the most important reports from the Lab and from collaborating researchers.

Potential directions for the coming years include the following:

- Design and implement additional functionality for the VMT collaboration environment, including dynamic geometric representations and intelligent tutoring support. (Research question: How do visual representations and automated guidance contribute to establishing common ground and scaffolding problem solving?)

- Explore web interfaces to support the spontaneous formation of ad hoc virtual teams within a large distributed community, including participants from different cultures and different time zones. (Research question: How to stimulate and support ad hoc teams and how to overcome geographic or cultural differences?)
- Further integrate synchronous and asynchronous media to coordinate group accomplishments at different time scales and different social scales, from intense interaction of small groups to community knowledge building over years. (Research question: What differences do temporal and social scales introduce into group cognition? How to archive synchronous interaction content as useful knowledge and data for the community to reuse asynchronously?)
- Scale up the VMT service to be a regular, year-round service of the Math Forum, used by a large number of groups in creative ways. (Research questions: How to foster and support an online community with minimal staffing, and to manage large numbers of interactions within a safe and productive context?)
- Collaborate with teachers and with math-teacher training programs to enhance the pedagogy, to support teacher involvement and to extend the user base of the VMT service. (Research questions: How to build a distributed community with different levels of expertise and to build teacher's reflective practice through participation in VMT?)
- Continue to hold data sessions of researchers to analyze data from new usage and to explore phenomena of interest in more depth. (Research question: What are the characteristics of group-cognitive problem-solving processes?)
- Apply new qualitative and quantitative social-science methods to the analysis of group-cognitive phenomena. (Research question: How to combine, e.g., conversation analysis and social network analysis or automated coding?)
- Develop quantitative measures of social presence, task performance, cooperative practices, longitudinal social relations and collaborative information behavior in self-assembling synchronous/asynchronous teams. (Research question: How can we measure processes on online group cognition?)
- Conduct a longitudinal microanalysis of the entire transcript from two four-hour Spring Fest sessions. This would be a ground-breading analysis approach and an innovative style of monograph, to be published by MIT Press. (Research question: What are the methodological issues in moving from

diachronic snapshots of group cognition in brief excerpts to longitudinal changes in collaboration and shared understanding?)

- Continue to publish analyses and to share data with international collaborators. Further refine the theory of group cognition, including building graphical and computational models. (Research question: How can aspects of the theory be summarized in models?)

It is important to note that these aspects of future work are not separable, but need to be conducted as parts of the integrated work of the Lab. The foundational theoretical work of the lab builds upon empirical microanalysis of situated practical activities and aims to contribute to the improved design of tools, concepts and principles to support practical activities.

Gerry Stahl is a leading researcher and theoretician in computer-supported collaborative learning (CSCL). He has presented at every CSCL conference and founded the *International Journal of CSCL*. Trained in computer science, human-computer interaction, artificial intelligence, cognitive science and philosophy, he is a tenured Associate Professor at the College of Information Science & Technology, Drexel University.

Sean Goggins specializes in mixed-methods research on virtual teams. He is an experienced software developer and is now Assistant Professor at the College of Information Science & Technology, Drexel University.

Stephen Weimar has been the Director of the Math Forum at Drexel University for 15 years. The Math Forum is the premier online resource for mathematics, receiving more than three million visits monthly.

The **Group Cognition Lab** includes other faculty, graduate students and staff at Drexel and elsewhere, including specialists in anthropology, conversation analysis, educational psychology, math education, teacher training and computer science. The Lab has on-going collaborations at Carnegie Mellon University, Rutgers, Hawaii, Missouri, Wisconsin, Singapore, Germany, Brazil and Romania.

The Language Technologies/HCI Institutes at CMU

Carolyn Rosé holds a joint appointment between the Language Technologies Institute and the Human-Computer Interaction Institute at Carnegie Mellon University (CMU). Locally at CMU, between her two departments she supervises or co-supervises a group of 10 graduate students, a post-doc, and a small number of undergraduates. As a tenure track professor at Carnegie Mellon University, she teaches courses related to collaborative learning, linguistic analysis, machine learning & text mining, and summarization.

The School of Computer Science at Carnegie Mellon University consists of 6 departments, including the Computer Science Department, the Machine Learning Department, the Language Technologies Institute, the Software Engineering Institute, the Human-Computer Interaction Institute, the Robotics Institute. The Language Technologies Institute is the only department of its kind in the nation that is completely dedicated to research in language technologies, and includes researchers from the full gamut of areas within that field. Similarly, the Human-Computer Interaction Institute was the first department of its kind and one of only two universities in the US with such a large and diverse faculty spanning all areas of the field of Human-Computer Interaction and containing the largest number of faculty named as CHI Fellows of any institution in the nation.

Carolyn Rosé is the Co-leader of the Social and Communicative Factors in Learning thrust of the Pittsburgh Science of Learning Center, which includes over 40 faculty from a variety of departments including Psychology, Education, Language Technologies, Robotics, and Human-Computer Interaction, both at Carnegie Mellon University and the University of Pittsburgh who are doing learning sciences research. The confluence of Rosé's two departments and the Pittsburgh Science of Learning Center provide a unique combination of human and technological resources that make her imminently well situated to successfully carry out innovative research.

Building on a foundation of research in speech translation, dialogue systems, intelligent tutoring, robust language understanding, and machine learning, Rosé has been working in the area of automatic discourse analysis for the past 15 years and has produced 25 peer reviewed publications related specifically to this topic (in addition to over 60 other peer reviewed publications on other topics) in prestigious venues such as the *International Journal of Computer-Supported Collaborative Learning*, the *Proceedings of Computer Supported Cooperative Work*, the *Proceedings of the Association for Computational Linguistics*, the *Proceedings of Artificial Intelligence in Education*. She was recently invited to write a chapter on linguistic analysis of collaborative learning for the *International Handbook of Collaborative Learning*. As the Secretary/Treasurer of the International Society of the Learning Sciences, Rosé has great visibility in the computer-supported collaborative learning community, and has co-organized workshops related to analyses of collaborative learning discussions yearly for the past four years. She is leading a number of research efforts, including a project bringing together research from the computer-supported collaborative learning community with that of the classroom-discourse community in collaboration with Lauren Resnick at the University of Pittsburgh, a project related to analysis of intercultural communication with Susan Fussell at Cornell University, and a project related to dynamic support for virtual math teams with Gerry Stahl at Drexel University. As a product of an earlier ONR funded effort, Rosé produced the TagHelper tools package for text mining that currently has over 1100 users in 58 countries.

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ALT: Dynamic Support for Virtual Math Teams

On-line learning promises education for the masses – quality educational opportunities available to all people, but especially those who are in the greatest need – although this dream is yet to be made a reality. The long term goal of the proposed work is to replicate the impact of local, on-campus programs targeting increased college preparedness and college success of minority and low income students, such as the well known Treisman Berkeley Professional Development Program, in a freely available, on-line learning environment. Making what would normally be a staff intensive program available ubiquitously at a dramatically reduced expense would be an enormous payoff. Our proposed solution is to develop a technological augmentation to available human support in a lightly staffed environment. This proposed project brings together a team with expertise in both technological development and careful experimentation both in the lab and in the classroom, a track record for large scale deployment of educational materials, a solid foundation in significant results from prior work on which we build in the areas of computer supported collaborative learning and tutorial dialogue systems.

Intellectual Merit: Our research attempts to understand how to structure interactions among peer learners in online education environments to address these problems. The proposed project seeks to enhance participation and learning in the Virtual Math Teams (VMT) online math service by designing, developing, implementing, testing, refining and deploying computer-supported tools to support facilitation in this lightly-staffed service. The key research goal is to optimize a design and implementation for adaptive feedback in support of collaborative problem solving that will maximize the pedagogical effectiveness of the collaboration by eliciting behavior that is productive for student learning in collaborative contexts.

Broader Impact: We are working towards understanding the pedagogical and technological features that make on-line education in general, and collaborative learning in particular, effective. If we can understand the causal connections between interaction and learning, then we can wield technology in ways that achieve maximal cognitive and social benefits for on-line learners. To the extent we are successful, our research will help realize the promise of on-line learning. Expensive instructors and content providers will continue to develop course materials and act as moderators to the extent that resources allow. Fellow students will support each other in dealing with their struggles with the materials.

Inexpensive machine agents will aid human facilitators both in matching students who can help each other and as well as by offering help to structure their collaborative learning conversations so that the presence of other students will lead to greater commitment to the course and learning. Making free open courses more successful will benefit all students, but especially those with lower income and from developing countries.

1. Vision

American children are in the middle of a group of 38 countries in terms of science and math education, far behind such countries as Singapore, Korea, Hong Kong or Japan (Mullis et al., 2000). On•line learning offers the potential to address this problem by providing free or inexpensive supplementary education for the masses – quality educational opportunities ubiquitously available, especially those who do not have the resources to pay for high quality private tutoring for their children. While this vision does not address the problem that some of the neediest students do not have access to computer resources, this vision is in line with the Advanced Learning Technologies mission to enable radical improvements in learning through innovative computer and information technologies.

The ultimate goal of the proposed work is to replicate the impact of what are normally local, on-campus programs targeting increased college preparedness and college success of minority and low income students, such as the Professional Development Program (PDP) (Treisman, 1985), in a freely available, on-line learning environment. We focus on middle school math since middle school is a pivotal time when students, especially girls, begin to lose confidence in and interest in math (Callahan & Clements, 1984; Dossey, Mulis, Lindquist, & Chambers, 1988; Brandon & Newton, 1985), and we target the well established Virtual Math Teams (VMT) online math service at http://mathforum.org/vmt as a venue for broad dissemination because of its strategic location in an on-line math service that reaches millions of students per week. In supporting collaboration, we focus on eliciting productive helping behavior, which we have observed to mediate learning in prior studies with this age group and domain content area (Gweon et al., 2007) as well as studies with older students (Gweon et al., 2006). Furthermore, we focus on eliciting proof-like explanations from students as part of our support for their helping behavior, since this is an important skill connected with a deep understanding of math concepts, and which continues to be a struggle for students throughout their school years. We bring together a team with expertise in technological development, careful experimentation in the lab and in the classroom as well as insightful ethnographic research in real on-line learning environments, a track record for large scale deployment of educational materials, and a solid foundation in significant results from prior work on which we build in the areas of computer supported collaborative learning and tutorial dialogue systems.

The purpose of this project is to enhance participation and learning in the Virtual Math Teams (VMT) online math service by designing, developing, implementing, testing, refining and deploying computer-support tools to enhance facilitation that is available to support students in this lightly-staffed service. It is the lightly staffed nature of this service that makes it a more economical solution that on campus programs such as PDP, mentioned above. One key research goal is to optimize the design and implementation of dynamic collaborative learning support agents that will participate in VMT chat sessions in order to maximize the pedagogical effectiveness of those interactions. Prototype dynamic support agents have already yielded positive learning effects in our pilot evaluations in lab (Wang et al., 2007) and classroom studies (Kumar et al., 2007-a; Chaudhuri et al., to appear) in the domains of science and engineering respectively, and a recent pilot evaluation shows promise with middle school kids learning about fraction arithmetic (Kumar et al., 2007-b). Another key research goal is to develop technology for monitoring collaborative behavior and automatically generating reports for human facilitators to allow them to quickly identify teams that require more attention (Kang et al., to appear-a; Kang et al., to appear-b). Our recent work on automatic collaborative learning process analysis from collaborative learning discussions between college age students (Donmez et al., 2005; Wang et al., 2007c, Rosé et al., in press) provides a foundation for this. In our proposed work we will carry this further by identifying which conversational events are most indicative of a need for support in interactions involving middle-school kids, who are less sophisticated in their communication skills and thus struggle with different issues in collaborative contexts. This will be accomplished through collaboration among CMU, Math Forum and VMT researchers.

We have already begun our joint work by integrating our research findings and infrastructure from our prior work in the areas of computer supported collaborative learning and tutorial dialogue systems. We have also piloted our integrated VMT environment, which we refer to as VMT-Basilica (Kumar et al., submitted-a; Kumar et al., submitted-b), in a purely on-line setting in order to collect realistic development data and so that our plans for our continued collaboration can be strongly influenced by observations of interactions in the exact environment where we will do our most important work towards a significant impact in the long run. In our exploratory data analysis we have taken a hybrid qualitative/quantitative approach to get a firm handle on consistent patterns that are general across the data as well as to notice the influence of important contextual variables that we will take into account in our subsequent experimental work, in line with methodology proposed in (Design-Based Research Collective, 2003).

Our research goal is supporting productive collaborative learning discussions in a computer-mediated environment in "the wild", specifically supporting students in working together in pedagogically effective ways. While the help students are capable of offering one another is not perfect, there is evidence that it is effective in spite of the errors students make when helping each other (Gweon et al., 2006), and possibly even because of these errors (Piaget, 1985; De Lisi & Goldbeck, 1999; Grosse and Renkl, submitted). If we can harness the potential of state-of-the-art technology for automatically filtering collaborative learning discussions that we have developed in our previous work (Donmez et al., 2005; Wang et al., 2007c), and we can use this automatic analysis to trigger interventions that support students in helping each other learn together (Gweon et al., 2006) using tutorial dialogue and intelligent tutoring technology as in some of our previous studies (Wang et al., 2007; Kumar et al., 2007), we could move towards a solution to our nation's educational problems in a cost effective, practical manner. To this end, our main research objectives include:

1. Extending the capabilities of the technical infrastructures created in our prior work at Carnegie Mellon University and Drexel University, which includes an elaborate environment for coordinating math teams and supporting their problem solving efforts as well as tools for automatic collaborative learning process analysis and for building collaboration support agents that are triggered by this analysis.
2. Conducting a series of investigations into the causal connections between conversational processes and learning as well as the causal connection between automatic interventions and collaborative behavior across multiple settings, including lab and classroom studies as well as investigations in the on-line VMT environment. This series of controlled and naturalistic observations will culminate in a large-scale summative evaluation in the on-line VMT environment.

In addition to producing new knowledge in the research area of Computer Supported Collaborative Learning, the results of this research will permanently extend the capabilities of an existing on-line math community, making it a more valuable resource beyond the end of the proposed research funding.

2. Foundational Resources Provided by the CMU and Drexel Teams

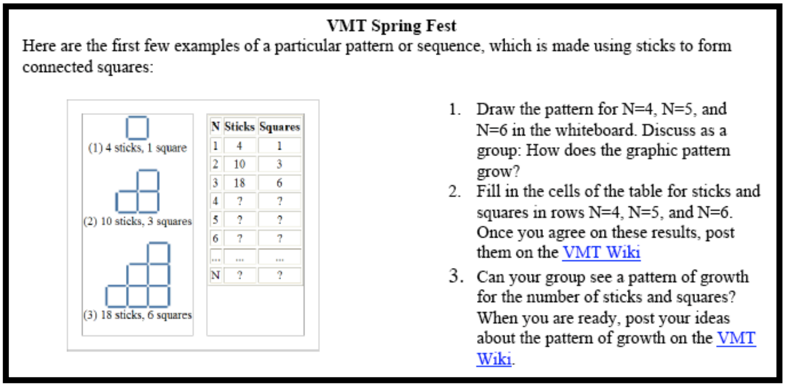
The CMU and Drexel teams both bring a rich storehouse of resources to the table to make use of in this effort.

2.1 Technological Foundation

For a technological foundation, the CMU team brings to the project much prior work developing and evaluating tutorial dialogue technology that can be used to deliver interactive support (Rosé et al., 2001; Gweon et al., 2005; Rosé et al., in press; Rosé et al., 2005; Kumar et al., 2006; Wang et al., 2006), prior work developing automatic collaborative learning process analysis technology that can be used to trigger interventions (Donmez et al., 2005; Wang et al., 2007c), other language technologies research related to text classification (Rosé et al., 2003; Rosé et al., 2005-b), robust analysis of explanations (Rosé, 2000; Rosé et al., 2002; Rosé & VanLehn, 2005) and dialogue analysis more generally (Rosé et al., 1995; Arguello & Rosé, 2006), as well as early work on design and evaluation of adaptive collaborative learning support (Gweon et al., 2006; Wang et al., 2007; Kumar et al., 2007) and investigations of group composition and gender effects in collaborative learning in an intelligent tutoring environment (Gweon et al., 2005b; Gweon et al., 2007).

The Drexel team brings the existing Virtual Math Teams (VMT) environment (http://mathforum.org/vmt). The Virtual Math Teams (VMT) project within the Math Forum uses peer collaboration in small student teams to enhance learning and participation in math discourse. Small groups of students are invited to chat rooms (see description of the Collaborative Environment in Section 3.1) where they discuss carefully designed math problems or math micro-worlds. VMT mentors are typically not present in the chat rooms, but they provide asynchronous feedback to the student groups upon request. We proposed to augment this environment with automatic, dynamic collaboration support. Math Forum and VMT staff will be involved at all stages of designing, developing, implementing, testing, refining and deploying these computer-support tools in close collaboration with researchers from Carnegie Mellon University. VMT researchers have extensive experience exploring the effectiveness of these materials for stimulating productive collaborative learning interactions. For analysis of collaborative discussions, VMT researchers have used a variety of methods that we will draw upon in our proposed work for on-line and off-line analysis of the learning and collaboration that takes place in the VMT-Chat environment, including statistical analysis of coded chats, ethnographic observation of participation and interaction analysis (adapting ethnomethodologically-informed conversation analysis to textual chat). A large number of studies of VMT chats are already available, including (Cakir et al., 2005; Sarmiento, Trausan-Matu, & Stahl, 2005; Stahl, 2006a, 2006b, 2006c, 2006d, 2006e; Strijbos & Stahl, 2005; Wessner et al., 2006; Zemel, Xhafa, & Cakir, 2005); see http://www.mathforum.org/vmt/researchers/publications.html for a more complete list.

2.2 Math Forum Materials



VMT Spring Fest

Here are the first few examples of a particular pattern or sequence, which is made using sticks to form connected squares:

N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?
2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT Wiki
3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT Wiki.

Figure 1. Example Math Forum Problem: The Sticks Problem

Selecting appropriate materials to stimulate productive collaborative conversations is essential to fostering the success of collaborative learning. Since the goal of much collaborative learning is to stimulate higher order thinking, typical tasks used in studies of collaborative learning are open ended problems with multiple possible solutions, especially ones with many trade-offs rather than right versus wrong solutions, or highly interpretative problems such as case study analysis. We draw from resources designed by The Math Forum, which has been providing a successful, highly popular online community and digital library for K-12 students, teachers and others for over a decade (Renninger & Shumar, 2002). Although the Math Forum works closely with school districts and teachers, its central focus is on providing informal learning experiences, by developing challenging, non-traditional math problems for students to think about and by collecting student responses. Although it has collected some of these responses into math books on algebra and geometry, it mainly organizes these responses as a digital library. In its various services (see Section 6 on Partnerships and http://mathforum.org for more details), the Math Forum facilitates interactions among students, teachers, pre-service teachers, volunteer mentors and paid staff.

An example problem is displayed in Figure 1 above. In the VMT environment, students work in small groups on the same problem over 3 sessions. In the first session, they work out solutions to the problem. In between the first and second sessions, students receive feedback on their solutions. In the second session, students discuss the feedback they received on their respective solutions and step carefully through alternative correct solutions. In that session and the subsequent session, they also discuss additional possible ways of looking at the problem including variations on that problem in order to take a step back and learn larger mathematics principles that apply to classes of problems rather than individual problems. Although the problem provides the opportunity to investigate multiple possible solutions and to engage in deep mathematical reasoning, our finding from analysis of chat logs where students have worked on this and other problems is that students tend to jump to finding one solution that works rather than taking the opportunity to search for alternative solutions. The moderator plays an important role in stimulating conversation between students, encouraging knowledge sharing and probing beyond a single acceptable solution. Thus, we plan to model our dynamic support agents after successful group moderators using a similar data driven process that was used to develop our CycleTalk tutorial dialogue agents (Rosé et al., in press; Kumar et al., 2006), patterned after successful human tutors (Rosé et al., 2005) supporting learning in the same environment that the chat agents now participate in. Examples of the proposed support are given in Section 3 below.

2.3 Tools for Building Dynamic Collaborative Learning Support

What the CMU team brings in terms of technological infrastructure are tools for automatic collaborative learning process analysis to trigger dynamic support in the midst of ongoing collaboration and tools for quick authoring of conversational agents to administer the interactive support. Note that both of these tool sets were developed under the NSF funded Pittsburgh Science of Learning Center (PSLC) as enabling technology projects. Whereas in the PSLC this work can support classroom studies in designated LearnLab courses (which do not include any courses using Math Forum materials), that center does not fund work in on-line learning communities, classroom studies in other classrooms, or lab studies. Thus, the proposed work will take resources developed in one NSF funded context, and extend the impact to a new and significantly broader context.

As part of a collaboration with the Knowledge Media Research Center in Tuebingen, Germany, we have developed a proof of concept for fully automatic collaborative learning process analysis (Donmez et al., 2005; Wang et al., 2007-b; Rosé et al., in press). We describe this work here as an example of the types of analyses and level of detail we are able to achieve with our automatic processing of conversational data. We refer to the coding scheme used in this work, which was developed by Weinberger & Fischer (2006), as the Weinberger and Fischer coding scheme. This coding scheme was developed for the purpose of addressing the question of how computer-supported collaboration scripts could foster argumentative knowledge construction in online discussions. Argumentative knowledge construction is based on the idea that learners acquire knowledge through argumentation with one or more learning partners, by better elaborating the learning material and by mutually refining ideas. Argumentative knowledge construction must be evaluated on multiple process dimensions. Thus, the Weinberger and Fischer coding scheme has five process dimensions. These dimensions are derived from different theoretical approaches and focus on specific conceptualizations of argumentative knowledge construction, and are supposed to be independent from each other. The main concepts are (1) epistemic activity, formal quality regarding argumentation, which differentiates in the (2) micro-level of argumentation and the (3) macro-level of argumentation, and (4) social modes of interaction. Independent of these dimensions, the segments have been coded whether they were or were not (5) a reaction to a previous contribution.

Each dimension offers a different perspective on the nature of the contribution, often drawing upon information of a different nature from the other dimensions, and thus offers evidence of the generality of our approach. For example, the Micro and Macro dimensions each characterize different aspects of the linguistic structure of the contributions whereas the Social Modes and Reaction dimensions focus on different types of social conventions and relational styles conveyed in and encoded in contributions. Automatic application of coding schemes such as this one make it possible to automatically detect dysfunctional communication patterns within running discourse. For example, they make it possible to determine whether participants are acknowledging each other's contributions, and considering them adequately without either giving in too quickly or rejecting each other's views out of hand. A major focus of our work has been increasing classification accuracy on low frequency events, since many times very infrequent events are nevertheless important to recognize with a high degree of accuracy because they are indicative of particular types of trouble.

The second technology provided by the CMU team is an infrastructure called TuTalk to support quick authoring of dialogue agents (Gweon et al., 2005; Jordan et al., 2007; Cui et al., to appear). This work includes 1) tools for non-technical users to author dialogue specifications for particular student exercises and 2) a backend system for supporting full spoken or text-based dialogue behavior that follows the authored specifications. In our prior work we have explored strategies for supporting the development of language understanding interfaces by non-linguists (Rosé & Hall, 2004; Rosé, Pai, & Argeullo, 2005). TuTalk provides a suite of corpus organizational tools to help authors prepare their corpus data in preparation for authoring using what we refer to as the InfoMagnets interface (Arguello & Rosé, 2006b). The TuTalk authoring interface is then used for finer grained processing, such as shifting topic segment boundaries and labeling more detailed utterance functionality, as well as authoring templates used for generating dialogue behavior. These tools were used to build the dialogue agents used in the successful classroom studies reported in (Kumar et al., 2006) in one week.

While our previous work developing dialogue agents has focused primarily on tutorial dialogue for individual learning, here we expand our scope to cover tutorial dialogue for collaborative learning, and have already seen success in that arena (Kumar et al., 2007-a; Kumar et al., 2007-b; Wang et al., 2007-a; Chaudhuri et al., to appear-a). Thus, here the purpose of the dialogue agents is not to lead one student to reflect on a past decision or come to a specific conclusion. Instead the dialogue agents will seek to direct the interaction between students, offering instruction only as a last resort. Building on work reported in (Rosé & Torrey, 2005), we seek to build dialogue agents that are effective at eliciting elaborated explanations from students in the context of the help seeking and help giving interactions with other students in order to implement dynamic support interventions.

3. Results from SGER: The VMT-Basilica Integrated Foundation for Supporting Collaborative Learning On-Line

In this section we describe how we have integrated elements from our previous work into a common technical foundation and have developed a foundational instructional approach that we build on and extend in our proposed work.

3.1 Collaborative Environment

The Math Forum and its Virtual Math Teams Project have collaborated closely with CMU personnel under an SGER grant to design, develop, implement, and pilot test the integrated VMT-Basilica environment. This was accomplished using the VMT-Chat environment, which was made available as a test-bed for collecting data about the performance of these tools. The opensource VMT-Chat includes the VMT Lobby, where people can select chat rooms to enter, and a number of math discussion chat rooms, that each include a text chat window, a shared drawing area and a number of related tools (for a more detailed description of the environment and how it is used, see (Stahl, 2006). Since the environment is available as Open Source, (1) it was easily extended for this project and (2) the results of this project can easily be made available to other researchers.

VMT-Chat includes the VMT Lobby – where people can select chat rooms to enter (see figure 2)

– and a number of math discussion chat rooms – that each include a text chat window, a shared drawing area and a number of related tools (see figure 3).

Figure 2. The VMT Lobby.

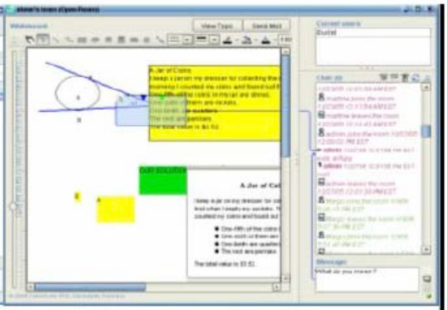


Figure 3. A VMT chat room.

Three types of rooms can be created in the lobby:

- Open rooms. Anyone can enter these rooms and participate in the discussion – see Figure 1, where open rooms are listed under math problems or topics.
- Restricted rooms. Only people invited by the person who created the room can enter.
- Limited rooms. People who were not originally invited can ask the person who created the room for permission to join.

Such flexibility allows the VMT service to be used in a wide range of ways and in limitless combinations and sequences:

- For instance, teams of students from the same classroom might first use the VMT environment to work together on a series of Problem of the Week (PoW) problems during class time, allowing them to become familiar with the system and build collaboration skills in a familiar social setting.
- Later they could split up and join groups with students from other schools to explore more open-ended mathematical situations.
- As they become more advanced users, they can create their own rooms and invite friends or the public to discuss topics that they themselves propose.

VMT-Basilica integrates the open source VMT-Chat with Basilica (Kumar et al., submitted-a; Kumar et al., submitted-b), which integrates all of the CMU technologies discussed above into a framework that supports rapid development of computer supported collaborative learning environments. It provides a clean software architecture where technologies such as TagHelper tools and TuTalk are encapsulated into abstract classes that can be instantiated as specific Filters and Agents respectively, where Filters listen in on the behavior occurring within an environment like VMT-Chat in order to notice specific behaviors, either in the chat or other interface widgets such as the whiteboard, and Agents exhibit behaviors, such as displaying graphics on the whiteboard, or participating actively in the chat.

Within this integrated framework, we are able to trigger a variety of interventions within the VMT-Chat environment that are sensitive to what is happening in the collaboration between students. We have already successfully piloted the integrated VMT-Basilica environment in a large classroom study related to collaborative design for environmentally friendly engineering (Chaudhuri et al., to appear).

3.2 Instructional Approach

Our goal is to maximize the benefit students receive from the interactions they have with one another. Not all instructional conversation between learners is equally effective, and often requires some form of support in order to become effective (Stegmann et al., 2004; Rummel et al., 2003). State-of-the•art forms of collaboration support proactively structure collaborative learning interactions using a broad assortment of approaches. Examples of such support includes assignment of students to roles (Strijbos, 2004), provision of prompts during collaboration (Stegmann et al., 2004), design of structured interfaces including such things as buttons associated with typical "conversation openings" (Baker & Lund, 1997), instructions to guide learners to structure their collaboration (Webb & Frivar, 1999), or even various forms of collaboration training (Rummel et al., 2006). These approaches to structuring collaboration play a role similar to training wheels on bicycles. Just as training wheels allow kids to have the experience of riding a bike before they are ready to do it independently, these forms of collaborative learning support increase the amount of productive collaboration behavior above that of what it would be without the structuring, thus allowing students to collaborate at a higher level than their own collaborative skills would naturally allow. As is well known, however, training wheels must eventually come off. And typically, they are removed by a watchful parent, who may decide after watching their child fall a few times, to put them back on for a time until the child has developed further in their own coordination and balance. In a similar vein, the learning sciences literature tells us that scaffolding should be faded over time (Collins et al., 1991), that over-scripting is detrimental to collaboration (Stegmann et al., 2004), and unnecessary support is demotivating (Dillenbourg, 2002). However, in order to fade collaboration scaffolding as a watchful parent, we must do so using technology that is sensitive to collaborative behavior in the environment. Thus, a major goal of our research is to support collaboration in a way that is responsive to what is happening in the collaboration rather than behaving in a "one size fits all" fashion, which is the case with state-of-the-art static forms of support.

Our instructional approach is modeled after constructivist principles of classroom discourse, such as those advocated in (Chapin, O'Connor, & Anderson, 2003).

Webb and colleagues present a series of studies in different educational settings that demonstrate the importance of the depth of instructional explanations, both for the speaker as well as the recipient (Webb, 1991; Webb, Nemer, & Zuniga, 2002). Much research shows the value of drawing out student reasoning in the form of elaborated explanations. In particular, one of the best substantiated educational findings in cognitive science research related to education is the educational benefit of explanation, and in particular, the self-explanation effect (Chi et al., 1989; Chi et al., 1994; Chi, 2000). Nevertheless, previous discourse analyses of collaborative conversations reveal that the majority of conversational interactions between students do not display the "higher order thinking" that collaborative learning is meant to elicit (Webb & Mastergoerge, 2003; Webb, Nemer, & Zuniga, 2002), and we have found this as well in our own observations of collaborative learning, both at the college level (Gweon et al., 2006) and at the middle school level (Gweon et al., 2007).

To begin to move past the traditional one-size-fits-all non-adaptive approaches to collaboration support, we have conducted a series of studies in which we experimentally investigate foundational issues related to the design of dynamic support for on-line collaborative learning (Gweon et al., 2006). These initial investigations demonstrated that explanation elicitation prompts such as those displayed in Table 1, delivered strategically, based on simple rules related to timing of contributions and distribution of labor between student, were effective for eliciting explanation attempts as well as significantly increasing learning. These very general purpose prompts were effective across a wide range of collaborative problem solving exercises. In our long term plans in the VMT context, in order to elicit the type of collaborative behavior that leads to more learning, we will use dynamic collaboration support agents based loosely on the style of our previous investigations at the secondary and post-secondary level (Gweon et al., 2006; Wang et al., 2007; Kumar et al., 2007).

Case	Prompts
1	The other student would benefit from more explanation. Please elaborate on your correction.
2	Help the student understand your correction. The other student seems to be struggling with this section of the problem. Please offer your assistance.
3	Please be sure you are working with the other student to solve the problem. It seems like the other student has not contributed lately. Why don't you see if they need help?
4	It seems like you are moving on before understanding your errors. Please spend more time reviewing this page. Does the other student understand the errors made on this problem? Please share your understanding of this page with the other student.

Our previous success with automating collaborative learning process analysis (Donmez et al., 2005; Rosé et al., in press) offers promise that the dynamic support mechanism evaluated using a Wizard-of-Oz setup in (Gweon et al., 2006) can be implemented and deployed fully automatically.

We have run a number of successful pilot studies in which we used dialogue agents to deliver interactive support when triggered by an automatic analysis of the collaborative learning discussions as they unfolded (Wang et al., 2007; Kumar et al., 2007-a). In these successful studies, the fully automatic interactive support lead to significant increases in learning in comparison to a control condition that did not have the interactive support. However, these studies did not take place in an open web environment such as the Virtual Math Teams environment. Thus, there is still much work to do to investigate how best to elevate the level of helping behavior in an environment such as the on-line VMT environment.

4. Full-Circle Methodology: Exploring the Design Space in Complementary Contexts

We propose to take advantage of the complementary insights we can gain from investigations in various settings, including lab studies, classroom studies, and studies in the Virtual Math Teams environment. Furthermore, we leverage a broad spectrum of methodologies, ranging from high internal validity studies in the lab and in the classroom, with pre/post test designs to high external validity investigations in the "wild" Virtual Math Teams environment where the same analyses of observable collaborative behavior are possible even with naturalistic, non-controlled observation, but experimental designs are less practical and must be administered with caution because of the way imposing too much control may interfere with the natural working of the community (In Section 4.4, we describe how we will carefully conduct a large-scale summative evaluation at the end of the project in such a way as to avoid interfering with the natural workings of the community any more than necessary.) With respect to analysis of log data, we will also employ a diversity of approaches including formal, quantitative analyses of log data based on categorical coding as well as ethnographic style analyses.

4.1 Illustration of Methodology

As an illustration of our full-circle, mixed-methods approach, we offer an example of how our informal collaboration to date is already yielding synergistic findings. Because our ultimate goal is to achieve success in the "wild" Virtual Math Teams environment, we begin with insights gained from an ethnomethodological analysis of chat logs collected in the Virtual Math Teams environment (Stahl, 2006). In one notable chat session, we observed a group of students that was successful at solving problems collaboratively that none of them were capable of solving alone. On close inspection of the chat logs, a student who at first appeared as "the class clown" emerged as a tone setter in the analysis, putting his team mates at ease, and allowing them to forage ahead as a group towards solutions to very challenging problems. From this analysis, a hypothesis emerges that interventions that break the tension and stimulate a light-hearted atmosphere in a collaborative learning setting may act as a "social lubricant", and thus may increase success in collaborative problem solving. The Carnegie Mellon team has tested this hypothesis experimentally in a classroom study, referred to as the Social Prompts study (Kumar et al., 2007-b), in which students worked in pairs in a collaborative problem solving environment that shares some common simple functionality with the Virtual Math Teams environment.

In the experimental condition of the Social Prompts study, before a problem is displayed in the shared problem solving space, a tutor agent first asks each student what we are referring to as a social question. The idea is to draw the students into a productive, collaborative attitude by encouraging them to put something they identify with personally into the math problems, so they feel as though they have worked together to make the math problems they will then work together to solve. As an example, consider the following scenario: The agent may first ask student 1 “Student 1, if you had to choose between a long flight or a long car ride, which seems more uncomfortable?” The student indicates that a car ride would be preferable. Then the tutor agent may then ask, “Student 2, which are more entertaining

– books or movies?”, and the student may respond that books are more amusing. These two pieces of information are then used to fill in slots in a template that is then used to generate the math problem. In particular, the resulting story problem says, “Jan packed several books to amuse herself on a long car ride to visit her grandma. After 1/5 of the trip, she had already finished 6/8 of the books she brought. How many times more books should she have brought than what she packed?” The lighthearted nature of the questions was meant to inject a note of playfulness into the conversation. In order to control for content and presentation of the math content across conditions, we used exactly the same problem templates in the control condition, but rather than presenting the social questions to the students, we randomly selected answers to the social questions “behind the scenes”. Thus, students in both conditions worked through the same distribution of problems.

The results of the Social Prompts study provided some evidence in support of the hypothesis that emerged from observations in the Virtual Math Teams environment. We began our analysis by investigating the socially oriented variables measured by means of the questionnaire, specifically perceived problem solving competence of self and partner, perceived benefit, perceived help received, and perceived help provided. For perceived benefit and perceived confidence, scores were high on average (about 4 out of 5) in both conditions, with no significant difference between conditions. However, with perceived help offered as well as perceived help received, there were significant differences between conditions. Students in the experimental condition rated themselves and their partner significantly higher on offering help than in the control condition. Interestingly, there is more evidence of requesting help in the control condition chat logs. However, these requests were frequently ignored. The learning gains analysis is consistent with the pattern observed on the questionnaire and offers some weak evidence in favor of the experimental condition on learning. The trend was consistently in favor of the experimental condition across tests and across units of material on the test. The strongest effect we see is on lab day 2 where students in the experimental condition gained marginally more on interpretation problems ($p=.06$, effect size .55 standard deviations). The student chat logs contain rich data on how the collaborative problem solving process transpired. We conducted a qualitative analysis of the conversational data recorded in the chat logs in order to illuminate the findings from the tests and questionnaire data discussed above. Overall, we observed that students were more competitive in the control condition. Insults like “looser”, “you stink”, “stupid” occurred frequently in the control condition, and never in the experimental condition. Instead, in the experimental condition we observe light hearted teasing. There were significantly more help related conversational episodes per problem in the Experimental condition (Kumar et al., 2007-b), and furthermore, it happened significantly more frequently in the Experimental condition that when students got stuck on a problem solving step, they received help and then were able to complete the step themselves instead of their partner completing it for them, which was the general case in the control condition.

The full-circle methodology that we propose begins with ethnographic observations from interactions in the Virtual Math Teams environment. These observations lead to hypotheses that can be tested in high internal validity environments such as lab and classroom studies. These studies help us to confirm causal connections between stimuli and subsequent effects, between which we observe a correlational relationship in our earlier ethnographic analyses. Discovered causal connections can then form the basis for the design of full-scale interventions that can then be prototyped and tested in the Virtual Math Teams environment. These investigations can eventually serve both as a test of the generality and robustness of findings from the lab and classroom studies as well as providing new insights that form the basis for new hypotheses that can then be tested in further cycles, although only a large-scale controlled study, as we propose for in the final year of the project, can provide definitive evidence in favor of an intervention. In our three year project, we propose three complete cycles, ending with a carefully designed, large scale experimental study in the Virtual Math Teams environment to verify the effectiveness of the interventions we will develop in that environment, as detailed in Section 5.

4.2 Investigation of Contextual Variables in the VMT Environment

From lab and classroom studies where we are able to use pre and post tests, we are able to determine which types of interactions are more conducive to learning than others. We have already conducted a series of successful classroom studies investigating questions related to the design of computer supported collaborative learning environments (Gweon et al., 2007; Wang et al., 2007; Kumar et al., 2007-a; Kumar et al., 2007-b; Chaudhuri et al., to appear; Kumar et al., submitted-a). One major question we address in the proposed naturalistic observations in the on-line VMT environment as well as the large-scale summative evaluation in that environment in year three is whether or to what extent we can use the same interventions in "the wild" to achieve the same effect on behavior that we observe in the lab or in the classroom. This behavior is directly observable from the logs we collect. Thus, we can investigate these important questions about the effect of alternative interventions on collaborative behavior in the VMT setting even without pre and post tests. Specifically, what we seek to learn from our investigations in the on-line VMT environment is how the contextual variables that distinguish that environment from the lab and the classroom environments may interfere with or change the effects of interventions on student behavior. Such variables include the time of the interaction (e.g., during school hours, in the evening, on the weekend, during the summer), location (co-located or distributed teams), reward structure (e.g., in class assignment, homework assignment, extra credit, or voluntary), group composition (e.g., same grade cohort, mixed grade/age), collaborative pre-disposition (e.g., students coming from schools where collaborative learning is encouraged and frequent versus schools where collaboration is not part of regular instruction), and experience in the environment (e.g., new to the on•line VMT environment versus having participated for a long time). We will carefully keep track of this information about students and take them into consideration as we interpret findings from naturalistic observations used for hypothesis formation. In order to test these hypotheses some of these variables will be manipulated in a quasi-experimental manner in the large-scale summative evaluation in year three.

4.3 Experimental Paradigm

All lab and classroom studies will use the following experimental paradigm.

Participants. Participants will be middle school children recruited through local newspapers or through their teacher and will be randomly assigned to pairs, which will then randomly be assigned to conditions. We recognize that many characteristics of students may interact with our experimental manipulations such as ability level of individual students, differences in ability level of students in pairs, gender of individual students as well as gender mix of pairs, level of interest and motivation of individual students. In order to accommodate this, we will recruit at minimum 20 pairs per condition in each study in an attempt to achieve a balance of all of these factors, and we will include these variables in our analyses.

Materials. All instructional materials including tests, questionnaires, and problem solving activities will be based on existing Math Forum materials, and will be adapted for studies by researchers both at CMU and the Math Forum working in close collaboration. We will also seek guidance from the math coach who is our partner at Propel Charter School (See Section 6). All collaborative work sessions except for controlled studies in year one will take place in the VMT environment described in Section 3.1.

Experimental Procedure. We will strictly control for time in all experimental studies. Each pair will participate in a single two hour session, which includes time for pre and post tests, in some studies a supplementary tutoring session, and group work. In all cases, the experimental manipulation will take place during the group work segment. In studies with a supplementary tutoring segment prior to group work, students will also take a middle test prior to group work in order to separate learning from tutoring from learning during group work. Pre, post, and middle tests will be isomorphic, and we will counter•balance the order of the tests in order to control for any potential differences in difficulty between tests, as in our prior work (Gweon et al., 2006; Gweon et al., 2007). As in our previous studies, students will also take a questionnaire at the end of their participation to assess their perceptions of the collaboration, their attitudes toward their mathematical learning and the on-line learning environment overall.

Experimental Manipulation. Based on our previous experience, with 20 pairs per condition, we expect each lab study to require 6 weeks times the number of conditions. Thus, a 4 condition study would require about 6 months to run. Allowing time for analysis of results and reflection in between experiments, we expect to run between 4 and 6 studies of this magnitude, or fewer larger studies, within the 3 years of the proposed work. Each study will include a control condition with fully unsupported collaboration in order to obtain an accurate measure of the value of each intervention. Some experimental manipulations, such as ones involving choices about which resources to provide students with, do not require sensitivity to the ensuing collaborative process, whereas others require detecting patterns of collaborative behavior that are indicative of trouble in the collaboration. In early lab studies, as we are continuing to extend the capabilities of our automatic process analysis technology to the specific demands of our proposed work, interventions will be triggered using a Wizard-of-Oz setup as in (Gweon et al., 2006; Benzmueller et al., 2003), where an experimenter is watching the collaboration remotely and selecting interventions at key points in the process. As the technology becomes reliable enough, we will replace the human intervention with automatic triggering of interventions.

Process Analyses. As in our prior studies of collaborative learning, in addition to analyses of test and questionnaire data, we will explore the collaborative process through analysis of the chat logs collected during group work (Meier et al., submitted; Weinberger & Fischer, 2006; Strijbos, 2004; Lally & De Laat, 2002). Variables related to group process such as amount of deep explanation behavior, help seeking and help provision behavior will be analyzed both as ends in themselves, i.e., examining the effect of our experimental manipulations on patterns of communication, but also as mediating variables in our comparisons of pre to post test gains and questionnaire findings.

Prior to each formal study, we will run several pilot testing sessions for each new condition in order to fine-tune our execution of our experimental manipulation.

4.4 Example study: Eliciting Helping Behavior with Dynamic Prompts

In our previous investigations with middle school students, we have observed that one area of needed support in collaborative problem solving is supporting the generation of explanations. We can offer some non-interactive support for this by means of fully worked out examples that include explanations, glossaries that define technical terms required for understanding the problems, and examples of clear explanations contrasted with unclear explanations. This type of support is in the spirit of the type of non•adaptive support for collaboration offered to students in state-of-the-art collaborative learning environments. What we propose to investigate that builds upon this prior work is the interaction between these non-adaptive forms of support and an adaptive form of support similar to the prompts used in our prior exploration of adaptive prompting with college aged students (Gweon et al., 2006). In that study, the adaptive support we offered students instructed them when to offer help but not how to offer help. But with middle school students (Gweon et al., 2007), we observed that students sometimes realized they should offer help but were not able to.

Thus, our first lab study we will contrast Non-adaptive support versus No support versus Non-Adaptive support versus Adaptive support (in the form of simple adaptive prompting as in (Gweon et al., 2006)). The purpose of the tutorial dialogue agents will be to scaffold the process of constructing an explanation by drawing the explanation out of a student step by step. We hypothesize that students will be better equipped to offer help in the Non-adaptive support condition than in the No Non-adaptive support condition, but may not be significantly more likely to attempt to offer help unless they have the additional support of the Dynamic support agents. We further hypothesize that low ability students will benefit more from the more elaborate form of Adaptive support than high ability students.

Here's an example knowledge construction dialogue agent, which can be used to deliver concept specific help. This is an example of the type of dialogue agent that can be authored using our development tools in under an hour (Cui et al., to appear; Jordan et al., 2007; Gweon et al., 2005-b), and which could be used for this study as a form of support for collaborative problem solving. Note that both students have the opportunity to participate in the conversation, and the agent offers students the opportunity to practice explaining math concepts with coaching. The goal of the conceptual dialogues is to encourage students to think about the ideas behind the fraction arithmetic problems.

Tutor: Let's think about why the flip and multiply strategy works. Consider this: If I have 1 divided by 1/2, can I turn that into something divided by 1?. If I want to turn the denominator, which is 1/2, into 1, what do I need to do to it?
Student1: I don't know how.
Tutor: You need to multiply by two. And after you do that, what do I have to do to the numerator?
Student1: also multiply by 2
Tutor: Right. When you multiply the numerator and denominator of the problem by the denominator of the fraction that is the denominator of the problem, you see a simpler version of the problem. So why does flipping and multiplying work?
Student2: what you're doing is multiplying the numerator and denominator by the same number
Student1: ya, multiplying by the denominator of the bottom fraction
Tutor: Right. So let's try another one. If I want to divide something by 2/3, what do I need to multiply the numerator and denominator by?
Student1: 2/3
Tutor: Right. You should continue to think about why it's 3/2.

We estimate that we will need to author approximately 6-10 such dialogue agents for a weeklong study. Since the agents target general mathematic concepts rather than specific errors or specific math problems, they can be used in a variety of different contexts.

4.3 Subsequent Lab Studies

The series of studies that we run under this grant will build one on top of the other in terms of results. Thus, it is not possible to fully plan out the exact series of studies that we will run as we fine tune the design of our collaboration support approach and accumulate findings from study to study. However, we have specific ideas about alternative follow-up studies planned after the initial one just mentioned. For example, one question is whether our adaptive support should emphasize encouraging help providing behavior or help seeking behavior. Students may be more motivated to respond to a help request coming directly from their partner student rather than a request to offer help to that student when the request comes from a computer agent. Furthermore, students may be more aware of the specifics of the need for help when the help request comes directly from the student who needs the help, and thus the manipulation of prompting help seeking behavior versus prompting help providing behavior may have an effect on the quality and specificity of the help that is offered. A similar manipulation would be contrasting prompts that simply request that help be offered to the partner student versus prompts that refer to specific types of help or help on a specific topic when that request comes from a computer agent.

4.4 Evaluations in the VMT Environment

The computer-based tools developed under the proposed grant will be tested in naturalistic observations in the on-line VMT environment on a small scale throughout the 3-year project, and will be evaluated in a large-scale summative evaluation in the 3rd year of the project.

The tools will be used in five ways:

1. In early naturalistic trial cases in the VMT environment, rather than directly intervening in student collaboration, instead the assessment of the collaborative learning interactions provided by the automatic process analysis technology discussed in Sections 2.3 and 3.3 will be provided asynchronously to human mentors who provide feedback to students between student sessions.
2. In a few trial cases, mentors will be in the chat room while the students are interacting. The mentors will use real-time data from the tools to provide synchronous mentoring to the students.
3. As the tools become more reliable, the support agents will interact with students within the environment, but in a mode where human moderators can intercept the messages when necessary.
4. When the agents have reached an acceptable level of performance, real-time support from the tools in the style found most successful in our lab studies will be provided synchronously to the students themselves during collaboration.
5. In all cases, explorations in the VMT environment will be more naturalistic than in the lab and classroom settings. Analysis of the naturalistic trial cases will mainly take the form of case studies. In the small scale evaluations in the VMT environment in the initial segment of the research project, brief interactions will be analyzed in detail to assess the impact of the data from the tools. Investigations in on-line settings cannot as easily be controlled and replicated to meet the requirements of traditional quantitative analysis. Therefore, qualitative interaction analysis is generally used in design-based research where conditions are changing as technology is redesigned and as the understanding of human participants also evolves (Design-Based Research Collective, 2003; Hutchins, 1996; Koschmann, Stahl, & Zemel, 2006; Maxwell, 2004). We expect these observations to complement the more

quantitative findings from our controlled investigations. Their value comes from the highly externally valid insights we will gain.

As a final acid test of the technology, in the final year we will run a large-scale evaluation in the VMT environment. We will endeavor to conduct this evaluation under as realistic of circumstances, true to how the VMT environment typically operates, as possible while maintaining enough experimental rigor to obtain generalizable and robust results. We will recruit students in the same way that students are typically recruited to participate in the VMT environment. Students who agree to participate will be given a pretest to assess their level of competence with the subject material going in to the study. We will ensure that this VMT "sub-community" does not mix with the larger VMT community during the time of the study, but beyond that we will not dictate the frequency or timing of their interactions in the environment any differently than typical VMT students. More specifically, there will be two such "sub-communities" for this study. In the control condition "sub-community", students will only receive the support that is currently offered in the VMT environment, specifically where limited support is offered by human moderators asynchronously. In the experimental condition, students will receive this support in addition to support by fully automatic support agents that will participate in all of their on-line interactions in the VMT environment for the duration of the study. We will keep careful track of when and how long each participant is logged into the VMT environment so that we can take this into account in our analysis. At the end of the study, students will take a post-test. We compare conditions in terms of (1) pre to post test learning gains, (2) time on task, and (3) amount of observed helping behavior.

5. Research Plan Overview Integrating Research and Education

Rosé will oversee all work conducted at CMU, which includes basic research on automatic collaborative process analysis and interactive collaboration support delivery as well as lab and classroom studies. Stahl and Weimar will oversee all work conducted at Drexel University, which includes ongoing development of the VMT environment and conducting naturalistic observations on-line in the VMT environment. The CMU and Drexel teams will collaborate closely to design studies that will take place in the VMT environment, as well as analyzing the data collected in those studies, culminating in a large summative evaluation in the VMT environment in the final year of the project. The CMU and Drexel team will conduct phone conferences twice a month to coordinate their efforts. The timeline of the proposed work will be organized around three cycles of the methodology proposed in Section 4:

Year 1. From the beginning of the project, all lab and classroom studies as well as the naturalistic VMT environment observations will be conducted using VMT-Basilica developed during our existing collaboration. Early design experiments in the on-line VMT environment will use a hybrid methodology where the behavior of an automated agent is enhanced by the involvement of a human behind the agent as in (Rosé & Torrey, 2005). At the same time, we will conduct the lab study proposed above in Section 4.4 using the existing VMT-Basilica framework. The study described in Section 4.4 already builds on our prior results and observations, and thus is consistent with our proposed mixed methods methodology. In the second half of year 1, we will elaborate the VMT-Basilica framework based on findings, as well as using this analysis to plan the next cycle of experimentation.

Year 2. During Year 2, in addition to running the next cycle of lab/classroom studies and observations in the VMT on-line environment, we will continue to extend the capabilities of our automatic collaborative learning process analysis technology in directions motivated by findings from earlier cycles of research.

Year 3. The final year of the project will proceed as Year 2 except that in the final 6 months of the project we will conduct a large-scale summative evaluation study in the VMT on-line environment, as proposed in Section 4.4.

PIs Rosé and Stahl both teach courses in Computer Supported Collaborative Learning, which under this grant will be integrated into a single distributed course. Both courses involve a significant project component, in which distributed teams of students from both universities will join forces to participate in the research. One such opportunity they will have will be to prototype dynamic collaborative learning support interventions using the tools provided by the Carnegie Mellon team, which will then be pilot tested in Drexel's Virtual Math Teams environment. Analysis of chat logs from Virtual Math Teams interactions, especially involving dynamic support agents, will also be a course activity. Thus, students in the courses will not only benefit by learning about the findings from the research, but they will also actively participate in the research. Whereas the course at Drexel emphasizes a socio•cultural approach to computer supported collaborative learning, the course at Carnegie Mellon has more of a cognitive emphasis. Thus, the distributed teams will provide an ideal environment for wrestling with issues on the frontier between these two communities and gaining greater insight into the deep connections between the social and cognitive foundations of collaborative learning.

Results from the proposed research will be presented in conferences and journals in the fields of computer supported collaborative learning, human-computer interaction, and computational linguistics.

6. Partnerships

We have an ongoing partnership with Propel Charter School in Homestead, Pennsylvania where we have run a Math Camp in summer of 2006 and subsequently ran an after school math club in order to collect data on math explanations and collaborative behavior from urban middle school kids in connection with the specific Math Forum materials we have used and plan to continue use in our studies. This partnership provides one context where the CMU team will do outreach work using the on-line environment that provides support to students outside the classroom as part of this project. See letter of support from Propel Charter School's math coach, Ariane Watson, written in support of an earlier proposal related to collaborative math problem solving that was not funded but nevertheless served as a stimulus for beginning to build this partnership in anticipation of an eventual funded research project.

The Math Forum at Drexel University, run by Co-PI Steve Weimer, manages a website (http://mathforum.org) with over a million pages of resources related to mathematics for middle school and high school students. This resource actively provides mathematics instruction to the full gamut of American students, but specifically targeting a very significant segment of low income and minority students. A leading online resource for improving math learning, teaching and communication since 1992, it is now visited by over a million different visitors a month. A community has grown up around this site, including teachers, mathematicians, researchers, students and parents using the power of the Web to learn math and improve math education. Studies of site usage show that students have fun and learn a lot; that educators share ideas and acquire new skills; and that participants become more engaged over time.

7. Results from Prior NSF Funding

Rosé has supervised NSF DRL-REESE/SGER-0723580 (Exploring Adaptive Support for Virtual Math Teams, $49,999.00,July 2007- June 2008). This SGER project provided strategic funds to develop and pilot test the VMT-Basilica environment described earlier in this proposal (Cui et al., in press; Kumar et al., submitted-a; Kumar et al., submitted-b; Chaudhuri et al., to appear). It builds on Rosé's earlier research supported by NSF EHR/SGER-0411483 (REC: Calculategy: Exploring the Impact of Tutorial Dialogue Strategy in Shaping Student Behavior in Effective Tutorial Dialogue for Calculus). This SGER project provided the foundational research towards the concept of adaptive collaboration support that this proposal is built upon (Gweon et al., 2005; Gweon et al., 2006; Kumar et al., 2007a; Kumar et al., 2007b; Wang et al., 2007). The most successful of these early studies (Kumar et al., 2007a) demonstrated that students working in pairs with adaptive support provided by tutorial dialogue agents learn 1.24 standard deviations more than students working alone without this support. Other publications from this work include foundational work for the subsequent TagHelper tools project (Gweon et al., 2005b), with subsequent work and downloadable toolkit at http://www.cs.cmu.edu/~cprose/TagHelper.html, which has a user base of over 350 users in over 30 countries.

CoPIs Weimar and Stahl have jointly supervised the Virtual Math Teams (VMT) project at Drexel University. NSF DUE 0333493 Collaboration Services, $450,000, August 2003 to July 2005, NSF REC 0325447 Catalyzing & Nurturing Online Workgroups, $2,299,978, September 2003 to August 2008. Virtual Math Teams (VMT), led by Gerry Stahl, Drexel University, College of Information Science and Technology, Steve Weimar, Director of The Math Forum @ Drexel, and Wes Shumar, Associate Professor, Culture and Communication, Drexel University: The VMT Project investigates issues of online collaborative mathematics problem solving by extending the Math Forum's popular "problem of the week" service for use by small groups of students. These issues include the pedagogy of online collaborative learning of school mathematics, the design of appropriate software and the methodology of empirical research in such settings. The VMT project has produced about 80 publications in journals, conferences and books (http://vmt.mathforum.org/vmt/researchers/publications.html). Six PhD dissertations are underway analyzing project data.

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SLC: Engaged Learning in Online Communities

The Catalyst project will plan a Sciences of Learning Center (SLC) focused on *Engaged Learning in Online Communities* and develop an interdisciplinary network of researchers to design a rigorous research agenda for understanding what online engaged learning is and could be at the individual, small group and community levels.

Vision. The richness of interactions fostered by the Web and efforts to leverage that potential richness like the NSF's NSDL program have spawned numerous innovative spaces for learning in small and large collaborative groups within informal and formal contexts. Such approaches may overcome barriers to learning based on geographic location, time constraints, gender, initial interest, self-confidence, minority status, age, disability, or skill levels of learners.

Background. The complexity of interacting factors and the differences among the individual, small group, and community dimensions of online learning have not yet been well defined or systematically studied. While individuals' interest has been found to gate attention, goal-setting, and learning strategies of learners in the physical world, little is understood about *what takes place when deep and engaged learning occurs in online communities*, how group configurations and community structures matter, or how learning by online groups can be supported to develop and be sustained over time. Experiments to date have primarily been descriptive formative evaluation studies, often focused on the individual unit and situated in particular social contexts that are not necessarily generalizable. The proposed project will review what presently is understood about learning dynamics in online communities, including hypotheses about the location of knowledge produced and the ways in which learning interacts and evolves for individuals and for groups in the evolution of online communities. Research will target (a) the cognitive and affective relation between learners and the groups or communities in which they participate and (b) the forms of joint-activity that learners engage in online, including the psychological and social characteristics of these activities.

Catalyst Approach. This Catalyst project will bring together established researchers from the US and abroad who have already begun to explore engaged learning of mathematics and science online. An interdisciplinary group of lead researchers will work with the PIs to develop the SLC research agenda and proposal through small group work online and off. The work of the PIs and lead researchers will be closely coordinated with activities of international research networks. A conference for invited researchers will refine and expand the scope of research conducted by the several focused workgroups. A journal special issue will motivate and report on the resulting research agenda to be pursued by the proposed SLC.

Intellectual Merit: The proposed Catalyst brings together a critical mass of researchers from a spectrum of approaches who have already made significant contributions to this timely area of the science of learning. The project will identify detailed and rigorous methods to study the relations between cognitive and affective components of online learning at three levels of analysis: the individual, small group, and community. Such knowledge can help design new global learning opportunities, regardless of minority status, age, disability, self confidence, initial interest, or skill levels.

Broader Impacts: The world of the 21st century will involve technologically mediated spaces, where online life-long learning will take place. Work-spaces, museums, schools, healthcare facilities, and other social institutions increasingly combine physical and virtual interactions. The work of this Catalyst and the SLC research agenda that it will define are essential to a world that increasingly involves computer-supported cooperative work and collaborative learning. The principles developed for mathematical and scientific learning can be explored and adjusted for other disciplines and new forms of formal and informal learning within online communities.

Vision

The world is increasingly mediated by advanced communication technologies and all social spaces are becoming hybrid spaces combining traditional physical space with social cyberspace. This is evident in the ways that cell phones, handheld computers, and the Internet are used. It also is clear in the ways that work-places and businesses are being reorganized around the flow of information. The most economically developed societies have made such significant social investments in communication and information technology that the sociologist Manual Castells (1996,1999) has argued for what he calls “the information society”.

Online communities appear to have a tremendous potential to reach a mass audience and to support engaged learning. Lenhart, Rainie, and Lewis (2001) reported that 73% of youth ages 12 through 17 use the Internet (surely even higher in 2005). Almost all online teens (94%) use the Internet to do research for school. The proportion of online girls that has used instant messaging (IM) exceeds that of boys -- 78% for girls and 71% for boys. Also, girls begin IM at an earlier age, with 72% of girls 12 to 14 using the service, compared to 60% of boys the same age who use IM.

New technologies have helped to form fluid linkages (e.g., between work and school) where there used to be abrupt divides. These technologies form rich socio-technical networks that have come to constitute life in this digital age, and participation in these networks is becoming commonplace. They exist in various stages, forms and venues, in non-profit Internet forums, newsgroups, and successful online professional learning communities such as the Math Forum (mathforum.org), Digital Library for Earth System Education (DLESE; dlese.org), and Hawai´i Networked Learning Communities (HNLC; hnlc.org). They also are evident in diverse and highly profitable enterprises such as multi-player video games, online courses, and consumer services (Match.com, Amazon.com, eBay). In fact, the socio-technical world cuts across socioeconomic and international lines and public access is increasing.

Although the Internet is widely used for socializing, conducting business and information retrieval, it is rarely used for the kind of knowledge-building and deep learning that is needed in a knowledge society. In fact, the online mode tends to pressure people into quickly locating facts or registering opinions without becoming engaged enough to foster more complex understanding of a topic, such as a scientific or mathematical theme. There are aspects of the online experience, such as persistence of text and computational support that suggest an untapped potential for individual, group and organizational cognition that is rare to find in the Internet today (Stahl, in press). **How can the technical potential of online engaged learning be realized in concrete social settings?**

Online learning is clearly a new context for learning that needs to be understood, because it is increasingly being used as a context for education. Online learning spaces can be highly reflexive. There are spaces in which the learner, as well as the mentor or teacher and the researcher can look at and reflect on the process of learning. These interactions and reflections can be used as tools to support other people's learning. Further, the creation of online spaces through cell phones, handheld computers, and the Internet can mean that learning interactions are occurring in cyberspace. This context raises questions about the nature of the relation between computer-supported collaborative learning environments, human learning and human development: **When deep and engaged learning occurs in online communities, what is taking place and how can it be supported and sustained?**

Online learning contexts have characteristics that allow for studies of processes in archived data such as reflection, revision, and questioning that cannot be undertaken as easily in the physical world. They also afford multiple options for engagement—including synchronous and asynchronous communication, writing, browsing, images, video, etc.—each of which has the potential to change the way in which a person represents and understands information they work with. This context also raises questions about the relation between a person's sense of him or herself as a learner online and the activities he or she takes on: **What new forms of joint activity online are responsible for different aspects of human development, and what are the psychological and social consequences of these forms of activity?**

Online learning communities and other informational technologies also allow networks to be formed quickly and easily. Often these networks can involve experts as well as novices. The communities that get formed allow for an easy kind of apprenticeship, and so readily become communities of practice (Lave & Wenger; 1991, Wenger, 1999). They have the potential to be very democratic, allowing many voices to speak, in addition to making visible the development and construction of learning to all who join the community. Understanding how collectivities get formed and under what conditions they best operate are critical issues(Klamma, Rohde & Stahl, 2004). Thus, this context also raises questions about leadership in online communities, contributors to the community, and sustainability of the community: **What are the necessary conditions for the development and sustainability of online learning communities?**

Understanding the interaction between the individual and contents of interest is critical. This interaction gates attention, goal-setting, and learning strategies (Hidi & Renninger, 2005). This interaction also enables learning interventions (Renninger, Sansone, & Smith, 2004). What is motivating to individuals and to the group? How are individual interests influenced by and also influencing the development of the group? In the learning sciences there has been a tendency to create a binary relation between individual and what might be termed situated cognition or group cognition. In online learning interactions, there is often a dialectical interplay between the individual and the community (Stahl, 2004). There appears to be valuable interaction going on in some moments online where the formal and informal meet and individual interest can be reshaped as individual-group-community interaction develops (Renninger & Shumar, 2004). This context raises questions about the learning opportunities in working with online communities, specifically the relation between the cognitive, affective, and social moments in learning and the flexibility inherent in the construction of online learning contexts: **What is the relation between learner development and the online collectivities in which learners participate?**

The online environment is new and it needs to be fully understood. It is being used widely and its potential for supporting individual learners to learn through collaboration in small groups and/or in the larger context of community that is associated with sites needs to be examined carefully. Because of its flexibility and the archiving that is possible, this environment affords study of issues central to the learning sciences that have not previously been able to be studied, as well as new dimensions of these issues that the online context introduces.

Background

This section presents an overview of research at the main centers involved in this Catalyst project: The Math Forum (e.g. Catalyzing & Nurturing Online Workgroups to Power Virtual Learning Communities –VMT, NSF REC 0325447), The Digital Library for Earth System Education (DLESE) Program (e.g REC 0215640), The Wisconsin Center for Education Research, and The Hawaii Networked Learning Communities (e.g., NSF Rural Systemic Initiative REC 0100393). Themes from prior research at the four main centers involved in this catalyst are brought into dialogue with other related research in the Learning Sciences to frame some of the issues for the development of the proposed center.

Online Contexts Redefine and Increase Learning Opportunities

As part of the NSF-supported *Virtual Math Teams* (VMT) project at the Math Forum, PI Stahl and collaborating researchers Weimar and Shumar currently investigate online collaborative problem solving in mathematics while addressing issues of software support for collaborative learning services within a digital library. Research to date has focused on the study of student collaboration via synchronous online collaboration in the context of university courses and Math Forum's Problem of the Week learning service. In addition research activities have identified key features for software support such as enhanced mathematical communication, support for organizing the results of conversations as they emerge, and mechanisms for facilitating contributions, in terms of both group attention to all contributions made and creating a participatory space for all students. Further research questions include: (a) How is *mathematics* done by online small groups of students such that we can say, for instance, that the group is displaying deep mathematical understanding versus simply manipulating things algorithmically without such understanding? (b) What methods are used systematically by small groups in *online*, *text-based* environments for taking turns, keeping interaction flowing, repairing mistakes or misunderstandings, opening and closing sessions, constituting the group as a collectivity, etc.? (c) Can online events, activities and environments be *designed* to stimulate group cognition and to lower the barriers to participation and group success? (d) How can math discourse communities be *catalyzed*, *grown* and *sustained* by networks of small groups interacting with each other?

Research at The Math Forum has also contributed to the potential of online contexts to increase access to fields such as mathematics and science that have not previously been accessible to all learners. Although preliminary, studies of online learning have begun to suggest that these contexts can lead to new senses of possibility (Markus & Nurius, 1986; Shumar & Renninger, 2002), because they enable learners to explore and to shift their identities as learners (Linehan & McCarthy, 2000). Learners through online scaffolded support are better able to see themselves as competent in a particular area of study and relinquish their incompetent identity (Renninger & Shumar, 2002. It appears that the Web and online learning could be a context for supporting the development of and/or deepening of interest, and consequently the attention, goal-setting, and learning strategies that learners bring to engagement (Hidi & Renninger, 2005). Such findings further suggest that the context of learning in online communities may make a difference for learners for whom access to subjects such as mathematics and science has been challenged previously.

Online Contexts and Theoretical Approaches to the Study of Complex Learning

Theory and research on online learning need to focus analyses, not simply on specific components such as the web environment itself, the student behaviors and interactions, or the designs of learning activities, but rather on the complex interactions among many factors that cannot sensibly be broken apart and studied individually. This will involve developing theoretical and methodological approaches that view learning environments as complex systems, a likely goal of our center. A complex systems approach has been foreshadowed throughout the years by Bransford et al.'s (Bransford, Brown, & Cocking, 2000) developing analyses of learning environments as learner-centered, assessment-centered, and knowledge-centered within larger social contexts. Activity theory (Engeström, 1999, 2001), in which the smallest unit of analysis is an entire complex activity system, has become an increasingly important theoretical lens for studies of learning with new media. Arrow, McGrath and Berdahl (2000) have also proposed a research agenda for the study of small groups as complex systems, with wide implications for the field of experimental social psychology

Online learning as a complex system is explicitly addressed in the work of Derry and colleagues (Derry, in press; Derry & Hmelo-Silver, in press) who have used the activity field construct to analyze complex interactions among student, task, facilitator and tools within online learning environments they created for teacher professional development. Their work is conducted in STELLAR (Socio-Technical Environment for Learning and Learning Activity Research), a general theory-based system they have created for designing and supporting online courses. They used STELLAR to create web-based courses in cognitive science for pre-service teachers, which were offered and studied in two university settings over several years. Online activities in these courses were explicitly designed to foster transfer of course ideas to professional practice through activities that systematically integrated text and video case study with problem-based learning. This work produced: 1. A theoretical model for online instruction on a large scale that addresses a continuing major problem: the failure of most college classrooms to teach conceptual content in ways that insure transfer to professional practice; 2. Extensive online video, text materials, instructional activities, and online tools for supporting this instructional model to teach cognitive science to future teachers; and 3. Empirical support from controlled and quasi-experimental studies for the STELLAR approach and theory, as well as hypotheses for future research on online learning.

Since 2002, students' evaluative ratings of STELLAR activities and tools have been stable and positive, and suggest students' preferences to work collaboratively rather than individually on activities (Derry, in press; Derry, Seymour, Lee, & Siegel, 2004). Derry and Hmelo-Silver (in press) developed psychometrically validated concepts-in-use rubrics to score the quality of pre-service teachers' discourse and products created in this environment. These data are important for understanding the level of specific acquisitions that are possible in the kinds of online environments that can be created with STELLAR. Stepwise regression analyses with these data suggested relations between preservice teachers' experiences on line and their actual learning outcomes, as well as their perceptions about how much they learned and their beliefs about the needs of the pupils with whom they work. These multiple layers of information are important for instruction, understanding student motivation and needed support, and conceptualizing the multi-dimensional character of learning. These types of archived data are simply unavailable except from the online environment.

In their study of online learning, STELLAR researchers employ For example, STELLAR researchers integrates findings from Cognitive Flexibility Theory (CFT) (Spiro, Collins, Thota, & Feltovich, 2003; Spiro, Feltovich, & Coulson, 1992), online professional development approaches through video case studies (e.g., Segoe, 2002), and from related cognitive theories of case-based reasoning (Kolodner & Guzdial, 2000), embodied perceptual learning (Glenberg, 1997), Schwartz and Brandsford's work on reflection as a scaffold for transfer, and self-regulated learning (Azevedo, Guthrie, & Seibert, 2004; Pintrich, 2000; Winne, 2001). Like the STELLAR project, our center will approach online learning from multiple theoretical perspectives.

Engaging learners through participation

STELLAR, Math Form and DLESE illustrate online learning environments that are committed to engaging learners through participation in authentic and personally relevant problem solving. Relevance and authenticity are strong motivators and have been found to help learners make connections between content knowledge and real world applications (Zech, Vye et al., 1998). This is a cyclic process as Verschaffel and De Corte (1997a) point out. However, learning in authentic contexts is not easy and goes against the grain of traditional instruction. Instruction organized around authentic problems may not honor the structure of the discipline being taught; problems bring concepts together in varied combinations. Thus online environments that engage students in authentic problem solving must provide well-designed facilitation and scaffolding to help students make sense of problems in terms of their previous, current, and future experiences (Salomon & Perkins, 1989). As a recent special issue of the Journal of the Learning Sciences on scaffolding shows, there are many theoretically important research issues associated with online scaffolding of authentic problem solving (Pea, 2004). These issues will be addressed in the work of our center.

Researchers and educators concerned with transfer have long used problem solving to help connect classrooms to problem contexts that are far removed from the instructional setting. However, an alternative that is often preferable to simulated problem solving is learning through engagement with the actual context of practice. Although many design issues remain to be resolved, online collaborative communities are well suited to support this kind of learning.

As an educational digital library, The Digital Library for Earth System Education (DLESE), like STELLAR and The Math Forum, places particular emphasis on supporting interactions between educators, students, and resource creators and developers, in both face-to-face and online communities (Marlino, Sumner, et al. 2001). The heterogeneous nature of the DLESE communities prompts an expansion and reconsideration of what learning may involve, moving beyond the context of the classroom, and towards a consideration of practitioners, content generators, and students considered as technologically supported communities. In particular, the expansion of technologically-supported learning contexts implies an equivalent expansion in the social and technical complexity of such contexts. In such an approach learning and knowledge can be seen not just as something passed between educators and students, but as general properties of wider social-technological networks; for instance, in a network educators may learn new practices from other educators, which they can then apply their own teaching contexts. Learning is relatively easy to track in a classroom, but how therefore is it to be conceptualized in networks of teachers, students, and resource creators – in what ways for instance does each group learn from the other groups in the network? DLESE researchers have begun an effort to answer questions such as these (Khoo 2001b, Khoo 2004, Sumner, Khoo et al., 2003).

Like Fischer (January, 2003), we argue that more online programs could encourage students at all levels to be life-long, reflective learners who employ new media to conduct research and collaborate with others to solve important problems. Emerging technologies and the new social discourses they afford enable and push us to conceptualize new systems for learning in which there are stronger linkages between learning environments and peoples' everyday lives. Increasingly, "students" of the future will learn in the process of living, working and playing in a world where people of all ages and backgrounds participate in local and global learning communities made possible by new media. How to design and scaffold online communities that support learning in real-world contexts will likely be a major part of the research agenda for our center.

Fostering Development of Collaborative Online Communities

Almost all authentic problems transcend the individual human mind and require collaboration, since knowledge is distributed across domains and individuals (Arias, Eden, Fischer, Gorman, & Scharff, 2000; Bennis & Biederman, 1997; John-Steiner, 2000). Collaboration on line takes on many forms. It can be individual work within an interactive context such as the Math Forum's Problems of the Week, in which an online mentor works with a student around his or her solution. Or, an individual can work with interactive site services, including the community of participants who populate the site, as in the case of the teacher working with the Math Forum. It can also be large or small group interactions that are formally structured and facilitated, as in the case of preservice teachers working within a STELLAR course. The Hawaii Networked Learning Communities, in turn, prioritizes deep engagement with a statewide school system to effect systemic improvement of science and mathematics education, using online collaboration technology to support the statewide community of educators engaged in this initiative. The emphasis to date has been on the pragmatics of this challenging application: gaining trust of the organizations and individuals within the over 30 schools statewide with which we work and developing the professional and leadership development model in conjunction with the software that supports it. Recently the network has reached the point where realistic evaluation can begin. Research foci for this project, including study of the expectations of new community members and what motivates their use or disuse of the online environment; the development of mentoring and collaborative relationships online and how these relationships effect change in practices within the organization; the use of an "artifact centered discussion" tool derived from previously funded NSF research, and use of a shared community database of educational resources.

Similarly, design support for collaboration takes many forms. It can be supported or hindered by a facilitator's guidance, and by design of online tasks, tools and representational support systems (Suthers et al, 2004). For example, the Virtual Math Teams project in which teams of students are organized online to work on sets of problems (e.g., problems that prepare them to take SATs, or rich non-routine projects), required thoughtful design of site services to promote productive interactions with others. A major design consideration in this instance was what feedback was required to support learners to continue working in the face of frustrating situations.

Whether or not participants are reflectively aware of the community-based aspects of their work online, the emergence of overlapping knowledge-building communities is a critical development in the Web-based universe. Helping this universe develop through scientifically-grounded design is an important part of our research agenda. If we assume that world of working and living relies on -- interdisciplinary and cross-cultural collaboration, creativity, definition and framing of problems, dealing with uncertainty and change, and distributing cognition across people and tools -- then the online learning environments we create need to prepare and support learners to be productive in such a world (Fischer & Derry, 2005).

Cognitive, Affective and Social Components of Engagement

Central to reform efforts in both mathematics and science are the goals of enabling learners (students, teachers, etc.) to make connections to and generate strategies for working with the tasks that they are presented (Ginsberg, 1998; Kuhn, 1989; Schauble & Glaser, 1990; Schoenfeld, 1992; Strauss, 1998; Tweney, 2001) and concern for the context, or conditions, that are needed to provide such support (Crowley & Schunn, 2001; RAND Mathematics Study Panel, 2003). Dewey (1914) in his now classic work, *Interest and Effort*, points to the power of interest to support students to engage, or make connections, to materials to be learned. He says that a person can not be made to have interest, but can be supported to develop interest. He also observes that where there is interest, effort follows.

In a forthcoming review of the literature, Hidi and Renninger (2005) note that interest—the predisposition to reengage particular content over time— differs from other motivational variables in at least four ways. First, interest has both affective and cognitive components, a position supported by neuroscientific research (LeDoux, 2000a, 2000b; Panksepp, 1998, 2003). Second, both the cognitive and affective components of interest have biological roots (Hidi, 2003; Davidson, 2000; Panksepp, 1998). Third, interest is an outcome of interactions between a learner and particular content. Finally, interest is always content specific rather than applying across all activity.

Interest has been found to have a significant impact on learners' *attention* (Hidi, 1990, 1995; Hidi, Renninger, & Krapp, 2004; McDaniel, Waddill, Finstad, & Bourg, 2000; Renninger & Wozniak, 1985; Schiefele, 1998), *goal setting* (Harackiewicz & Durik, 2003; Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000; Pintrich & Zusho, 2002; Sansone & Smith, 2000); and *levels of learning* (Alexander, 1997; Alexander & Murphy, 1998; Hoffmann, 2002; Koeller, Baumert, & Schnable, 2001; Krapp & Fink, 1992; Renninger, 1989, 1990; Renninger, Ewen, & Lasher, 2002; Renninger & Hidi, 2002; Sadoski, 2001; Schiefele, 1999; Schiefele & Krapp, 1996; Schraw & Dennison, 1994; Wade, Buxton, & Kelly, 1999).

Because interest exists in the interaction between learners, particular content, and the social context in which the learning occurs, interest is a variable that can be impacted by changes in support or feedback and features of learning contexts including opportunities to work with others (Renninger, Sansone, & Smith, 2004). Interest appears to develop through phases that begin with the triggering of interest and can lead to well-developed individual interest over time (Hidi & Renninger, 2005). Although not well understood, shifts in interest over time appear to be characterized by the changing relation between positive affect and opportunities to develop and/or deepen knowledge.

While students need to have positive feelings about an activity if they are to think that it is "cool" and worth trying (Resnick, Rusk, & Cooke, 1998); activities need to be both appealing and substantial if learners are to continue to work with and learn from them over time. Importantly, interest can be supported to develop and with support, it can deepen over time (Renninger, 2000). Given that the online environment is new and affords numerous and evolving opportunities for learning, it has attracted the attention and use of a wide-range of learners. The goal for these learners is that they will continue to engage over time, exerting effort to make connections to and generate strategies for working with content that may be more difficult to learn, or less accessible, in other contexts. Not only does their learning need to be promoted and sustained, but the staff members of communities of which they are a part need information about the ways in which they and their design can help. Because it gates attention, and with support can develop and/or deepen over time, the variable of interest appears particularly promising for exploring the affective, cognitive, and social components of engaged learning in online communities

Research Agenda

The online environment is new and it needs to be fully understood. It is being used widely and its potential for supporting individual learners to learn through collaboration in small groups and/or in the larger context of community that is associated with sites needs to be examined carefully. The context of the Web affords possibilities for archiving and studying aspects of learning that have not before been available and subject content (e.g., mathematics) that has not been known to exist.

The complexity of interacting factors and the differences among the individual, small group, and community dimensions of online learning have not been systematically studied in terms of participants' learning and how learning can be supported. Experiments to date have primarily been descriptive formative evaluation studies focused on particular contexts that are not generalizable. In Catalyst discussions and the proposed studies of a SLC, commonalities of findings across online contexts need to be identified, methods should draw on multiple disciplines, and systematic studies that allow comparison across forms of online learning, and include control groups need to be designed and conducted.

Thus, key considerations for the proposed Catalyst year include characterization of what presently is understood about the unique aspects of learning dynamics in online communities, including (a) hypotheses about the way in which learning interacts and evolves for individuals and for groups in the development of online communities and (b) information about what practitioners and developers need and want to understand. What is presently understood as well as the hypotheses to be developed about learning online will be framed around the center's key research questions from the vision:

- When deep and engaged learning occurs in online communities, what is taking place and how can it be supported and sustained?
- What new forms of joint activity online are responsible for different aspects of human development, and what are the psychological and social consequences of these forms of activity?
- What are the necessary conditions for the development and sustainability of online learning communities?
- What is the relation between learner development and the online collectivities in which learners participate?

It is expected that research slated for study by a SLC will target (a) the cognitive, affective and social relations between learners and the communities in which they participate (individual, small group, and/or community) and (b) the forms of joint-activity that learners engage online, including the psychological and social consequences of these forms of activity. Sampling needs to be purposeful and independent variables need to include, at minimum, gender, minority status, and age of participant.

Specific research goals to be developed during the catalyst year that will inform the center are listed below:

- Develop a framework for engaged online learning based on insights from the learning sciences and innovative use of new media
- Identify success models for engaged online learning in various STEM fields.
- Develop and study prototype online learning environments that:
    - Engage students in educational experiences that will help qualify them for and support them in successful STEM careers.
    - Scaffold students to learn through participation in technically, scientifically, socially, and artistically important inquiry and design.
    - Improve teaching and learning-environment design at all levels by fostering engaged individual and collaborative learning.
    - Provide models for broadening the sectors of the nation's population that aspire to and participate in STEM education.
- Understand what it means to be connected and what it means to collaborate for students in school, where they will be using powerful mobile devices for learning, entertainment, socializing, etc.
- Creating a center where the scientific principles underlying this new form for interaction is studied in all its forms.

The Catalyst year then will involve the bringing together of the existing data and studies on online learning communities in order to consolidate the descriptive phase of research in this area. The research teams will then frame the different learning theory perspectives and appropriate methodologies for those perspective in order to define the work in this field and create and organization structure around the further development of that work. Finally these intellectual activities will be brought into dialogue with the discussion about the organization of the Center for Engaged Learning in Online Communities in order to frame the structure of the center and make sure it maps onto the intellectual imperatives in this field. This work will ultimately contribute to the development of the center proposal.

Project Plan & Timeline

The Catalyst Project has the central goal of collaboratively developing a research agenda for extending the frontiers of knowledge on engaged learning in online communities. There are three primary deliverables:

The creation of an American network of researchers committed to defining and carrying out this research agenda. This network will coalesce into an online learning community. It will be effectively connected to research centers and networks in other parts of the world. It will have its own identity and infrastructure.

A proposal for a Science of Learning Center for the study of engaged learning in online communities. This proposal will describe an appropriate intellectual, organizational, technical and physical infrastructure to support rigorous, scientific study of this topic. The Center will bring together researchers with diverse, multidisciplinary approaches, in partnership with active online communities and schools across the country and around the world.

A special issue of the *International Journal of Computer-Supported Collaborative Learning* (*ijCSCL*) on the topic of engaged learning in online communities. This will be an important public presentation of the research agenda, reviewing the state of the art and motivating the agenda. The articles in this issue will be scholarly and peer-reviewed. Drafts of the articles will be presented at relevant international conferences: CSCL, CSCW, CRIWG, AERA, EARLI.

These deliverables will be developed through an iterative process of meetings and online collaborations involving the PIs, lead researchers, collaborating researchers and international collaborators. The process will be designed to foster partnership-building and interdisciplinary investigation of central research issues.

Following is a chart summarizing this process during the 18 month project period:

#	month	activity
0	June 2005	Preliminary informal meetings with IKIT and others at CSCL 05 in Taiwan. PI visit to NIE in Singapore.
1	July	Meeting of Catalyst PIs: define 5 workgroup focal areas.
2	Aug	Invite lead researchers to join workgroups, approx. 5 people in each of 5 online groups. PI meets with Kaleidoscope, KMRC, and other international network contacts at European Association of Research in Instruction and Learning (EARLI 05) conference in Cyprus

3	Sept	Workgroups hold meetings to outline whitepapers. Website is established. PI keynote presentation at CRIWG conference in Brazil.
4	Oct	Each workgroup drafts a whitepaper on its focal area.
5	Nov	Major meeting held to outline Center research agenda based on whitepapers.
6	Dec	Draft Center research agenda. Select additional lead researchers for Center to complete disciplinary coverage.
7	Jan. 2006	Draft preliminary Center proposal. Select PIs for Center.
8	Feb	Submit preliminary Center proposal.
9	Mar	Hold workgroup meetings to revise Center proposal.
10	April	PIs of Center meet to critique and strategize proposal. Present research agenda at AERA 06 conference.
11	May	Draft final Center proposal.
12	June	Submit final Center proposal; present research agenda at International Conference of the Learning Sciences (ICLS 06) at Indiana.
13	July	Outline journal special issue papers.
14	Aug	Draft journal special issue papers.
15	Sept	Circulate, review and critique journal special issue papers.
16	Oct	Present research agenda at CSCW 06 conference.
17	Nov	Final drafts of journal special issue papers.
18	Dec	Prepare Center start-up. Submit journal special issue papers to ijCSCL.

The planning process will take place at the individual, small group and community levels simultaneously. Although ideas and documents will be circulated widely though a wider research community, five small groups will take the lead in focusing the work and developing core working documents. The five Catalyst PIs will be individually responsible for organizing and facilitating these groups. Each workgroup will concentrate on a broad area, such as the effect of individual cognition and affect on participation, the knowledge-building function in small groups or the impact of diversity on learning in online communities.

Initially the PIs will continue the process of collecting key research questions from both participating researchers and from leading practitioners in the online communities of the partners. The first set of working groups will pull together critical findings, important unanswered questions, and perceived needs or opportunities for collaboration from other fields. These will form the basis of whitepaper drafts articulating the research agenda from each focus. The larger conference will bring together representatives from the working groups and other leaders in the field to react to the whitepapers, along with sample data to stimulate ideas for shared infrastructure for data collection and analysis. The conference will identify gaps in the research considered so far, critique priorities, and build connections across the working groups and to other relevant research, including the generation of proposals for possible studies to address the emerging issues. The PIs will draft a Center research agenda based on the conference and working group results to date. The next set of smaller working groups will be reconfigured to focus each on a core research program and the related coordinating functions of the proposed Center. The evolving PI team for the Center integrates working group output and takes a draft Center proposal back out to the field looking for theoretical and empirical studies that tie together Center foci. Strong paper concepts that emerge from the whitepaper and proposal process will be cultivated for development and submission to the journal after the proposal submission.

Web technology will be used for on-going communication within the Catalyst project. A project website will include support for email lists, threaded discussion forums, chat rooms, videoconferencing, wikis, a document repository and web pages. Each month, work on the project will be documented on the website, so that all participants can access and comment upon work product and draft deliverables. Infrastructure support for the Catalyst project will be supplied by the Math Forum and the project will be coordinated by the Math Forum Director and the PI.

The publication of a special issue of *ijCSCL* and presentations at relevant conferences will motivate researchers to think deeply about the research agenda and to review the state of the art in a thorough way. It will ensure that the work of the Catalyst grant has a meaningful outcome and furthers progress on the topic of engaged learning in online communities regardless of eventual Center funding. *ijCSCL* is an appropriate venue for this topic (see http://ijCSCL.org), and a number of Editorial Board members are involved in the Catalyst project, including the PI, who is one of the Executive Editors along with one of the Catalyst international collaborators. *ijCSCL* is an international journal and includes all the contacts for the international networks associated with this project (see below) on its Editorial Board.

The Catalyst project brings together an exciting mix of researchers (see below). The project is designed to mold this collection of people and small research centers into an integrated community — itself an online learning community. The nature of the problem being addressed by this Catalyst project requires a deeply interdisciplinary and tightly collaborative process. The PIs are all experienced in coordinating interdisciplinary efforts. They will use the large and small meetings as well as the online communications to intertwine and merge different perspectives to arrive at cross-perspective issues and views. The emergent research agenda must be more than the sum of participants' individual professional agendas — and the Catalyst project will be structured to achieve this through its community-building emphasis.

Project Personnel

Principal Investigators

The PIs are learning sciences researchers associated with four active online learning communities. They have each been involved with a variety of online learning community projects. Among them, they have studied a diversity of different kinds of efforts (see Background and individual bios).

- Gerry Stahl, Drexel University, Virtual Math Teams Project at the Math Forum @ Drexel
- Sharon J. Derry, University of Wisconsin, Wisconsin Center for Education Research
- Mary Marlino, UCAR, Digital Library for Earth System Education Program Center
- K. Ann Renninger, Swarthmore College, Math Forum @ Drexel
- Daniel D. Suthers, University of Hawaii, Hawaii Networked Learning Communities

The PI team will be supported by Stephen Weimar, Director of the Math Forum @ Drexel, who brings a deep experience with K-12 education and organizational development.

Lead Researchers

These are the researchers who will most likely be involved on the focal workgroups, drafting the whitepapers and journal articles. Most have confirmed their involvement (see letters in Appendix), although the list is still somewhat in formation. Many of these people are the pioneers of the field of online learning. Some continue to be leaders, while others are conducting rigorous research on related topics that are central to issues of engaged online community and its development. They bring diverse methodologies from a spectrum of fields. Although most may consider themselves interdisciplinary, they were trained in education, psychology, computer science, information science, anthropology, philosophy, social sciences, cognitive sciences, learning sciences.

Robert B. Allen, Drexel University
Sasha Barab, Indiana University
Amy Bruckman, Georgia Tech University
Paul Cobb, Vanderbilt University
Kevin Crowley, University of Pittsburgh
Danny Edelson, Northwestern University
Clarence (Skip) Ellis, Univ. of Colorado
Gerhard Fischer, University of Colorado
Mary Gauvain, Univ. California at Riverside
Geri Gay, Cornell University
Ricki Goldman, New Jersey Inst. of Techn.
Rogers Hall, Vanderbilt University
Judy Harackiewicz, Univ. of Wisconsin
Starr Roxanne Hiltz, New Jersey Inst. Of Technology
Cindy Hmelo-Silver, Rutgers University
Jim Kaput, Univ. Massachusetts, Dartmouth
Mick Khoo, University of Colorado
Wesley Shumar, Drexel University
Elliot Soloway, University of Michigan
Nancy Songer, University of Michigan
Rand Spiro, Michigan State University
Tamara Sumner, University of Colorado
Stephen Weimar, Math Forum @ Drexel
Margaret Wilsman, University of Wisconsin

Collaborative Researchers, American

A list of about two dozen other researchers will also be involved in this Catalyst project. They may attend the major project meeting, participate in online discussions, contribute to the whitepapers and co-author journal articles. Most of the people listed above work in research centers with associates, students and networks of colleagues. So this Catalyst will engage a critical mass of the relevant research communities.

International Collaboration

The Catalyst project on engaged learning in online communities – and its successor SLC Center – will be the US partner in an international collaboration. There are several reasons for such a collaboration:

- Online communities can easily extend across national boundaries
- Collaborative learning is enhanced by the inclusion of international perspectives
- A number of countries are more advanced than the US in the fostering of collaborative learning
- A number of leading learning scientists interested in online communities are located abroad
- The research communities of the learning sciences and computer-supported collaborative learning (CSCL) are international in character
- International collaboration will enhance the dissemination and impact of the Center's findings

The PIs have well-established international ties in the relevant international research community. A research workshop associated with the PI's VMT project at the Math Forum last summer brought together 36 researchers from 10 countries, including members of some of the networks collaborating on this project. The project will formally collaborate with the following research networks:

- The Kaleidoscope Network of Excellence in the European Union, a network of learning researchers in Europe that includes a 300-member CSCL SIG. Contact: Barbara Wasson, University of Bergen, Chair of the CSCL SIG.
- The Knowledge Management Research Center, a major social science research center conducting basic research on learning. Contact: Friedrich Hesse, University of Tübingen, Director of KMRC in Tübingen, Germany.
- CRIWG, a network of Latin American CSCL and CSCW researchers. Contact: Hugo Fuks, Catholic University of Rio de Janeiro, Brazil.
- Learning Sciences and Technologies Group in the National Institute of Education (**NIE**). Contact: Chee-Kit Looi, Nanyang Technological University, Singapore.
- Institute for Knowledge Innovation & Technology (IKIT), an international network growing out of the work on CSILE. Contact: Marlene Scardamalia, University of Toronto, Canada.

Diversity

One of the co-PIs (Suthers) conducts research on online learning in the context of his own teaching at the University of Hawai`i, a minority-serving post-secondary institution located in an EPSCoR state. He is also engaged in studying learning in the context of online communities of K-12 students and teachers within the "Hawai`i Networked Learning Communities" (HNLC) project, a partnership between the Hawai`i Department of Education and the University of Hawai`i at Manoa (NSF Rural Systemic Initiative, Cooperative Agreement #0100393). The overall goal of the HNLC is to improve science, mathematics and technology learning in the K-12 rural schools. The project focuses on professional development and leadership development for teachers and administrators in the state's rural and remote schools, most of which are located on the outer islands of the state. Of the participating schools, 14 schools are located on the island of Hawai`i, with eight schools on Kaua`i, six on Maui, three on O`ahu, three on Moloka`i and one on Lana`i. To reduce the isolation of the teachers and administrators in these remote and rural schools which are even further isolated because of the island configuration of the state, the project utilizes internet technology in the form of a "Virtual Community Center" (hnlc.org) to support collaboration between a distributed statewide community of teachers and students.

The student population is culturally diverse, and there is no single "majority" ethnic group among students. The largest populations are Filipino ranging (across three cohorts) between 27-29% and the Part-Hawaiian student group (23-25%%). These two groups combined with the Native Hawaiian students (4-6%) represent just under two-thirds of the student population and these students are underrepresented in the target courses in math and science. Furthermore, HNLC reaches an under-served population as defined by socioeconomic status. Currently, 6.2% of the students are Limited

English Proficient and 48.1% eligible for free or reduced price lunch. In addition to the issues of size and rural isolation, the September 2003 release of the state data on No Child Left Behind (NCLB) Annual Yearly Progress (AYP) status revealed that 85% of project schools did not meet AYP compared to a state-wide rate of 66%. More significantly, nine of the 20 schools or 45% are in "corrective action" or "planning for restructuring" compared to only 24.5% of state's schools. In combination with low student performance and small size, many HNLC schools are impacted by low teacher certification rates and poor economics. These findings suggest that the project's rural schools are among the most impacted in the state. As a result, the HNLC project provides a challenging testbed for the role of online communities in helping schools meet performance objectives.

Evaluation and Assessment

In preparing a Center proposal it is essential to assess the effective working relations of the collaborators and the level of productivity and quality in the results. Sara Kiesler's studies of the KDI program confirm the importance of planning and regular onsite meetings for geographically spread collaborations. Derry, Weimar, Marlino and others involved have significant experience studying effective collaborations and in organizational development and strategy. This team will conduct a survey of project participants in December and then again in October of the following year concerning levels of participation, the quality of the meetings, the quality of the work between meetings, the quality of the results and the emerging design and focus of the Center. An internal review will also be conducted to analyze project activities for the level of interaction, follow through and continuity, adherence to the timeline and plan, and the contributions of various means of collaboration to the overall effort. The team will be able to draw on participating ethnographers such as Wes Shumar and Mick Khoo who have experience studying the development of project groups. These results will form the basis for the design of collaboration functions supporting the Center.

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ITR: Catalyzing & Nurturing Online Workgroups to Power Virtual Learning Communities

Project Summary

The Math Forum website (www.mathforum.org) combines educational activities, a digital library of resources, automated and manual mentoring, discussion forums and other mathematics-related services for students, teachers and the public. As an intellectual home to about a million people, it demonstrates how the Internet can host large global learning communities. However, learning here has been primarily oriented toward individual learning. The Math Forum now aims to bring together some of its visitors with similar interests to work on common issues: students exploring a math issue together, teachers developing curriculum, or technologists and educators designing interactive math applets and support tools.

Collaborative learning in small workgroups can be particularly effective in motivating interest in math and in building and communicating deep understanding. A proliferation of small groups will heighten the sense of a vital community and increase its ability to become self-sustaining and vigorous. The groups will help people increase their community participation and their interest in mathematics.

Problem: How can one catalyze the formation of online workgroups? If there are a couple thousand users logged into the Math Forum when you log in, how can you automatically be put in touch with an optimal selection of 4 to 6 of those people whose interests and abilities best complement yours? Once formed, how can your group be nurtured with online tools, processes, structures and mentoring to maximize group success and collaborative learning? How can networks of different kinds of small groups support one another within the context of the larger community?

The Project will investigate these questions and related issues through a series of pilot studies, controlled experiments, prototypes and field studies using group-formation and group-scaffolding software that is designed, implemented and assessed in collaboration with an international, multidisciplinary group of leading HCI, CSCW and CSCL researchers. In particular, three different kinds of groups will be formed and supported: (a) groups of students who visit the site and work on a "collaborative problem of the week", (b) groups of teachers, student teachers and mentors who develop new problems, and (c) multidisciplinary groups of

international researchers and developers who design and assess technologies and interventions.

Intellectual Merit: This Project explores a primary open challenge of the Internet – with detailed and rigorous methods, under controlled and real-world global conditions: how to foster effective collaborative online learning. It joins the multidisciplinary expertise of the international CSCL community with the practical success of the Math Forum to study how to mediate the growth of a large virtual learning community, and to design, develop and assess tools for the automated support of small workgroups acquiring, managing and negotiating knowledge.

Innovation in IT: An unfulfilled promise of the Internet is to bring together people who do not know each other or live close by, but who could benefit from interacting within knowledge-rich contexts. This Project addresses core issues of computer support for collaborative learning (CSCL): how best to form and structure intimate learning workgroups within global knowledge-building communities and how to effectively scaffold their interactions.

Integration of Research & Education: The Math Forum is a major practical success of prior NSF research, forming a virtual community of about a million students, teachers and mathematicians. This Project will systematically initiate and support efforts to form small collaborations within the large body of users who now interact as individuals with the site. This fundamental research into innovative support for small group collaborative online learning will take place within a vibrant and realistic large-scale context and will impact all levels: student motivation and learning, teacher development, and community evolution – generating a new model of global virtual learning communities, incorporating the power and motivation of small-group collaboration.

Broader Impacts: The Math Forum model, with automated formation of small groups and support for interactions developing deep understanding of mathematics, will be suggestive for virtual learning communities in other domains, taking advantage of other digital libraries. This model provides opportunities for students and teachers excluded from collaborative learning due to geographic isolation, disadvantaged schools, physical disability, discrimination and other physical or social factors. The model stimulates both student motivation and teacher development, transforming interest in mathematics from a social stigma into a bridge to global friendships.

Integrating Diversity: A central Project hypothesis is that groups integrating diversity of all kinds learn better.

International Collaboration: The Project builds on the PI's prior work on an EU grant. Core aspects of the Project – including technology design, pedagogy and assessment – will be conducted by workgroups of American and European leaders of the CSCL community in collaboration with Project staff. Annual workshops at international conferences will bring these collaborators together with each other and with wider international audiences.

Project Description

1. Vision

It is January 2009 and the proposed project has just ended. Tanja is home schooled in up-state New York because of a physical disability; Sarah lives on a remote Navaho reservation; Damir attends school in Croatia. They each read the same "Problem of the Week" (POW) on the Math Forum (MF) website and became interested in it. The problem is to specify a general equation or algorithm for saying how many squares a straight line segment on graph paper will go through, given the coordinates of the line. Based on previous visits of Tanja, Sarah and Damir individually, the new MF website software determines that they have a mix of interests and skill levels that might work well in a small group solving this problem together. MF invites them and a couple more students to work together. Tanja, Sarah and Damir respond and find themselves together in MFCE, the online Math Forum Collaboration Environment. MFCE helps them to coalesce into an on-going group to work on this problem; to communicate both synchronously and asynchronously; to represent the problem and its features; to store, reflect upon and reorganize their collaborative ideas; to negotiate a group response to the problem; to document how they arrived at their response; to submit their response to MF; to receive immediate feedback; and to decide if they want to continue collaborating.

Sandra, a teacher who has used MF with her math classes for years, reads the solution submitted by Tanja, Sarah and Damir and starts to think about a related problem, which she posts to a MF discussion. A number of other teachers respond with interest, and the MF website software invites them to work together with a MF staff person to develop this idea into a publishable POW. They use MFCE to collaborate, reviewing several of the responses to the previous POW and eventually releasing a new problem that asks how many regions are formed by connecting N points on a circle to each other.

MF staff notice that a number of recent POWs involve drawing simple line figures and counting features such as vertices and regions. They request MFCE to set up a work group with several of their technical collaborators around the world who might be available and appropriate. Together, the people who respond form a group, specify user requirements, brainstorm designs, develop prototypes, conduct user testing and develop a new tool for MFCE. This tool allows student groups to collaboratively sketch representations that help them visualize and communicate about features of 2D drawings.

Back to the present. This Project will explore the potential of the Internet to bring together small groups of people like the three groups described above, who share interests and skills that might allow them to learn collaboratively and to build knowledge together. By the start of the grant period, MF is projected to be serving over a million students per month. This means that by the end of the grant period it will be common to have over a thousand math-oriented people online with MF at the same time during peak usage. This is a rich pool for forming compatible small groups at various levels of mathematical interest for collaborative learning.

It is clear from current learning theory that collaborative learning is an effective way for many people to learn, particularly people who tend to be left behind in classroom situations (Johnson & Johnson, 1989). It is also clear from experience that an approach that emphasizes discourse and inter-personal interaction helps to build deep understanding of mathematical principles – rather than simply exercising rote memorization – in keeping with contemporary pedagogical priorities (NCTM, 2000; Renninger & Shumar, 2002). What is not clear is whether software can be developed to match people who are using the Internet based on their known interests and skills, or whether these people can be formed into effective groups for collaborative learning. There has been almost no relevant research about online group formation (Haake et al., 2003; Wessner et al., 2002; Wessner & Pfister, 2001). Even in face-to-face settings, there are many open questions about how to form effective learning groups and then how to structure their collaborative tasks (Stahl, 2000b). Finally, only rather primitive software is available to support collaborative knowledge building (Stahl, 2002d). This project will explore the theoretical, technological and pedagogical issues and will systematically design, implement and assess an integrated approach to foster the building of mathematical knowledge in virtual groups.

2. Innovation & Significance

The long-heralded promise of the Internet was that people could not only access the whole world of information from any location, but also that they could meet people who shared their interests and could explore ideas together (Bush, 1945; Engelbart, 1995; Hiltz & Turoff, 1978; Rheingold, 1993). With the exponential growth and the specialization of the world's knowledge in mathematics and science, for instance, it is unlikely that someone with a particular momentary interest would happen to know many other people in their physical neighborhood with that interest at that time. Yet, there are currently few examples of technologies that fulfill this promise of the Internet and allow one to find and work with some of the many people who might share one's interest across the nation or around the world. This project proposes to develop such a technology and to demonstrate its effectiveness in the learning of school mathematics.

Information technology (IT) to date has transformed how individuals work and learn. The Internet has leveraged the productivity of desktop support by allowing individuals to communicate ideas (email, messaging, chat, newsgroups, video-conferencing) and to share information (websites, digital libraries, shared repositories). But there has been little progress toward supporting the intense interactions of spontaneous small group collaboration that builds shred knowledge. The motivation for this Project is that support for small group collaboration may yield the next major benefits of IT for working and learning. Progress in this direction may consist largely of adapting and packaging technologies that are now within reach – for the tough research and implementation issues are more social than purely technical. Careful, detailed, rigorous study is needed of particular technologies in specific social contexts. This Project will study alternative IT solution to catalyzing and nurturing several kinds of workgroups within the context of the MF virtual community.

The Math Forum (MF) is an NSF-supported organization and mathematics website that offers a variety of services, primarily to students and teachers interested in topics of mathematics commonly encountered from kindergarten through calculus courses. It currently receives over 800,000 online visitors a month. Most of these are people who are solving mathematics problems on an individual basis. MF is interested in supporting more collaborative approaches to learning – not only for student visitors working on the popular Problems of the Week (POWs), but also for teachers developing curriculum and for people associated with MF who are developing new resources such as new POWs. MF would like to harness, extend and apply IT to foster and support the formation of small groups of people to explore topics in mathematics.

Computer support for collaborative learning (CSCL) is an established research field, offering technology, theory and pedagogy. Although there are comprehensive CSCL systems to support classroom learning (e.g., WebCT, Blackboard, Lotus LearningSpace, Knowledge Forum / CSILE, WISE / KEY, Synergeia / BSCL), these systems do not include support for the formation of small workgroups based on criteria of compatibility – even within classrooms, let alone in larger, more amorphous communities. The proposed project will support the formation and subsequent collaborative learning processes of a variety of specific types of small groups drawn from the MF community.

This project will approach group formation in a systematic way, developing theory, technology and pedagogy that are integrated together. The collaborative learning theory will describe the phases of group interaction, such as: group formation, task specification, brainstorming, proposals, negotiation and publication of results. These reflections will build not only on theoretical frameworks common in the CSCL literature, but specifically on past studies of the MF virtual community (e.g., Renninger & Shumar, 2002; Renninger et al., 1989). The computer support technology will provide a comprehensive environment within which virtual groups can successfully pass though these phases. It will be developed using best practices of user-centered human-computer interaction and extensive iterations of user testing within MF. The pedagogy will describe the nature of appropriate group membership criteria, problem characteristics and process facilitation. It will involve a reorganization of the usual MF process oriented to individual learning into one oriented to collaborative group learning, as described in the following paragraph.

The MF community can be described as a pyramid, with a broad base of individual first-time visitors, followed by successive layers of: loyal readers, contributors, facilitators and finally a small staff. While MF began in 1996 as a top-down, funded effort, its goal is to create a self-sustaining community where ideas, POWs, and activities flow up from the bottom. The formation of virtual groups will be a major means for achieving this, by encouraging and supporting people to move up the pyramid from occasional visitor to co-designer of MF services. In particular, groups will be formed at three levels in this project: (a) visitors/readers who want to solve collaborative POWs (cPOWs), (b) contributors/facilitators who formulate new cPOWs and (c) facilitators/staff who maintain and extend the MF technical infrastructure. (a) New problems will be offered that are suited to collaborative learning, stressing richer, more open-ended topics designed to foster discussion of deeper mathematical understanding. (b) These new cPOWs will be designed by groups formed of contributors, who will have access to an extensive digital library of past MF problems, math-related applets and studies of responses to previous problems. (c) Groups of facilitators, programmers and MF staff will form to maintain MF's mathDL and related services, including the production of new mathlets (programmable applets for computers and handhelds), in response to the needs of groups (a) and (b).

The project is designed to be highly iterative, so that the different aspects of the project can evolve in response to each other. The project starts on the basis of considerable experience with POWs solved by individuals – generally working within supportive communities of classrooms or MF mentoring, but without collaborative learning groups. The first year focuses on micro-analysis of this experience, incorporating previous studies of the MF virtual community, but clarifying the theoretical and pedagogical issues as well as the specific user requirements for the technology. In the second year, technological supports are gradually introduced to support group formation and knowledge building. An initial set of cPOWs that have been meanwhile adapted from old problems is used. In the third and fourth years, groups at all three levels are active; well-defined experiments and formative evaluations drive revision of the technologies and practices. In the final year, the project will observe the stable functioning of self-forming groups at all three levels and will evaluate the success of people finding compatible group partners and learning mathematics collaboratively. Logging of group interactions as well as MF hits will allow for careful quantitative and qualitative evaluation of the theory, technology and pedagogy.

3. Theory

Collaborative learning, as understood in this proposal, involves a focus on the group level of analysis. Of course, construction of knowledge by a group can also be seen as co-construction by the individuals in the group, and the building of knowledge by the group has direct implications for learning by the participants. However, it is also true that the group can produce knowledge that none of its members would have produced by themselves and it is true that, for instance, the meaning of things said in group discourse is defined by the group interaction itself rather than simply by ideas in the minds of individuals (Stahl, 2003c). Although this project will also be concerned with the learning of individual participants, its focus will be on the building of knowledge by small groups. This emphasis is consonant with theories from cognitive science, communication theory, anthropology, education and CSCL, such as situated action (Suchman, 1987), activity theory (Engeström, 1999), situated learning (Lave & Wenger, 1991), distributed cognition (Hutchins, 1996), etc.

Traditional learning theory assumes that learning happens entirely in the mind of the individual, it can be led or facilitated by a teacher, the content is to some extent irrelevant (in that one can learn anything) and that this is a primarily cognitive act. But advances in learning theory have led to very different assumptions about the learning process. First is the realization that learning is a constant and ongoing process. People are always learning whether it is part of some specific curriculum or not. As Dewey pointed out the purpose of teaching and education is not just to help students learn but to create opportunities for experiences that lead to productive forms of learning (Dewey, 1938/1991). That means connecting new experiences with a persons prior experience base and creating opportunities for educative new experiences. In other words, creating a social context where new experiences can lead to the moral, emotional and intellectual development of the person. From Dewey to Vygotsky (Vygotsky, 1930/1978) one strand of learning theory has focused on the individual in social context and how that context creates opportunities for learning. While there have been tremendous advancements here in our understanding of learning, it is still often thought of as primarily something that happens to the individual (even if in a social context) and something that is primarily cognitive.

Very recent work on situated learning (Lave, 1991; Lave, 1996; Lave & Wenger, 1991) activity theory (Engeström et al., 1999) and cultural theories of learning (Cole, 1996; Holland et al., 2000) have moved thinking about learning from the individual to the intersubjective experience and from the cognitive to the whole person including affective dimensions of learning. This work has led to several important implications for understanding learning. First and perhaps most importantly, learning is a social process that involves individual interest, membership in a community where others are learning and engaged in productive social practice and that knowledge is built intersubjectively and shared among members of the community. Finally the constraints on learning and knowledge production are constraints that exist within the social system, its form of organization and patterns of interaction and not within the individual. These important theoretical realizations about learning then have tremendous implication for collaborative learning and CSCL.

The emphasis on the group unit has methodological implications. The analysis of what takes place in project experiments will rely heavily upon interaction analysis (Duranti, 1998; Garfinkel, 1967; Heritage, 1984; Jordan & Henderson, 1995; Sacks, 1992) (Stahl, 2002e) and community ethnography (Renninger & Shumar, 2002). These analyses will study in quantitative and qualitative terms how small groups function to mediate the building of a larger knowledge-building community and how groups engage in sequences of different kinds of interactions to build their knowledge. Tentative theories about how this knowledge-building process takes place will be subjected to empirical study, feeding back into revised formulations of a theory of collaborative knowledge building.

While we know a great deal more about the social nature of the learning process, many of our educational institutions continue to be structured in ways that assume learning is individual and a matter of transferring information from teacher to student. That sad fact means that many of the things students learn most effectively in school are patterns of resistance and lessons from the marketplace that appeal more to a social and collaborative form of learning. While some schools have begun to implement collaborative forms of learning there are real limitations due to the political context of local schools and the difficulty of organizing resources and groups that cluster together concentrations of expertise and appeal to individual's interests. The Internet and digital libraries such as the Math Forum create an important strategic opportunity to bring a more collaborative community of practice to individuals who may be distributed geographically in different school and institutional sites. Therefore a critical next step in theoretical development is to figure out how to make online groups self-forming and self-replicating.

4. Pedagogy

The building of deepened understanding and increased knowledge of mathematics takes place in motivational community contexts, such as classrooms and research fields (Lave, 1991; Lave, 1996). Interactions within small groups can mediate effectively between individuals and these larger communities, providing supportive settings and engaging activities (Wenger, 1998). Small groups can build knowledge (collaborative learning) that draws upon and may extend the community knowledge while making it available to the individual participants who contribute to the group knowledge. According to theories of situated learning (Lave & Wenger, 1991), changing patterns of participation in which individuals become progressively more involved are important features of community learning; we have already seen signs of this taking place in the Math Forum virtual community in the documented example of Sonia and her son (Renninger & Shumar, 2002, p. 66 ff). This project will investigate the effects of online collaborative math learning by extending the services of the Math Forum and its growing community. It will explore the effect this has in drawing average or poorly motivated students into intellectual engagement, as well as involving students and teachers already excited about math in a larger community.

Mathematics is often thought of as the discipline of “the right answer.” A small group of teachers and Math Forum (MF) staff became uncomfortable with this designation because it can interfere with efforts to help students express their mathematical thinking, learn from mistakes, experiment effectively, and pursue their mathematical interests. They asked, how can we transform the student's question “Am I right?” into “How can I develop confidence and judgment that I am on the right track when working on a problem?” and “How can I know that I am improving my mathematical problem-solving and communication skills?” They decided that engaging students in discourse about mathematics was the way to go.

Discourse can make thinking public and create an opportunity for the negotiation of meaning and agreement (Bauersfeld, 1995). At the same time, discourse provides collective support for developing one's thinking, drawing it out through the interest, questions, probing, and ideas of others (Cobb, 1995; Krummheuer, 1995; Wood, 1995; Yackel, 1995), and discourse enables students to connect their own everyday language with the specialized language of mathematics (Vygotsky, 1934/1986). Articulating what they know allows students to clarify their own understandings. Through discourse, a teacher can better grasp the mathematical needs of the class: what the students know, misconceptions they may have, and how these might have developed (Resnick, 1988). Teachers and students gain perspective on their own thoughts through the attempt to understand the thinking of others, in the process laying the foundation for a supportive learning community (Brown & Campione, 1994).

Within the mathematics education community there is strong interest in the use of discourse for teaching and learning mathematics (Atkins, 1999; NCTM, 2000; Schifter, 1996). The teacher's role is described in broad terms as facilitative, to include listening carefully to students, framing appropriate questions, and mediating competing perspectives. Students are expected to develop problem-solving skills: defining problems, formulating conjectures, and discussing the validity of solutions. Stigler and Hiebert (1998) report similar roles for teachers and students in mathematics classrooms in Japan, where mathematical discourse is an integral part of instruction.

The best way to foster domain-oriented discourse is to catalyze active small workgroups. In heterogeneous small groups, students are challenged to stretch and learn within their “zone of proximal development” “in collaboration with more capable peers” (Vygotsky, 1930/1978, p. 86). At the same time, the mentoring experience is productive for the “more capable” peer’s learning by teaching – and these roles are likely to reverse in other situations when the group members have complementary strengths.

5. Technology

Consider the Internet. It is a huge computational machine. It processes information reflective of the interests of millions of people. It is not simply a poorly organized repository of textual facts; it is the infrastructure of a global community. No one can navigate around it easily to find the particular things of interest to them and no one can relate to the world’s population in a human way. Yet, for most people, there must be gems of information hidden out there and potential friends or colleagues who could help them to make sense of those gems. The taming of the Internet’s informational and human vastness poses the technical challenge of our time. While much research is conducted on searching and organizing the information, surprisingly little has been done on bringing together groups of people on a human scale to use the Internet collaboratively.

Some organizations have explored systems for locating expertise within their staffs (Ackerman & McDonald, 1996); but the techniques for that do not transfer to the problem of finding people on the Internet with matching interests. There have been some experiments with social awareness, to display other people who are viewing the same web page at the same time (Graether & Prinz, 2001), but this hint is not enough to support group formation. A group formation project in Japan matched learning theories (Inaba et al., 2000; Supnithi et al., 1999), but not people. A prototype for group formation in Germany allowed students who knew each other to self-select groups (Wessner et al., 2002; Wessner & Pfister, 2001), but this approach does not scale to large groups who do not know each other personally. A spin-off of the German research is being expanded and developed for distance education, and the proposed Project will collaborate with that one (see section on International Collaboration).

The PI began exploring support for group formation while teaching an online HCI (Human-Computer Interaction) course for graduate students at Drexel. His students studied the issue and came up with several low-fidelity prototypes that they subjected to user testing. The PI developed an automated grouping agent, which he used to form work groups in a subsequent course. In both the student prototypes and the grouping agent, groups were formed based on specific criteria about the participants: their schedules, their interests and their skill levels. These pilot studies for the proposed project suggest the kinds of balance that should be sought in forming distributed groups. For instance, if synchronous communication is to be possible within the group – especially given different global time zones – members must have similar schedules. On the other hand, collaborative teams often work best when there is a diversity of perspectives and skills, along with a commonality of interests. Thus, a matching algorithm must optimize certain similarities and other differences. Diverse theories of collaboration stress the power of heterogeneity: cognitive dissonance (Festinger, 1957), perspectives (Boland & Tenkasi, 1995; Goldnam-Segall, 1998; Stahl & Herrmann, 1999), interdependence (Johnson & Johnson, 1989), zone of proximal development (Vygotsky, 1930/1978), cognitive flexibility (Feltovich et al., 1996). This Project will systematically explore the hypothesis that balanced heterogeneous small groups collaborate more effectively and will develop algorithms and prototypes to implement support for this.

The pilot study of group formation was conducted with a class using two different online collaboration environments: Blackboard and BSCL. Blackboard is a commercial system to support collaboration. It is used widely in university courses, particularly in the US. Blackboard can be extended (in Java) by third party developers using the Blackboard Building Blocks SDK (see http://buildingblocks.blackboard.com/bin/bbdn_info.pl).

BSCL (Basic System for Collaborative Learning) is a system with collaboration support for classrooms that is similar to Blackboard (Stahl, 2002d). It was designed and developed by the PI and others in 2001/2002 as part of a European Union research project. BSCL is an extension (developed in Python) to BSCW (Appelt & Klöckner, 1999), a shared repository CSCW system widely used in European research and learning organizations. It is available for free to academic organizations. The PI has a license to develop it during the period of this Project (see Letter of Support in Supplementary Documentation).

The Math Forum has custom software (developed in a Perl-based environment) to support the virtual community and digital library of math resources and activities.

This Project will design, develop and evaluate software extensions to Blackboard, BSCL and Math Forum. This software will implement alternative approaches to group formation, discussion, shared representations, social awareness and knowledge management within the context of catalyzing and nurturing small groups within the Math Forum community.

6. Project Team

Information Science & Technology

Drexel University has a long history of technology leadership, dating back to the 1980's when it was the first university to require entering undergraduates to have a PC.

Drexel University's College of Information Science and Technology is rated the #1 graduate school of library science information systems by US *News and World Report* (http://www.usnews.com/usnews/edu/grad/rankings/lib/brief/infsp3_brief.php). This interdisciplinary College offers online and campus-based undergraduate and graduate programs in computer science (e.g., HCI, databases, software engineering) and library science (including digital libraries).

The PI is an Associate Professor in the College of Information Science and Technology. He brings a multidisciplinary background to the Project, with PhD dissertations in philosophy/social theory and computer science/AI (Stahl, 1975; 1993a). He has developed a series of collaboration support systems: Hermes (Stahl, 1993b), WebNet (Stahl, 2000a), WebGuide (Stahl, 1999a; 1999b; 2001; Stahl & Herrmann, 1999), BSCL (Stahl, 2002d; 2003b), and other educational software: Teachers Curriculum Assistant (Stahl et al., 1995a; Stahl et al., 1995b) and State-the-Essence (Kintsch et al., 2000; Stahl & dePaula, 2001).

The PI specializes in CSCL research, having published on CSCL theory (Stahl, 1993b; 1998; 2000c; 2002c; 2003a; 2003c) and the use of discourse analysis as an assessment methodology (Stahl, 2002a; 2002e; 2002f; Stahl & Sanusi, 2001). He was Program Chair of CSCL 2002 and Editor of the CSCL 2002 Proceedings

(Stahl, 2002b). He is Workshop Chair of CSCL 2003 and Communications Chair and founding Board member of the International Society for the Learning Sciences (ISLS) (http://www.isls.org).

The Math Forum

The Math Forum was founded in 1992 as the Geometry Forum at Swarthmore College, expanded to The Math Forum in 1996, and funded in its development by the National Science Foundation. It has become one of the most successful applications of the Internet to education through the development of interactive services that bridge the higher education, K12, and industry communities. These services form the basis for a knowledge building environment that generates high quality mathematical content, supports student learning, integrates the benefits of technology with education, and is used for teacher professional development and pre-service teacher education. The Math Forum now comprises over 1.2 million pages of content, has over 2 million visits a month, receives up to 9,000 queries a month at its Ask Dr. Math expert service, and mentored over 27,000 students during the 2000-2001 school year through its Problem of the Week services. Among its current projects are two NSF grants, one focused on the use of online student mentoring programs in pre-service teacher education courses, and the other on the development of MathTools, a digital library for software in mathematics education, arithmetic-calculus.

Education & Ethnography

Drexel University also has a School of Education and a Department of Culture & Communication, both of which are represented in this Project. Prof. Wesley Shumar is a cultural anthropologist in the Department of Culture & Communication who specializes in educational anthropology and has conducted ethnographic studies of the Math Forum for many years.

National and International Collaborators

A unique feature of this Project is the involvement of leading national and international researchers. They bring expertise from a variety of relevant specialties and perspectives. Their participation will provide a natural means for sharing practical knowledge from Europe and the US as well as for disseminating the results of this Project across the nation and globe. To ensure a strong cadre of collaborators, the following researchers have already expressed strong interest in participating in the Project; others can join in the future:

Americans: Geri Gay (Cornell), Ricki Goldman-Segall (NJIT), Cindy Hmelo-Silver (Rutgers), Christopher Hoadley (Penn State), Timothy Koschmann

(Southern Illinois U), Bonnie Nardi (Agilent), Leysia Palen (Colorado), Linda Puliam (California State U.), Mark Schlager (SRI).

International: Wolfgang Appelt (Fraunhofer-FIT, Germany), Hugo Fuks (Rio, Brazil), Joerg Haake (Distance U, Germany), Kai Hakkarainen (Helsinki, Finland), Thomas Herrmann (Dortmund, Germany), Jim Hewitt (Toronto, Canada), Victor Kaptelinin (Umea, Sweden), Anders Morch (Oslo, Norway), Wolfgang Prinz (Aachen, Germany), Volker Wulf (Siegen, Germany).

These individuals are established leaders in the HCI, CSCW and CSCL research communities, having made important contributions in theory, system design and assessment methodology. They all recognize the importance of collaboration, both in theory and in practice.

7. Prior Work

The Math Forum

REC-9618223, $971,300, March 1999 to February 29, 2000

The Math Forum is arguably the most widely used math education site on the Internet (search for "math" on Google.) It began in January of 1996 as a proof-of-concept grant from the NSF to extend the work of the Geometry Forum into other areas of mathematics and to investigate the viability of a virtual center for mathematics education on the Internet. The Math Forum has developed a vast Web site of over 925,035 learning resources and it receives over 650,000 visitors a month, with mentored user services such as Ask Dr. Math, for students of all ages, Problems of the Week services for grades 3-12, and Teacher2Teacher for discussions of pedagogy.

The Math Forum's home page allows browsing and searching the Internet Mathematics Library of over 8600 annotated entries of hand-selected resources. The cataloguing features are based on American Mathematical Society categories, and are enhanced by recommendations of the American Mathematics Metadata Task Force.

The Math Forum provides many ways for people to interact with one another, with different points of access for people of varied strengths, needs, and interests. Community building is an important part of Forum activities and has formed the basis of much of the content development on the site. The Math Forum represents a vision about the possibilities for an Internet community that extends the collegiality found in schools, classrooms, or the workplace. Evaluation of the

Forum is used in program design, development, and facilitation, and provides an assessment of impact.

JOMA Applet Project

DLI-2 Award Number 9980185

Its goals were to 1) search the Web an other resources to locate and collect applets and similar programs developed by the mathematics research and teaching communities, 2) review and test these systematically, and 3) to make them easily accessible to undergraduate faculty and students. JOMA, *the Journal of Online Mathematics and its Applications,* is published by the Mathematical Association of America. This project was the basis for MathDL an undergraduate-level digital library, NSDL Award Number 0085861, a joint project between the MAA and the Math Forum, which is developing the technical infrastructure.

These projects have given us considerable experience constructing libraries and supporting technologies, such as metadata for the NSF digital library initiative. In addition, numerous Forum staff members have contributed to NSDL activities, meetings and working groups. The Math Forum was a founding member of the SMETE Open Federation, the largest identifiable user base for the National STEM Education Digital Library.

ESCOT (Educational Software Components of Tomorrow)

REC Award Number 9804930

This was a testbed for the integration of innovative technology in middle school mathematics. The Math Forum, working with SRI and other partners, developed team-based approaches that produced math tools for integration into the Problems of the Week.

The Math Forum Online Mentoring Project

DUE Award Number 0127516

This is developing a guide to enable professors to integrate online mentoring experiences into their mathematics and mathematics education courses. Pre-service teachers in these courses mentor students submitting their solutions to the Math Forum's Problems of the Week. The results of this project will be used to train mentors for the Technology Problem of the Week (tPOWs), part of a new NSDL funded digital library of mathematics software.

Organizational Memory and Organizational Learning (CSS)

"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 was instrumental in the PI's turn from earlier work on organizational memory to support for collaborative learning. 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 (Fischer, 1994). 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 (Stahl, 1998; 2000a). Gradually, interest in organizational learning aspects led to involvement in CSCL and the model of collaborative knowledge-building environments (Fischer et al., 1999). A number of software prototypes were developed to explore the use of the Web as a communication and collaboration medium. Of these, the most important for the proposed work was WebGuide a prototype threaded discussion system that provided multiple perspectives on the discussion, comparison of perspectives and control over rearrangement of notes (Stahl & dePaula, 1998; Stahl et al., 1998). Deployment of WebGuide in classrooms raised serious issues of adoption and concerns of socio-technical and social informatics (Kling, 1999) issues: motivation, media competition, critical mass, social practices, seeding, management, re-seeding, convergence of ideas, peer-to-peer collaboration, deployment strategies.

WebGuide and Environmental Perspectives (NOAA)

"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 supporting personal and group perspectives. It was a joint effort between the PI, a middle school teacher, and a research group at the 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 conferences (Stahl, 1999a; 1999b; 1999c; Stahl & Herrmann, 1999).

Innovative Technology for Collaborative Learning (European Commission)

"Innovative Technology for Collaborative Learning," Fraunhofer-FIT and researchers in Finland, Spain, Netherlands, Italy and Greece. May 2001 – May 2003. European Commission Project IST-2000-26249.

This grant supported software design and development of BSCL by researchers in Finland, Germany and Spain. The software was implemented as extensions of BSCW, a mature CSCW product used by 200,000 unique users since 1996 (Appelt, 1999). The PI went to work with the BSCW team at Fraunhofer-FIT near Bonn, Germany, for the first year of the project. He prototyped the BSCL innovations and published descriptions of them (Stahl, 2002d; Stahl, 2003b). During its second year, the project is assessing the use of the new software in schools in Finland, Netherlands, Italy and Greece.

8. International Collaborations

The proposed NSF Project builds on the work of the European ITCOLE Project and its BSCL software. The PI was the primary designer and prototyper of the BSCL software when he worked at Fraunhofer-FIT in Germany. The Project with the Math Forum will involve close collaboration with the BSCW/BSCL team at FIT and has their full support. FIT will continue to support the BSCL code, making it available for free to educational institutions throughout the world. They will also provide training to Project staff who will be modifying the BSCL code. FIT has granted a five year developers license to the PI to work on extending BSCL as part of this Project. Both Wolfgang Appelt, the BSCW/BSCL team manager and Wolfgang Prinz, the director of the CSCW department at FIT personally support the proposed Project and its collaboration with FIT (see Supplementary Documentation).

The idea of automated support for group formation for workgroups in online learning is a research topic at the Distance University of Germany (Fern-Uni, Hagen). Joerg Haake, who has begun research on this topic (Haake et al., 2003; Wessner et al., 2002) will be a close collaborator with this Project.

In general, a number of leading international HCI, CSCW and CSCL researchers have already agreed to collaborate on this Project, participating in the workgroups that will conduct much of the project planning, experimental designing, software design and assessment. Others will be added as needed. The names, affiliations and research interests of these international collaborators are listed in the attached Biographical Sketches section.

9. Project Assumptions, Hypotheses & Methods

The global design of the Project is diagrammed in Figure 1. The core question is how best to balance group formation and how best to support the collaborative learning of the formed groups. The global hypothesis is that carefully balanced groups and properly supported or coached groups will learn better and produce higher quality results. This hypothesis is tested by comparing groups in which differences among the members have been balanced in accordance with various algorithms with randomly assigned or self-selected groups. Then, an assortment of software tools and structures will be used to support the collaboration processes of the groups. The results of groups with these supports will be compared with the results of groups without these special supports. Thus, the Project will not only demonstrate that groups in the upper right quadrant learn better (assuming the global hypothesis is confirmed), but it will also be able to distinguish the effects of the structure of the catalyzed groups from the effects of their nurturing.

To test the global hypothesis, a number of assumptions and secondary hypotheses are made:

Assumption 1: Collaborative learning is good. While we will investigate the processes of collaborative learning and discover much about its power, its difficulties and its limitations, this Project will not focus on comparing it with individual learning.

Assumption 2: Small groups are useful for building communities. The Project looks at virtual communities like the Math Forum as being built out of the interactions of individual members as they participate in small groups; it will observe the forms of leadership, changing roles, group continuities and community structures that emerge and evolve as groups are catalyzed or as they spontaneously form.

Assumption 3: It is useful and sufficient to focus on the group as the unit of analysis. While it is necessary to analyze the contributions of individuals to a group's learning, it is possible to interpret the meaning of group discourse without making assumptions about or investigating the psychological states or personal interpretations of the individual members. The Project will only use instruments like individual interviews and post-tests in focused and limited ways.

Assumption 4: The success of collaborative learning at the group level can be measured by quantitative evaluation of the group products (such as solutions to math problems and the rationale for the solution). In addition, the Project will take a qualitative look at group process, but this will not provide the primary judgment of a group's success.

Assumption 5: The intertwining of differing perspectives is productive of group learning.

Hypothesis 1: Catalyzing carefully balanced heterogeneous groups will create groups that learn better than randomly assigned groups.

Assumption 6: Collaboration is a complex process and people must learn how to interact productively.

Hypothesis 2: Providing tools that help groups to structure their interactions, that support specific phases of their collaborations and that coach their group process will create groups that learn better than they would have without those tools.

Method 1: The Project will assess the effect of balanced formation and support for collaboration primarily by quantitative evaluation of the group's produced solutions to problems (see Figure 2).

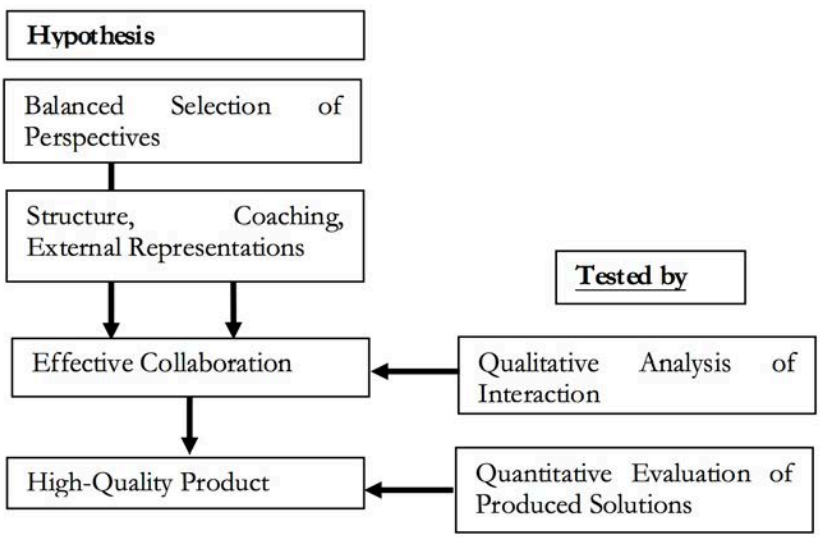

Figure 2

Method 2: Secondarily, the Project will analyze the group interaction to assess the quality of the collaborative process.

10. Plan of Work

The five year Project period is planned to be January 1, 2004 – December 31, 2008. Roughly, work during these years will be focused as follows: Year I (2004) pilot studies; Year II (2005) controlled experiments; Year III (2006) prototype evaluations; Year IV (2007) field studies; Year V (2008) assessment and dissemination.

This Project is based on a belief in the power of collaborative knowledge building. Therefore, the Project will be a highly collaborative effort – and the success of that effort will itself be an object of study in the Project. Accordingly, the work will be conducted through the organization of three sets of workgroups: student workgroups, curricular workgroups and infrastructure workgroups. Project staff will be responsible for organizing these workgroups and coordinating the activities and results of the Project.

Project Staff

Project staff is based at Drexel University and works out of the Math Forum offices. Their primary activities will be related to supporting the catalyzing and nurturing of the student, curricular and infrastructure workgroups. Staff will be responsible for ensuring that these groups get started and function effectively to carry out their roles in the Project. It is acknowledged that most of the workgroup members are volunteers with significant limits on their time and that staff will have to support them to allow them to focus their effort effectively on making their most important contributions. Staff will work closely with these groups (often as members of the curricular and infrastructure workgroups) and will carry out the daily activities needed to implement the plans of these groups, such as drafting detailed proposals for the groups to review, transcribing videotapes, prototyping / implementing / releasing newly designed software, conducting statistical analyses of data, collecting / documenting / preserving Project data and materials. They will make all Project data and materials available online to the infrastructure workgroups and will ensure that these are preserved for future purposes. They will ensure that all logs and transcripts are distributed and preserved in a manner that protects privacy of students and guarantees anonymity. Project staff will be responsible for the successful functioning of the Project and for the production of required reports and other documentation.

Student Workgroups

Student workgroups are primarily organized online, although some Year I activities will take place face-to-face in local school classrooms. Student workgroups will increasingly be supported by online tools created as part of the project. They will be one of the sets of workgroups studied in the Project.

Year I: Pilot studies will explore collaborative learning using Math Forum problems in local middle- or high-school contexts, in face-to-face situations or with commercial mediation systems like instant messaging. Groups of 3 to 6 students will be selected by hand, with teacher input. Principles of group selection and group process from the research literature and from project hypotheses will be tested in this context. F2F interactions will be videotaped, digitized and transcribed. Transcripts and computer logs will be logged and reviewed to identify key interactions, which will be subjected to detailed discourse analysis and complementary forms of micro-ethnographic analysis. This is a highly explorative, qualitative phase of the project to build a focused experience base of small student groups working on Problems of the Week.

Year II: Controlled experiments of groups working on Math Forum problems will compare groups with different selection criteria: self-selection, teacher selection, homogeneous matching, heterogeneous balancing, knowledge complementing, random. These experiments will generate quantitative data related to evaluation of the group's problem solution. Experiments will also be conducted to explore different kinds of math problems: longer time periods, more open-ended, more discussion-oriented.

Year III: Prototype evaluations will start to introduce tools for group selection and group scaffolding designed as part of the Project and based on the results of the previous two years' results. Experiments this year will focus on alternative forms of scaffolding, including automated group process guidance, human mentoring, tools to support specific group processes (brainstorming, discourse, knowledge management, math representations, negotiation, textual references).

Year IV: Field studies will be done by enhancing the Math Forum environment with tools based on previous results. This will permit students from the broader Math Forum virtual community to be invited into workgroups. The interaction of selection criteria and forms of scaffolding will be studied (e.g., whether certain tools are more helpful for certain types of groups).

Year V: Experiments in the final year are reserved for unanticipated follow-up studies whose need is indicated by preliminary assessment of the Project results. This is a time to scale-up use of the group formation and scaffolding tools to become a normal part of the Math Forum. Observations will be made of the impact of collaborative student workgroups on the growth and dynamics of the virtual community and on the community's impact on public interest in mathematics.

Curricular Workgroups

Curricular workgroups are primarily organized online, although some activities will take place face-to-face at the Math Forum or at special workshops held annually for mentors, teachers and student teachers in the curricular workgroups. Curricular workgroups will increasingly be supported by online tools created as part of the project. They will be one of the sets of workgroups studied in the Project.

Year I: Pilot studies will explore collaborative design of new Math Forum problems, in face-to-face situations or with commercial mediation systems like instant messaging. Problems will be designed for use by collaborative workgroups of students. Groups of 3 to 6 participants will be selected by hand, from the pool of teachers, student teachers and mentors who assist in defining new math problems. Principles of group selection and group process from the research literature and from project hypotheses will be tested in this context. F2F interactions will be videotaped, digitized and transcribed. Transcripts and computer logs will be logged and reviewed to identify key interactions, which will be subjected to detailed discourse analysis and complementary forms of micro-ethnographic analysis. This is a highly explorative, qualitative phase of the project to build a focused experience base of small adult groups devising Problems of the Week.

Year II: Controlled experiments of groups designing Math Forum problems will compare groups with different selection criteria: self-selection, staff selection, homogeneous matching, heterogeneous balancing, knowledge complementing, random. These experiments will generate quantitative data related to evaluation of the group's problem generating ability. In addition to designing new problems suitable for collaborative student workgroups, the curricular workgroups will design ways of incorporating such collaborative problem-solving in school classrooms, possibly mixing workgroups across schools or even across countries (taking into account issues of language and time zones, for instance).

Year III: Prototype evaluations will start to introduce tools for group selection and group scaffolding designed as part of the Project and based on the results of the previous two years' results. Experiments this year will focus on alternative forms of scaffolding, including automated group process guidance, human mentoring, tools to support specific group processes (brainstorming, discourse, knowledge management, math representations, negotiation, textual references). The tools for adults searching the problem database and designing new problems may be different from the tools for students solving problems.

Year IV: Field studies will be done by enhancing the Math Forum environment with tools based on previous results. This will permit teachers and mentors from the broader Math Forum virtual community to be invited into these workgroups as they demonstrate interest and background for this work. The interaction of selection criteria and forms of scaffolding will be studied (e.g., whether certain tools are more helpful for certain types of groups).

Year V: Experiments in the final year are reserved for unanticipated follow-up studies whose need is indicated by preliminary assessment of the Project results. This is a time to scale-up use of the group formation and scaffolding tools to become a normal part of the Math Forum. Observations will be made of the impact of curricular mentor workgroups on the growth and dynamics of the virtual community, such as how it enables adults to move into more central forms of community participation.

Infrastructure Workgroups

Infrastructure workgroups consist of Project staff and collaborators from the international CSCL community. They are primarily organized online, although some activities will take place face-to-face at annual workshops associated with CSCL conferences. Infrastructure workgroups will increasingly be supported by online tools created as part of the project. They will be one of the sets of workgroups studied in the Project. The infrastructure workgroups will help to clarify applicable theory, point to existing relevant literature, define appropriate pedagogy, develop experimental methodology, specify technology requirements, evaluate software designs and provide on-going formative assessment of Project progress.

Year I: Four infrastructure workgroups will be formed, each including European researchers, American researchers and Project staff. Each group will have a multidisciplinary mix of skills: technical, psychological and pedagogical. They will design and monitor the pilot studies of the student and curricular workgroups and will participate in the analysis of the results.

Year II: The infrastructure workgroups will design and monitor the controlled experiments of the student and curricular workgroups and will participate in the analysis of the results.

Year III: The infrastructure workgroups will design and monitor the prototype evaluations of the student and curricular workgroups and will participate in the analysis of the results. They will also start to use some of the new tools for their own collaborations.

Year IV: The infrastructure workgroups will design and monitor the Field studies of the student and curricular workgroups and will participate in the analysis of the results, including studying the interaction of selection criteria and forms of scaffolding.

Year V: In Year V, the infrastructure workgroup members will disseminate the results of this Project at conferences, other projects and publications, both in the US and abroad. They will analyze the effect of active workgroups on the growth and dynamics of the larger virtual community, such as how it results in community knowledge and in changing patterns of participation.

11. Anticipated Results & Impact

Intellectual Merit: This Project explores a primary open challenge of the Internet – with detailed and rigorous methods, under controlled and real-world global conditions: how to foster effective collaborative online learning. It joins the multidisciplinary expertise of the international CSCL community with the practical success of the Math Forum to study how to mediate the growth of a large virtual learning community, and to design, develop and assess tools for the automated support of small workgroups acquiring, managing and negotiating knowledge.

Innovation in IT: An unfulfilled promise of the Internet is to bring together people who do not know each other or live close by, but who could benefit from interacting within knowledge-rich contexts. This Project addresses core issues of computer support for collaborative learning (CSCL): how best to form and structure intimate learning workgroups within global knowledge-building communities and how to effectively scaffold their interactions.

Integration of Research & Education: The Math Forum is a major practical success of prior NSF research, forming a virtual community of about a million students, teachers and mathematicians. This Project will greatly expand on-going efforts to form small collaborations within the large body of users who now interact with the site and learn mathematics primarily as individuals. This fundamental research into innovative support for small group collaborative online learning will take place within a vibrant and realistic large-scale context and will impact all levels: student motivation and learning, teacher development, and community evolution – generating a new model of global virtual learning communities, incorporating the power and motivation of small-group collaboration.

Broader Impacts: The Math Forum model, with automated formation of small groups and support for interactions developing deep understanding of mathematics will be suggestive for virtual learning communities in other domains, taking advantage of other digital libraries. This model provides opportunities for students and teachers excluded from vital collaborative learning due to geographic isolation, disadvantaged schools, physical disability, discrimination and other physical or social factors. The model stimulates both student motivation and teacher development. It fosters interest in mathematics by transforming it from a stigma into a bridge to global friendships.

Integrating Diversity: A central Project hypothesis is that groups integrating diversity of all kinds learn better.

International Collaboration: The Project builds on the PI's prior work on an EU grant, including its pedagogy, software and assessment. Core aspects of the Project – including technology design, pedagogy and assessment – will be conducted by workgroups of American and European leaders of the CSCL community in collaboration with Project staff. Annual workshops at international conferences will bring these collaborators together with each other and with wider international audiences.

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NSDL: Collaboration Services for the Math Forum Digital Library

Project Summary

Statement of need. NSDL is intended to serve learners in both collaborative and individual settings, as well as formal and informal modes. If one carefully studies learning in school, workplace and home, one finds that most learning is a subtle mix of collaborative and individual effort. Unfortunately, to date digital library services focus almost exclusively on the needs of individual users. Support for "collaboration" has been largely limited to mechanisms for anonymous, asynchronous collaboration within the whole user community, where results obtained by individuals may be fed back into metadata for future use by all. Little support has been developed for direct collaborative use of digital libraries by small groups of people working together.

Project approach. The adaptation of groupware components from current CSCW and CSCL systems makes it feasible to develop collaborative learning environments as digital library services, significantly increasing the potential impact, efficiency and value of digital libraries. This Project provides a model and test case of such an approach – within the successful Math Forum Digital Library (MFDL).

Target audience. The MFDL offers a variety of theoretical, practical, pedagogical, interactive and fun resources and services related to K-12 mathematics. It already supports a user community of close to a million distinct users. A popular service is the Problem of the Week (PoW), which is solved in and out of schools, by individuals and small groups. The MFDL now aims to extend the appeal and mathematical depth of these PoWs by bringing students together in small, online groups for asynchronous and synchronous collaborative learning at a distance.

The *Project goals* for advancing collaborative services in the NSDL are the following:

To better understand the computer support needs of small groups collaborating in a digital library.

- To design a collaborative learning environment within a digital library.
- To evaluate the use of a collaborative learning environment within a digital library.

- To incorporate a collaborative learning environment within a digital library as a sustainable service.

The *Project objectives* are to achieve these goals using the MFDL as a model and test case:

- To study the computer support needs of small groups of students (user teams) collaborating on PoWs in the MFDL.
- To develop special PoWs and associated curricular resources for collaborative usage, with the help of teachers and student teachers (creator teams). These teams will mine the MFDL and provide new resources to it as well as rate, annotate and organize existing resources.
- To design a Math Forum Collaborative Learning Environment (the MFCLE) within the MFDL, with the help of international CSCL (computer support for collaborative learning) researchers and developers (design teams).
- To prototype, evaluate and iterate the design of the MFCLE, in accordance with HCI best practices.
- To implement a stable version of the MFCLE, providing collaborative work areas and tools to communicate and collaborate with team members and other MFDL community members.
- To evaluate the use of the MFCLE by user teams, creator teams and design teams.
- To incorporate the MFCLE as a sustainable service of the MFDL.
- To disseminate the MFCLE as a reproducible model of a digital library service that promotes collaborative learning.

The *Project team* consists of four co-PIs, creator teams (student teachers, teachers and MFDL staff) and design teams (national and international CSCL researchers and MFDL staff). PI Stahl has developed numerous collaborative learning environments, has published on CSCW and CSCL theory, methodology and evaluation, and teaches HCI. Co-PI Weimar has been Director of the MFDL since its founding in 1994. Co-PI Bach is professor of educational technology. Co-PI Shumar is an educational ethnographer and long-time evaluator of the MFDL.

Intellectual merit. This Project creatively combines leading-edge collaboration technologies with one of the most popular services of a successful digital library to provide a model of support services for collaborative digital library usage. The Project brings together four co-PIs with the required mix of expertise, along with teams of engaged educators and international researchers.

Broader impact. The Project develops collaboration services for digital libraries, providing a sustainable model. It promotes the involvement of geographically isolated, disadvantaged and disabled students, distributed teachers and international researchers by inviting them into collaborative learning teams hosted, supported and informed by a digital library. It pioneers a path for enhancing NSDL impact and building virtual learning communities.

Project Description

1. Statement of Need

1.1. The Need for Collaboration Support

NSDL is intended to serve learners in both collaborative and individual settings, as well as formal and informal modes. If one carefully studies learning in school, workplace and home, one finds that most learning is a subtle mix of collaborative and individual effort (Fischer & Granoo, 1995; Stahl, 2002d). Unfortunately, to date digital library services focus almost exclusively on the needs of individual users. Support for "collaboration" has been largely limited to mechanisms for anonymous, asynchronous collaboration within the whole user community, where results obtained by individuals may be fed back into metadata for future use by all. Little support has been developed explicitly for direct collaborative use of digital libraries by small groups of people working and learning together. This Project proposes to develop collaboration support technology for small groups pursuing a shared goal as a digital library service, and to demonstrate its effectiveness in the learning of school mathematics.

How will these small groups of people with a shared interest and/or complementary skills come together? The long-heralded promise of the Internet was that people could not only access the whole world of information from any location, but also that they could meet people who shared their interests or could help them and that they could then explore ideas together (Bush, 1945; Engelbart, 1995; Hiltz & Turoff, 1978; Rheingold, 1993). With the exponential growth and the specialization of the world's knowledge in mathematics and science, for instance, it is unlikely that someone with a particular momentary interest would happen to know many other people in their physical neighborhood with that interest at that time. Yet, there are currently few examples of technologies that fulfill the promise of the Internet and allow one to find and work with some of the many people who might share one's interest across the nation or around the world.

Of course, we see with Internet newsgroups, for instance, that people already do struggle to engage in collaborative problem-solving even with the primitive nature of available tools and the haphazard character of opportunities for group formation. This Project hypothesizes that systematic support for the building of small groups will foster more effective collaborative learning, and that providing appropriate tools for their group interactions will further increase their effectiveness in taking advantage of digital libraries. It should also result in longer-term, more in-depth collaborative learning.

1.2. Target Audience: The Math Forum Digital Library Community

The Math Forum Digital Library (MFDL) – begun with NSF support – is an extensive mathematics website supported by a professionally staffed organization. It offers a variety of services, primarily to students and teachers interested in topics of mathematics commonly encountered from kindergarten through calculus courses. The digital library includes over a million web pages with FAQs, math challenges, discussions, interactive applets, articles and technical sources. It currently receives over 800,000 distinct online visitors a month. Most of these are people who are solving mathematics problems on an individual basis, whether from school, work or home.

A popular service of the MFDL is its "Problem of the Week" (PoW), which is solved in and out of schools, by individuals and small groups in classrooms. PoWs offer motivating opportunities for inquiry-driven learning that is active and engaging. The MFDL now aims to extend the appeal and mathematical depth of these PoWs by bringing students together in small, online groups (called "user teams" in this Project) for asynchronous and synchronous collaborative learning at a distance. MFDL is also interested in supporting collaborative approaches for teachers developing new PoW curriculum ("creator teams") and for people associated with MFDL who are developing new collaboration services ("design teams"). In general, MFDL would like to harness, extend and apply collaboration technologies to foster and support small groups of people within the MFDL virtual community.

Computer support for collaborative learning (CSCL) is an established research field, offering technology, theory and pedagogy that can be adapted, extended and applied in digital libraries (Stahl, 2002f). Although there are comprehensive CSCL systems to support classroom learning (e.g., WebCT, Blackboard, Lotus LearningSpace, Knowledge Forum / CSILE (Scardamalia & Bereiter, 1996), WISE / KEY (Slotta & Linn, 2000), Synergeia / BSCL (Stahl, 2002e)), these systems do not include support for the formation of small workgroups based on criteria of similarity of interest and complementarity of skills – even within classrooms, let alone in larger, more amorphous communities. The proposed

Project will develop ways to support the formation and subsequent collaborative learning processes of a variety of specific types of small groups drawn from the MFDL community by taking advantage of what is known in CSCL.

This Project will approach group formation in a systematic way, developing theory, technology and pedagogy that are integrated together. The collaborative learning theory will describe the phases of group interaction, such as: group formation, task specification, brainstorming, proposals, negotiation and publication of results (Stahl, 2000c). The Project will build not only upon insights from the CSCL literature, but specifically on past studies of the MFDL virtual community (Renninger, Weimar, & Klotz, 1989; Renninger & Shumar, 2002a). The computer support technology will provide a comprehensive environment within which virtual groups can successfully pass though these phases (Stahl, 2002e). It will be developed using best practices of user-centered human-computer interaction (HCI) and iterations of user testing within MFDL (Preece, Rogers, & Sharp, 2002). The pedagogy will describe the nature of appropriate group membership criteria, problem characteristics and process facilitation. It will involve a reorganization of the usual MFDL process oriented to individual learning into one oriented to collaborative group learning, as described in this proposal.

The MFDL community can be described as a pyramid, with a broad base of individual first-time visitors, followed by successive layers of: loyal readers, contributors, facilitators and finally a small staff. While MFDL began in 1996 as a top-down, funded effort, its goal is to create a self-sustaining community where ideas, PoWs, and activities flow up from the bottom. The formation of virtual groups will be a major means for achieving this, by encouraging and supporting people to move up the pyramid from occasional visitor to co-designer of MFDL services. In particular, groups will be formed at three levels in this Project:

1. User teams: visitors/readers who want to solve collaborative PoWs. They will work on problems that are particularly suited to collaborative inquiry, stressing richer, more open-ended topics designed to foster discussion of deep mathematical understanding.

2. Creator teams: contributors/facilitators who formulate the new collaborative PoWs. These groups of contributors will have access to the extensive digital library of past MFDL problems, math-related applets and studies of responses to previous PoWs. Collaborative approaches at this level of the pyramid are particularly appropriate for developing curriculum to be shared among teachers of a given grade, lifelong learners with a common special interest or mentors who want to answer questions collaboratively that are too time-consuming for individual mentors to answer.

3. Design teams: facilitators/staff who maintain and extend the MFDL technical infrastructure. Groups of researchers, programmers and MFDL staff will form to extend the MFDL through the production of new mathlets (programmable applets for computers and handhelds) and collaboration tools in response to the needs of the user and creator teams.

The Project is designed to be iterative, so that the different aspects of the Project can evolve in response to each other. The Project starts on the basis of considerable experience with PoWs solved by individuals – generally working within supportive communities of classrooms or MFDL mentoring, but without collaborative learning groups. The early Project phases focus on micro-analysis of this experience, incorporating previous studies of the MFDL virtual community, but clarifying the theoretical and pedagogical issues as well as the specific user requirements for technology. Then technological supports are gradually introduced to support group formation and collaborative knowledge building. An initial set of collaborative PoWs that have been meanwhile adapted from old PoWs is used. Later in the Project, groups at all three levels are active; well-defined user testing and formative evaluations drive revision of the technologies and practices. In the final phases, the Project will observe the stable functioning of self-forming groups at all three levels and will evaluate the success of people finding compatible group partners and learning mathematics collaboratively. Logging of group interactions as well as MFDL hits will allow for careful quantitative and qualitative evaluation of the theory, technology and pedagogy.

1.3. Vision Scenario

User Team

It is January 2006 and the Project has just ended. Tanja is home schooled in upstate New York because of a physical disability; Sarah lives on a remote Navajo reservation; Damir attends school in Croatia. They each read the same collaborative PoW in the MFDL and became interested in it. The problem is to specify a general formula or algorithm for saying how many squares a straight line segment on graph paper will go through, given the end coordinates of the line. Based on previous visits of Tanja, Sarah and Damir individually, the MFDL website software determines that they have a mix of interests and skill levels that might work well in a small group solving this problem together. MFDL invites them and a couple more students to work together. Tanja, Sarah and Damir respond and find themselves together in MFCLE (the MFDL's online collaborative learning environment). This shared virtual work environment helps them to coalesce into a group to work on this problem; to communicate both synchronously and asynchronously; to represent the problem and its features; to store, reflect upon and reorganize their collaborative ideas; to negotiate a group response to the problem; to document how they arrived at their solution; to submit their solution to MFDL; to receive feedback; and to decide if they want to continue collaborating.

Creator Team

Sandra, a teacher who has used MFDL with her math classes for years, reads the solution submitted by Tanja, Sarah and Damir and starts to think about a related problem, which she posts to a MFDL discussion. A number of other teachers respond with interest, and the MFCLE invites them to work together with a MFDL staff person to develop this idea into a publishable PoW. They also use MFCLE to collaborate, reviewing several of the responses to the previous PoW and eventually releasing a new problem to the MFDL that asks how many regions are formed by connecting N points on a circle to each other.

Design Team

MFDL staff notice that a number of recent PoWs involve drawing simple line figures and counting features such as vertices and regions. They request MFCLE to set up a work group with several of their technical collaborators around the world who might be appropriate and available. Together, the people who respond form a group, specify user requirements, brainstorm designs, develop prototypes, conduct user testing and develop a new tool for the MFCLE. This tool allows student groups to collaboratively sketch representations that help them visualize and communicate about features of 2D drawings.

Back to the present.

This Project will explore the potential of digital libraries to bring together small groups of people like the three groups described above, who share interests and skills that might allow them to learn collaboratively and to build knowledge together. By the start of the grant period, MFDL is projected to be serving about a million students per month. This means that by the end of the grant period it will be common to have a thousand math-oriented people accessing MFDL at the same time during peak usage. This is a rich pool for forming matched small groups at various levels of mathematical interest for collaborative learning.

1.4. Impact

It is clear from current learning theory that collaborative learning is an effective way for many people to learn, particularly people who tend to be left behind in classroom situations (Johnson & Johnson, 1989). It is also clear from MFDL experience that an approach that emphasizes discourse and inter-personal interaction helps to build deep understanding of mathematical principles – rather than simply exercising rote memorization – in keeping with contemporary pedagogical priorities (NCTM, 2000; Renninger & Shumar, 2002b). What is not clear is how software should be designed to match people who are using digital libraries based on their known interests and skills, or whether these people can be formed into effective groups for collaborative learning. There has been almost no relevant research about online group formation (rare exceptions include: Haake et al., 2003; Wessner et al., 2002; Wessner & Pfister, 2001). Even in face-to-face settings, there are many open questions about how to form effective learning groups and then how to structure their collaborative tasks (Stahl, 2000b). Finally, although a variety of software is available to support collaborative knowledge building (Stahl, 2002d), it has not been incorporated into digital libraries. This Project will review the theoretical, technological and pedagogical issues and will systematically design, implement and assess an integrated approach to foster the collaborative building of mathematical knowledge in a digital library.

The availability of groupware components from current CSCW and CSCL systems that can be adapted to specific needs makes it feasible to develop collaborative learning environments as digital library services, significantly increasing the potential impact, efficiency and value of digital libraries. Collaborative small groups of different kinds can help to grow and structure a digital library, while building an active, engaged virtual community around the library. This Project provides a model and test case of such an approach – within the popular MFDL.

2. Project Goals

2.1. Goals

The *Project goals* for advancing collaborative services in the NSDL are the following:

1. To better understand the computer support needs of small groups collaborating in a digital library.
2. To design a collaborative learning environment within a digital library.
3. To evaluate the use of a collaborative learning environment within a digital library.
4. To incorporate a collaborative learning environment within a digital library as a sustainable service.

2.2. Objectives

The *Project objectives* are to achieve these goals using the MFDL as a model and test case. Specifically, the popular PoW service will be extended to collaborative

PoWs for collaborative solution within a virtual learning environment, by achieving the following Project objectives:

1. To study the computer support needs of small groups of students (user teams) collaborating on PoWs in the MFDL.
2. To develop special PoWs and associated curricular resources for collaborative usage, with the help of teachers and student teachers (creator teams). These teams will mine the MFDL and provide new resources to it as well as rate, annotate and organize existing resources.
3. To design a Math Forum Collaborative Learning Environment (the MFCLE) within the MFDL, with the help of international CSCL (computer support for collaborative learning) researchers and developers (design teams).
4. To prototype, evaluate and iterate the design of the MFCLE, in accordance with HCI best practices.
5. To implement a stable version of the MFCLE, providing collaborative work areas and tools to communicate and collaborate with team members and other MFDL community members.
6. To evaluate the use of the MFCLE by user teams, creator teams and design teams.
7. To incorporate the MFCLE as a sustainable service of the MFDL.
8. To disseminate the MFCLE as a reproducible model of a digital library service that promotes collaborative learning.

3. Project Design

3.1 Theoretical Framework

Collaborative learning, as understood in this proposal, involves a focus on the group level of analysis. Of course, construction of knowledge by a group can also be seen as co-construction by the individuals in the group, and conversely, the building of knowledge by the group has direct implications for learning by the participants. However, it is also true that the group can produce knowledge that none of its members would have produced by themselves (Fischer & Granoo, 1995; Hatano & Inagaki, 1991). For instance, the meaning of things said in group discourse is often defined by the group interaction itself rather than simply by ideas in the minds of individuals (Mead, 1934/1962; Stahl, 2003c; Wittgenstein, 1953). Although this Project will also be concerned with the learning by individual participants, its focus will be on supporting the building of knowledge by small groups. This emphasis is consonant with recent theories from cognitive science, communication theory, anthropology, education and CSCL, such as situated action (Suchman, 1987), activity theory (Engeström, 1999), situated learning (Lave & Wenger, 1991) and distributed cognition (Hutchins, 1996).

Traditional learning theory assumes that learning happens entirely in the mind of the individual, that it can be led or facilitated by a teacher, that the content is to some extent irrelevant to the process (in that one can learn anything this way), and that this is a primarily cognitive act. But advances in learning theory have led to very different assumptions about the learning process. First is the realization that learning is a gradual and long-term process; people are always learning whether it is part of some specific curriculum or not. As Dewey pointed out, the purpose of teaching and education is not just to help students learn specific facts, but to create opportunities for experiences that lead to productive forms of learning through student exploration (Dewey, 1938/1991). That means connecting new experiences with a person's prior experience base and creating opportunities for educative new experiences. In other words, creating a social context where new experiences can lead to the moral, emotional and intellectual development of the person. Starting from Dewey or Vygotsky (Vygotsky, 1930/1978), one strand of learning theory has focused on the individual in social context and how that context creates opportunities for learning. While there have been tremendous advancements here in our understanding of learning, learning is still often thought of by many followers of this strand as primarily something that happens to the individual (even if in a social context), and something that is primarily cognitive. Others have developed a more socially-oriented perspective.

Recent work on situated learning (Lave, 1991; Lave & Wenger, 1991; Lave, 1996) activity theory (Engeström, 1999) and cultural theories of learning (Cole, 1996; Holland, Hutchins, & Kirsh, 2000) have moved thinking about learning from the individual to the intersubjective experience, and from the cognitive to the whole person, including tacit and affective dimensions of learning. This work has led to several important implications for understanding learning: First, and perhaps most importantly, learning is a social process that involves individual interest, membership in a community where others are learning and engaged in productive social practice. Second, that knowledge is built intersubjectively and shared among members of the community. Finally the constraints on learning and knowledge production are constraints that exist within the social system, its form of organization and patterns of interaction, rather than predominantly within the individual. These important theoretical realizations about learning have tremendous consequences for collaborative learning and CSCL.

The emphasis on the group unit has methodological implications. The analysis of what takes place in Project investigations of MFDL and MFCLE usage will rely heavily upon interaction analysis (Duranti, 1998; Garfinkel, 1967; Heritage, 1984; Jordan & Henderson, 1995; Sacks, 1992; Stahl, 2002a) and community ethnography (Renninger & Shumar, 2002). These analyses will study in quantitative and qualitative terms how small groups function to mediate the establishment of a larger knowledge-building community, and how groups engage in sequences of different kinds of interactions to build their knowledge. Tentative theories about how this knowledge-building process takes place will be subjected to empirical study, feeding back into revised formulations of a theory of collaborative knowledge building (Stahl, 2000c, 2002b, 2003b).

While we know a great deal about the social nature of the learning process, many of our educational and digital library institutions continue to be structured in ways that implicitly assume learning is individual and a matter of transferring information from teacher to student. That sad fact means that many of the things students actually learn most effectively in school are patterns of resistance from peers and commercial lessons from the marketplace that appeal more to their social and collaborative form of learning (Shumar, 1997). While some schools have begun to implement collaborative forms of learning, there are real limitations due to the political context of local schools and the difficulty of organizing resources and groups that cluster together concentrations of expertise and appeal to individual interests. Digital libraries such as the MFDL create an important strategic opportunity to bring a more collaborative, learning-oriented community of practice to individuals who may be distributed geographically in different school and institutional sites. Therefore, a critical next step is to figure out how to make online groups self-forming, successful and self-replicating.

3.2. Pedagogical Framework

Mathematics is often thought of as the discipline of “the right answer.” In 1998-2001, a small group of teachers and MFDL staff became uncomfortable with this designation because it can interfere with efforts to help students express their mathematical thinking, learn from mistakes, experiment effectively, and pursue their mathematical interests. They asked, how can we transform the student's question “Am I right?” into “How can I develop confidence and judgment that I am on the right track when working on a problem?” and “How can I know that I am improving my mathematical problem-solving and communication skills?” They decided that engaging students in discourse about mathematics was the way to go.

Discourse can make thinking public and create an opportunity for the negotiation of meaning and agreement (Bauersfeld, 1995). At the same time, discourse within a supportive and trusted small group provides collective support for developing one's thinking, drawing it out through the interest, questions, probing, and ideas of others (Cobb, 1995; Krummheuer, 1995; Wood, 1995; Yackel, 1995), and discourse enables students to connect their own everyday language with the specialized language of mathematics (Vygotsky, 1934/1986). Articulating what they know allows students to clarify their own understandings. Through discourse, a teacher can better grasp the mathematical needs of the class: what the students know, misconceptions they may have, and how these might have developed (Resnick, 1988). Teachers and students gain perspective on their own thoughts through the attempt to understand the thinking of others, in the process laying the foundation for a supportive learning community (Brown & Campione, 1994).

Within the mathematics education community there is strong interest in the use of discourse for teaching and learning mathematics (Atkins, 1999; NCTM, 2000; Schifter, 1996). The teacher's role is described in broad terms as facilitative, to include listening carefully to students, framing appropriate questions, and mediating competing perspectives. Students are expected to develop problem-solving skills: defining problems, formulating conjectures, and discussing the validity of solutions. Stigler and Hiebert report similar roles for teachers and students in mathematics classrooms in Japan, where mathematical discourse is an integral part of instruction (Stigler & Hiebert, 1998).

An effective way to foster domain-oriented discourse is to catalyze active small workgroups. In heterogeneous small groups, students are challenged to stretch and learn within their “zone of proximal development” “in collaboration with more capable peers” (Vygotsky, 1930/1978). At the same time, the mentoring experience is productive for the “more capable” peer’s learning by teaching – and these roles are likely to reverse in other situations when the group members have complementary strengths.

The building of deepened understanding and increased knowledge of mathematics takes place in motivational community contexts, such as classrooms and research fields (Lave, 1991; Lave, 1996). Interactions within small groups can mediate effectively between individuals and these larger communities, providing supportive settings and engaging activities (Wenger, 1998). Small groups can build knowledge (collaborative learning) that draws upon and may extend the community knowledge while making it available to the individual participants who contribute to the group knowledge. According to theories of situated learning (Lave & Wenger, 1991), changing patterns of participation in which individuals become progressively more involved are important features of community learning. We have already seen signs of this taking place in the MFDL virtual community in the documented example of Sonia and her son (Renninger & Shumar, 2002, p. 66 ff). The MFDL already exploits and supports collaborative mechanisms in the community, for instance by archiving PoW user solutions in a structured and indexed format designed to optimize accessibility and pedagogic impact. This Project will investigate the effects of online collaborative math learning by extending the services of the MFDL and its growing community. It will explore the effect this has in drawing average or poorly motivated students into intellectual engagement, as well as involving students and teachers already excited about math in a larger community.

3.3. Project Team

The Project team consists of four co-PIs (in various schools of Drexel University), creator teams (student teachers, teachers and MFDL staff) and design teams (national and international researchers and MFDL staff).

College of Information Science & Technology

Drexel University has a long history of technology leadership as a former Institute of Technology, including being the first university to require entering undergraduates to have a PC and more recently being judged the "most wired" university according to Yahoo.

Drexel University's College of Information Science and Technology is rated the #1 graduate school of library science information systems by US *News and World Report* (http://www.usnews.com/usnews/edu/grad/rankings/lib/brief/infsp3_brief.php). This interdisciplinary college offers online and campus-based undergraduate and graduate programs in computer science (e.g., HCI, databases, software engineering) and library science (including digital libraries).

PI Gerry Stahl is an Associate Professor in Drexel University's College of Information Science and Technology. He brings a multidisciplinary background to the Project, with PhD dissertations in philosophy/social theory and computer science/AI (Stahl, 1975, 1993b). He has developed a series of collaboration support systems: Hermes (Stahl, 1993a), WebNet (Stahl, 2000a), WebGuide (Stahl, 1999a, 1999b; Stahl & Herrmann, 1999; Stahl, 2001), BSCL (Stahl, 2002e, 2003a), and other educational software: Teachers Curriculum Assistant (Stahl, Sumner, & Owen, 1995; Stahl, Sumner, & Repenning, 1995) and State-the-Essence (Kintsch *et al.*, 2000; Stahl & dePaula, 2001).

Stahl specializes in CSCL research, having published on CSCL theory (Stahl, 1993a, 1998, 2000b, 2002b, 2003b, 2003c) and the use of discourse analysis as an assessment methodology (Stahl & Sanusi, 2001; Stahl, 2002a, 2002c, 2002d). He was Program Chair of CSCL 2002 and Editor of the CSCL 2002 Proceedings (Stahl, 2002f). He is Workshop Chair of CSCL 2003 and Communications Chair and founding Board member of the International Society for the Learning Sciences (ISLS) (http://isls.org). He teacher online and in-class courses on HCI, CSCL and CSCW at Drexel, using small group collaborative learning methods.

The Math Forum Digital Library

Co-PI Steven Weimar has directed the MFDL since 1994. The MFDL is hosted at Drexel University. The MFDL began in 1992 as the Geometry Forum at Swarthmore College, expanded to the MFDL in 1996. It was funded in its development by the National Science Foundation, but has become largely self-sustaining in its stable services. It has become one of the most successful applications of the Internet to education through the development of interactive services that bridge the higher education, K-12, and industry communities. These services form the basis for a digital library that generates high quality mathematical content, supports student learning, integrates the benefits of technology with education, and is used for teacher professional development and pre-service teacher education. The MFDL now comprises over 1.2 million pages of content, has over 2 million visits a month, receives up to 9,000 queries a month at its "Ask Dr. Math" expert service, and mentored over 27,000 students during the 2000-2001 school year through its "Problem of the Week" services. Among its current projects are two NSF grants, one focused on the use of online student mentoring programs in pre-service teacher education courses, and the other on the development of MathTools, a digital library for software in mathematics education from arithmetic to calculus.

Education & Ethnography

Drexel University has a School of Education and a Department of Culture & Communication, both of which are represented in this Project. Co-PI Craig Bach is a professor in the School of Education, where he explores the use of technology in education, having developed several hypermedia presentations of topics in mathematics and philosophy. Co-PI Wesley Shumar is a cultural anthropology professor in the Department of Culture & Communication, who specializes in educational anthropology and has conducted ethnographic studies of the MFDL for many years.

3.4. Prior Work

The Math Forum

REC-9618223, $971,300, March 1999 to February 29, 2000

The MFDL is arguably the most widely used math education site on the Internet (search for "math" on Google). It began in January of 1996 as a proof-of-concept grant from the NSF to extend the work of the Geometry Forum into other areas of mathematics and to investigate the viability of a virtual center for mathematics education on the Internet. The MFDL has developed a vast Web site (http://mathforum.org) of over a million learning resources and it received more than 650,000 distinct visitors a month (making 2 million visits) in 2001, with mentored user services such as Ask Dr. Math, for students of all ages, PoW services for grades 3-12, and Teacher2Teacher for discussions of pedagogy.

The MFDL home page allows browsing and searching the Internet Mathematics Library of over 8,600 annotated entries of hand-selected resources. The cataloguing features are based on American Mathematical Society categories, and are enhanced by recommendations of the American Mathematics Metadata Task Force (http://mathmetadata.org/).

The MFDL provides many ways for people to interact with one another, with different points of access for people of varied strengths, needs, and interests. Community building is an important part of MFDL activities and has formed the basis of much of the content development on the site. The MFDL represents a vision about the possibilities for an Internet community that extends the collegiality found in schools, classrooms, or the workplace. Evaluation of the MFDL is used in program design, development, and facilitation, and provides an assessment of impact.

Publications: Virtual communities (Renninger & Shumar, 2002a, 2002b; Shumar & Renninger, 2002); Problems of the Week (Renninger & Shumar, 1998; Renninger, Farra, & Feldman-Riordan, 2000); geometry interactions (Renninger *et al.*, 1989).

JOMA Applet Project

DLI-2 Award Number 9980185

The goals of this Project were to (1) search the Web and other resources to locate and collect applets and similar programs developed by the mathematics research and teaching communities, (2) review and test these systematically, and (3) make them easily accessible to undergraduate faculty and students. JOMA, *the Journal of Online Mathematics and its Applications,* is published by the Mathematical Association of America. This Project was the basis for MathDL.

Bridging Research and Practice

REC Award Number 9805289

BRAP was a joint program with TERC and Michigan State University investigating the possibilities for multimedia articles to open more effective communication between researchers and teachers. The MFDL developed a collaborative process through which teachers designed and conducted research into the use of discourse in the math classroom. A video-paper was produced jointly with researchers that served as the focal point for an online conversation with the mathematics education community at large. See http://mathforum.org/brap/wrap.

MathDL

NSDL Award Number 0085861

MathDL is an undergraduate-level digital library, a joint Project between the MAA and the Math Forum, which is developing the technical infrastructure. The MathDL and previous projects have given the Math Forum considerable experience constructing libraries and supporting technologies, such as metadata for the NSF digital library initiative. In addition, numerous Forum staff members have contributed to NSDL activities, meetings and working groups. The Math Forum was a founding member of the SMETE Open Federation, the largest identifiable user base for the National STEM Education Digital Library.

ESCOT (Educational Software Components of Tomorrow)

REC Award Number 9804930

The ESCOT Project was a testbed for the integration of innovative technology in middle school mathematics. The Math Forum, working with SRI and other partners, developed team-based approaches that produced math tools for integration into the Problems of the Week.

The Math Forum Digital Library Online Mentoring Project

DUE Award Number 0127516

The Online Mentoring Project is developing a guide to enable professors to integrate online mentoring experiences into their mathematics and mathematics education courses. Pre-service teachers in these courses mentor students submitting their solutions to the MFDL's Problems of the Week. The results of this Project will be used to train mentors for "Technology PoWs," part of a new NSDL funded digital library of mathematics software.

Organizational Memory and Organizational Learning (CSS)

"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 was instrumental in the PI's turn from earlier work on organizational memory to support for collaborative learning. The project started from a model of computer support for organizations as domain-oriented design environments in which both domain knowledge and local knowledge are stored in the form of artifact designs and associated design rationale (Fischer *et al.*, 1993). This CSCW model evolved into one of Collaborative Information Environments, that emphasized the interactive, asynchronous, persistent discussion of concepts and issues within an organization (Stahl, 2000a). Gradually, interest in organizational learning aspects led to involvement in CSCL and a model of collaborative knowledge-building environments (Stahl, 2001). A number of software prototypes were developed to explore the use of the Web as a communication and collaboration medium. Of these, the most important for the proposed work was WebGuide, a prototype threaded discussion system that provided multiple perspectives on the discussion, comparison of perspectives and control over rearrangement of notes. Deployment of WebGuide in classrooms raised serious issues of adoption and concerns of socio-technical and social informatics (Kling, 1999) issues: motivation, media competition, critical mass, social practices, seeding, management, re-seeding, convergence of ideas, peer-to-peer collaboration, deployment strategies.

WebGuide and Environmental Perspectives (NOAA)

"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 supporting personal and group perspectives. It was a joint effort between the PI, a middle school teacher, and a research group at the 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 conferences (Stahl, 1999a, 1999b, 1999c; Stahl & Herrmann, 1999).

Innovative Technology for Collaborative Learning (European Commission)

"Innovative Technology for Collaborative Learning," Fraunhofer-FIT and researchers in Finland, Spain, Netherlands, Italy and Greece. May 2001 – May 2003. European Commission Project IST-2000-26249

This grant supported software design and development of BSCL by researchers in Finland, Germany and Spain. The software was implemented as extensions of BSCW, a mature CSCW product used by 200,000 unique users since 1996 (Appelt, 1999). The PI went to work with the BSCW team at Fraunhofer-FIT near Bonn, Germany, for the first year of the Project. He prototyped the BSCL innovations and published descriptions of them (Stahl, 2002e, 2003a). During its second year, the Project is assessing the use of the new software in schools in Finland, Netherlands, Italy and Greece.

Our current related work and related proposals

MFDL staff periodically try out mechanisms to support small group collaboration on a small scale. They have provided chat services or encouraged face-to-face groups in classrooms to submit team responses to PoWs. These trials generally produce immediate interest from the community, indicating that systematic support for small groups could have dramatic results in stimulating participation in the MFDL and the associated community.

The PI is exploring small group formation approaches and innovative software functionality to support small group collaboration in online courses using digital libraries. Each of his HCI courses engages in user studies, software design and user testing of specific applications in this area.

The co-PIs of this proposal recognize that many research and technical issues related to this Project require careful research and technology innovation that go well beyond the scope of this Project. They have therefore submitted an NSF ITR proposal for innovative technology to form and support small groups and will submit a ROLE proposal for related research on collaborative learning by small groups. Particular co-PIs are also involved in other projects and proposals, including the PI’s participation in an NSDL proposal for small group knowledge construction in college classrooms and co-PI Shumar’s participation in another NSDL targeted-research track proposal. These related projects – if funded – would be complementary to the Project proposed here, but mutually independent. Although co-PI hours might have to be adjusted, there would be different Research Assistants and different goals, objectives and timetables. The present proposal aims to quickly establish a model of collaboration services in a digital library, based on research and technology that is almost at hand. Parallel research and innovation efforts would allow that model to be refined and extended in the future.

3.5. Infrastructure Technology

This Project aims to adapt existing technologies as much as possible and to combine compatible software components into an integrated environment to support collaborative use of a digital library by small groups working together on the Internet, specifically to support the solving of collaborative PoWs using the MFDL. Useful components for supporting collaborative communication are available in various configurations and on different programming platforms. There are, for instance, search, document exchange, email, chat, threaded discussion and whiteboard components in CSCL systems and in Open Source libraries. While it may not be feasible to develop specialized intelligent interfaces like Ariadne (Twidale & Nichols, 1998b) within the scope of this Project, the primary advantage of recording and displaying processes like goal definition, problem reframing, query refinement and result processing are obtained in a general way with persistent chat and threaded discussion tools. The only major component that has to be designed from scratch for the Project is a group formation component.

There do not seem to be any group formation components currently available, although the idea is not unprecedented (Swanson, 1964; Twidale & Nichols, 1998a). Some organizations have explored systems for locating expertise within their staffs (Ackerman & McDonald, 1996); but the techniques for that do not transfer to the problem of finding people with matching interests using a digital library. There have been some experiments with social awareness, to display other people who are viewing the same web page at the same time (Graether & Prinz, 2001), but this hint is not enough to support group formation. A "group formation" project in Japan matched learning theories (Inaba et al., 2000; Supnithi et al., 1999), but not people. A prototype for group formation in Germany allowed students who knew each other to self-select groups (Haake, Schuemmer, & Haake, 2003; Wessner & Pfister, 2001; Wessner, Dawabi, & Haake, 2002), but this approach does not scale to large groups who do not know each other personally. A spin-off of this German research is being expanded and developed for distance education; the Project will collaborate with Jörg Haake and associates through the design teams (see section on International Collaboration). It will also collaborate with H. Ulrich Hoppe and Bonnie Nardi, who have both prominently argued for supporting small group collaboration for tasks like digital library search (Hoppe & Zhao, 1994; Nardi & O'Day, 1996).

The PI began exploring support for group formation while teaching an online HCI (Human-Computer Interaction) course for graduate students at Drexel. His students studied the issue and came up with several low-fidelity prototypes that they subjected to user testing. The PI developed an automated grouping agent, which he uses to form work groups in subsequent courses. In both the student prototypes and the grouping agent, groups were formed based on specific criteria about the participants: their schedules, their interests and their skill levels. These pilot studies for the proposed Project suggest the kinds of balance that should be sought in forming distributed groups. For instance, if synchronous communication is to be possible within the group – especially given different global time zones – members must have similar schedules. On the other hand, collaborative teams often work best when there is a diversity of perspectives and skills, along with a commonality of interests. Thus, a matching algorithm must optimize certain similarities and other differences. Various theories of collaboration stress the power of heterogeneity, of the utility of seeing things differently: cognitive dissonance (Festinger, 1957), perspectives (Boland & Tenkasi, 1995; Goldnam-Segall, 1998; Stahl & Herrmann, 1999), interdependence (Johnson & Johnson, 1989), zone of proximal development (Vygotsky, 1930/1978), cognitive flexibility (Feltovich et al., 1996).

A pilot study of group formation was conducted by the PI with classes using two different online collaboration environments: Blackboard and BSCL. Blackboard is a commercial system to support collaboration. It is used widely in university courses, particularly in the US. Blackboard can be extended (in Java) by third party developers using the Blackboard Building Blocks SDK (see http://buildingblocks.blackboard.com/bin/bbdn_info.pl).

BSCL (Basic System for Collaborative Learning) is a system with collaboration support for classrooms that is similar to Blackboard (Stahl, 2002d). It was designed and developed by the PI and others in 2001/2002 as part of a European Union research Project. BSCL is an extension (developed in Python) to BSCW (Appelt & Klöckner, 1999), a shared repository CSCW system widely used in European research and learning organizations. It is available for free to academic organizations. The PI has a license to develop it during the period of this Project (see Letter of Support in Supplementary Documentation).

The MFDL already has an infrastructure of custom software (developed in an object-oriented Perl-based environment) to support the virtual community and digital library of math resources and activities. It is possible to extend this system in various directions, such as using ZOPE or other Open Source components, extending Blackboard or adapting features of BSCL. Java applets can also be developed, adapting from the PI's WebGuide system. The Project will select one of these approaches during its early phases.

4. Plan of Work

4.1. Timeline

The two year Project period is planned to be January 1, 2004 – December 31, 2005. Roughly, work during these years will be focused as follows, based on Drexel University's quarter calendar. Here are the major software system development efforts for the Math Forum Collaborative Learning Environment (MFCLE) by quarter:

- Winter 2004 – Project start-up
- Spring 2004 – User studies of groups working on PoWs
- Summer 2004 – Explore multiple designs for the MFCLE
- Fall 2004 – Prototype an initial version of the MFCLE
- Winter 2005 – Test the prototype with user teams
- Spring 2005 – Develop a robust version of the MFCLE

- Summer 2005 – Debug & refine the MFCLE; integrate it into the MFDL
- Fall 2005 – Project wrap-up and dissemination

User teams will be formed throughout the Project to work on collaborative PoWs. They will use online collaboration technologies from early on, gradually adopting the MFCLE as it becomes available. Their work with these technologies will be studied to determine user requirements of the software in the first quarters and to evaluate the various versions of the software later.

Creator teams will develop collaborative PoWs throughout the Project for use by user teams and for adoption in the MFDL. Creator teams will also use online collaboration technologies throughout, gradually adopting versions of the MFCLE as they becomes available in order to experience first hand the affordances of these environments.

Design teams will focus on design of the MFCLE technology, initially reviewing available components, then designing an integrated environment, and later evaluating it in user tests. The design teams will also use online collaboration technologies throughout, gradually adopting the MFCLE as it becomes available in order to experience first hand its affordances.

Project objectives will be achieved by meeting the following milestones:

1. June 2004 – Produce a user requirements document specifying the major components and functionality for MFCLE.
2. August 2004 – Produce at least 5 PoWs specifically designed for use by collaborative teams.
3. October 2004 – Produce at least 3 alternative designs for an initial version of the MFCLE.
4. February 2005 – Produce a working prototype of an initial version of the MFCLE capable of being tested by user teams.
5. May 2005 – Produce a formal evaluation of the prototype with user teams.
6. August 2005 – Develop a stable version of the MFCLE for release.
7. October 2005 – Incorporate the MFCLE into the MFDL.
8. December 2005 – Disseminate the MFCLE model by releasing MFCLE to the MFDL community, by submitting at least 3 papers in international conferences, and by sharing Project results with the NSDL community and with the international researchers involved in the Project.

4.2. Management Plan

The PI, Stahl, will have primary responsibility for all aspects of the Project. Weimar and Stahl will share Project fiscal management, with accounting maintained by the Math Forum and Drexel University. Weimar and Stahl will share Project staff management, recognizing that many staff are long-time employees of the Math Forum, contributing part-time.

The Project Management Team consists of the four co-PIs and will meet twice a month.

The Project Staff consists of the four PIs, four Math Forum curricular staff, three Math Forum technical staff and a Project graduate research assistant:

- G. Stahl, Information Science – Design Teams Coordinator
- S. Weimar, Math Forum – User Teams Coordinator
- C. Bach, Education – Creator Teams Coordinator
- W. Shumar, Anthropology – Evaluation Coordinator
- I. Underwood, Math Forum – MFDL Ask Dr. Math
- A. Fetter, Math Forum – MFDL Problem of the Week
- K. Lasher, Math Forum – MFDL Problem of the Week
- S. Alejandre, Math Forum – MFDL Problem of the Week
- L. Smith, Math Forum – MFDL IT director
- D. Tristano, Math Forum – MFDL software developer
- J. Zhu, Math Forum – MFDL system administrator
- GRA, Information Science – software developer

The Project Staff will hold monthly meetings at the Math Forum offices. These meetings will plan detailed Project milestones and activities; review progress made according to the milestones; prepare for up-coming activities; review and revise the Project plan; and make other decisions about the Project as needed. Minutes of these meetings will be posted on the Project website with other Project resources for review by the design teams, acting as Project advisors.

Project management will be conducted following a collaborative model, in keeping with the philosophy of the Project. Project activities will involve the collaborative teams, with Project staff providing staff support and taking responsibility to ensure tasks are accomplished. Each set of teams will be coordinated by a co-PI: Weimar (user teams), Bach (creator teams), Stahl (design teams). The Project takes an assessment-heavy approach to investigating the requirements for and effectiveness of technology; Shumar will coordinate the experimental design, ethnographic investigation, and formative and summative assessment of the Project. Stahl is responsible for software design and development; Smith for integration of software into the MFDL site; Weimar for involvement of students and teachers, as well as integration of Project activities with other MFDL activities; and Bach for pedagogical aspects of the Project.

Development of collaborative PoWs and other curricular materials will be done through the creator teams, consisting primarily of teachers and student teachers. The design teams – including national and international researchers as well as Project staff and interested members of the creator teams – will assist in the design and evaluation of Project experiments and of software for use in the experiments; they will monitor and guide the progress of the Project. All teams will be encouraged to be self-reflective and to become increasingly involved in the Project.

MFDL PoW staff will participate in planning, design and facilitation of the user and creator teams. MFDL staff will help with logistics, using their existing systems and networks of contacts. They will also help with hosting workshops for the teams as needed.

Shumar will coordinate all data collection, and will focus the teams as needed for formative evaluation tasks. Stahl is responsible for Project reports, including annual reports to NSF, culling from team summaries. Stahl, Bach and Shumar will prepare papers for conferences. Stahl and Weimar will be responsible for dissemination within the NSDL community.

4.3. National and International Collaborators

An important feature of this Project is the involvement of leading national and international researchers in the design teams. They bring expertise from a variety of relevant specialties and perspectives. Their participation will provide a natural means for sharing practical knowledge from Europe and the US as well as for disseminating the results of this Project across the nation and globe. To ensure a strong cadre of collaborators, the following researchers have already expressed strong interest in participating in the Project; others can join in the future:

National

Geri Gay (Cornell), Ricki Goldman-Segall (NJIT), Cindy Hmelo-Silver (Rutgers), Christopher Hoadley (Penn State), Timothy Koschmann (Southern Illinois U), Bonnie Nardi (Agilent), Leysia Palen (Colorado), Linda Puliam (California State U.), Mark Schlager (SRI), Dan Suthers (Hawaii).

International

Wolfgang Appelt (Fraunhofer-FIT, Germany), Thanasis Daradoumis (Barcelona, Spain), Hugo Fuks (Rio, Brazil), Jörg Haake (Distance U, Germany), Kai Hakkarainen (Helsinki, Finland), Thomas Herrmann (Dortmund, Germany), Ulrich Hoppe (Duisburg, Germany), Jim Hewitt (Toronto, Canada), Victor Kaptelinin (Umea, Sweden), Anders Morch (Oslo, Norway), Wolfgang Prinz (Aachen, Germany), Barbara Wasson (Bergen, Norway), Volker Wulf (Siegen, Germany).

These individuals are established leaders in the HCI, CSCW and CSCL research communities, having made important contributions in theory, system design and assessment methodology. They all recognize the importance of collaboration, both in theory and in practice. See the Biographical Sketches section for more information.

The proposed NSF Project builds on the work of the European ITCOLE Project and its BSCL software. The PI was the primary designer and prototyper of the BSCL software when he worked at Fraunhofer-FIT in Germany. The Project with the MFDL will involve close collaboration with the BSCW/BSCL team at FIT and has their full support. FIT will continue to support the BSCL code, making it available for free to educational institutions throughout the world. They will also provide training to Project staff who will be modifying the BSCL code. FIT has granted a five year developers license to the PI to work on extending BSCL as part of this Project. Both Wolfgang Appelt, the BSCW/BSCL team manager, and Wolfgang Prinz, the director of the CSCW department at FIT, personally support the proposed Project and its collaboration with FIT (see Supplementary Documentation).

The idea of automated support for group formation for workgroups in online learning is a research topic at the Distance University of Germany (Fern-Uni, Hagen). Jörg Haake, who has begun research on this topic (Haake et al., 2003; Wessner et al., 2002) will be a close collaborator with this Project.

4.4. Project Evaluation

The Project will be considered successful if it achieves the objectives stated in Section 2.2 and meets the associated milestones stated in Section 4.1. But evaluation also plays two non-trivial roles in the work of this Project: (1) on-going testing of the software as an integral part of the user-centered design of the new technology, and (2) study of collaborative learning in a digital library as promised in Goals 1 and 3 as stated in Section 2.1. These two roles can be fulfilled by an ethnographic approach.

Evaluation for the Project is designed to provide specific data about the quality of interactions in the different kinds of teams using MFCLE. Data collected will largely be descriptive ethnographic data, which is appropriate to the needs of the Project. The goal will be to provide a detailed description of the interactions within each of the kinds of teams and to interview team participants to capture their feelings about how well their groups worked. These descriptions will allow Project staff to assess which teams are doing well and which ones are less successful. Drawing on prior MFDL work with the ESCOT Project, teams will be evaluated in terms of their ability to communicate, develop a sense of shared worldview and create a feeling of group belonging – all of which contribute to successful work practices (Shumar, 2002; Lave & Wenger, 1991; Wenger, 1998). Analysis of studies of the teams will also contribute to the overall evaluation of the Project and the success of its implementation.

In year I the analysis of *user teams* will consist of two categories: face-to-face groups and virtual groups. We will observe two sites in schools where collaborative group work is ongoing. These may be groups using PoWs and they may be doing other projects. The face-to-face sites will involve extensive observation over the period of the collaborative problem solving. This may involve regular classroom participation for a week or two. Interactions will be videotaped and participant observation data will be collected. In addition to the two face-to face sites, four virtual workgroup sites will be established. These will be virtual groups of students who have volunteered to work collaboratively on the math problems. Data from these groups will be collected on synchronous and asynchronous forms of interaction (chat transcripts, discussion lists, emails, and interviews with participants). Preliminary analysis of this student data will assess the patterns of interaction and begin to create a typology of successful group dynamics, as well as get participants' sense of the quality of the group interaction. Drawing on earlier work on mathematical thinking at the MFDL, interactions will also be assessed for the quality of the work that went into the problem-solving in the group (Renninger, et al., 2000).

Face-to-face work in teams will be videotaped. The videos will be time-stamped and logged. Interesting episodes will be carefully transcribed. The MFCVE software will be instrumented to log usage data, including digital library queries submitted. Interactions captured will be coded at the utterance level, using grounded theory techniques to develop an appropriate coding scheme (Strauss & Corbin, 1998). Particularly rich interactions will be subjected to discourse analysis (Duranti, 1998; Jordan & Henderson, 1995; Sacks, 1992).

The year I *creator team* evaluation will focus on the analysis of two teams over the course of the year. Interactions in these teams will be tracked on synchronous and asynchronous forms of interactions (chat transcripts, discussion lists, email, and interviews). Face-to-face interactions of the teams will be videotaped and observed directly. Analysis of group interaction and discourse will center around the emerging patters of leadership, creation of a sense of group belonging, and the ability to communicate across differences of group, culture, need, etc. Finally, two *design teams* will be evaluated by collecting virtual chat interactions, discussion lists and interviews with members of the group. Analysis of group interaction will follow the same pattern as the curricular workgroups.

In year II, evaluation of the *user teams* will follow a similar format to the evaluation of the virtual groups in year I. Five groups will be evaluated. Data collected will come from synchronous and asynchronous forms of interaction plus teacher interviews on the impact of the team on the students' classroom interactions. Problem solving will be analyzed in terms of the group's process of mathematical thinking and interaction. The qualitative data will also be analyzed looking at the impact of group heterogeneity on individual learning and the effect of group composition on collaborative learning moments. The better performing groups of each year will be compared with the method of group selection. Quantitative data will be used to determine the extent to which involvement in collaborative small teams working on PoWs led to a general increase in usage of the MFDL and participation in the MFDL community. In year II, *creator team* and *design team* evaluation will follow the pattern set up in year I. Two creator and two design teams will be studied each year. Data will be collected through synchronous and asynchronous communication and interviews with group members. Data analysis will follow the pattern in year I and will be done to identify effective teams as well as teams that enhance the development of individual members of the group.

5. Anticipated Results & Impact

5.1. Dissemination & Outcomes

Dissemination of Project results, both in the US and in Europe, is built into the Project design. Dissemination to the international research community, to practicing educators and to the public generally will take place primarily through the following mechanisms:

- Involvement of international researchers. Approximately two dozen researchers will be intimately involved in this Project, primarily through the design teams. Many of their graduate students will also be involved.
- Workshops at international conferences. The Project will sponsor at least one workshop to bring together international and American researchers in the design teams. This may be coordinated with international conferences on

education such as CSCL, ICLS, AERA and EARLI. Most of the researchers involved in this Project regularly attend these conferences and present at them. These conferences will be primary sites for the presentation of results from this Project. Project staff will submit papers and organize presentations about the Project results at these conferences.

- Involvement of teachers and student teachers. Perhaps two dozen teachers and student teachers will be intimately involved in this Project, primarily through the creator teams. As the results of this Project become part of MFDL's regular services, increasing numbers of teachers and student teachers will participate in spontaneously formed curricular workgroups.
- The MFDL virtual community. This is a rapidly growing community that already numbers over a million distinct individuals. They will learn about the results of this Project as collaborative problems become a regular feature of the MFDL and as community participants are automatically invited to join small groups for collaborative learning of mathematics.
- The NSDL community. The MFCLE will be presented at NSDL gatherings and through NSDL communications as a model for collaborative services in digital libraries.

5.2. Sustainability & Contribution

The results of this Project, particularly the MFCLE service, will be fully incorporated in the MFDL. The MFDL is a permanent program within Drexel University, so that services developed in this Project will continue to exist and be used indefinitely. Although the MFDL receives grants to engage in research and service expansion, it strives to develop revenue sources to sustain existing services. The collaboration services of this Project will contribute to building new lines of revenue, including contracted services with school districts for which MFDL will provide custom collaboration services and support.

5.3. Integration of Research & Education

The MFDL itself integrates research and education. It provides resources and services to support math education over a broad range of school grades, as well as meeting educational needs of employees, mathematicians and lifelong learners. The MFDL organization is heavily involved in research on digital libraries, often in conjunction with academics at Drexel University (like the co-PIs in this Project).

The specific content of this Project applies technologies at the forefront of CSCL and CSCW research to educational needs. The emphasis on small group collaboration as an important mode of educational practice also comes out of recent research in learning theory.

5.4. Integrating Diversity

A central Project hypothesis is that groups integrating specific kinds of diversity learn better. The MFCLE software will be designed to optimize diversity during the group formation process.

5.5. Intellectual Merit

This Project creatively combines leading-edge collaboration technologies with one of the most popular services of a successful digital library to provide a model of support services for collaborative digital library usage. The Project brings together four co-PIs with the required mix of expertise, along with teams of engaged educators and international researchers.

This Project systematically explores an important open challenge of the Internet: how to foster effective collaborative online learning in digital libraries. It joins the multidisciplinary expertise of the international CSCL community with the practical success of the MFDL to study how to mediate the growth of a large virtual learning community, and to design, develop and assess tools for the online support of small workgroups acquiring, managing and negotiating knowledge.

5.6. Broader Impacts

The Project develops collaboration services for digital libraries, providing a sustainable model. It promotes the involvement of geographically isolated, disadvantaged and disabled students, distributed teachers and international researchers by inviting them into collaborative learning teams hosted, supported and informed by a digital library. The MFDL PoW service already attracts hundreds of thousands of people to the digital library and its resources; with the MFCLE support, more people will become more intensely involved in the user community. Other digital libraries can copy this model, providing services that attract visitors to specific resources and involve them in group activities. This Project pioneers a path for enhancing NSDL impact, building effective virtual learning communities.

The MFCLE software, with automated formation of small groups and with support for interactions that develop deep understanding of mathematics, will be suggestive for virtual learning communities in other domains and other digital libraries. This model provides opportunities for students, teachers and researchers excluded from collaborative learning due to geographic isolation, disadvantaged schools, physical disability, discrimination and other physical or social factors. The model stimulates both student motivation and teacher development, transforming interest in mathematics from a potential social stigma into a bridge to global friendships.

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Part II: Other Proposals at Drexel University

Foundations: Educational Online Communities for At-Risk Youth

Submitters: Mike Atwood (Drexel/IST), Gerry Stahl (Drexel/IST), Fran Cornelius (Drexel/Nursing), Steve Weimar (Drexel/Math Forum), Debra McGrath (Drexel/Nursing, Inst for Healthcare Informatics)

For submission to: Philadelphia-area and national foundations

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Introduction

Drexel University is a leader in the development, deployment and adoption of telecommunications technology to support education. In particular, the College of Information Science and Technology (IST) and the College of Nursing and Health Professions (CNHP) operate major online curricula for college and graduate study. The Math Forum has pioneered successful use of networked digital libraries of educational materials for K-12 students.

The John C. Ford Program based in Houston, Texas, has introduced a successful tele-community educational after-school program in partnership with community schools. The intent of this proposal is to create a similar partnership with the parents and children attending the community schools of lower North Philadelphia, IST, CNHP, Math Forum and the Ford Program to create an educational online community for at-risk youth. The purpose of this project is to improve academic performance, life skills and health status of persons living in lower North Philadelphia.

The Need

The lower North Philadelphia community served by this project – known as the 11th Street corridor – is a community in need. There is a remarkably high concentration of public housing in this community: six conventional public housing developments with 5,583 residents. The population is predominately African-American women heads of household and their children. There is a disparately high percentage of unemployed individuals and of families in poverty compared to other neighborhoods in Philadelphia. Families living in this community have the lowest median family and household income in the city. (See Appendix A.)

National data suggest that the cycle of poverty, poor health status, and low educational achievement has become self-perpetuating in many communities. As in other impoverished communities, the residents of 11th Street suffer from significant health issues. This community experiences higher rates of morbidity and mortality compared to other areas, especially due to diseases such as hypertension, diabetes, asthma, and high risk behaviors such as cigarette smoking, substance abuse and risky sexual behaviors. (See Appendix B.)

Education – the acquisition and application of knowledge – is a critical component in breaking this cycle. The Ford Program offers an opportunity to engage in a hands-on interactive learning environment that empowers, educates and enriches the lives of students and their families. Drexel University proposes an expansion of the Ford Program, which will offer an innovative collaborative intervention with broad-based impact.

Long-Range Goals

We will provide a unique and innovative after-school program for youth and their families in low-income neighborhoods of Philadelphia. Our broad goal is to provide an educational community in which students and their families will be able to develop competencies that will translate into the following:

- Students will develop the skills to succeed academically and become connected to professionals from the health and information sciences. Students will be able to explore these professions and enter career paths at an early stage, leading to reduced school dropout rates and increased college attendance.
- Parents will develop personal relationship and technical skills essential for the workplace. These are the tools needed for upward mobility in the work world.
- Both students and parents will join a community of learners and experts to acquire business, presentation and computer literacy skills. The acquisition of these skills will lead to a higher level of self-confidence and ultimately to an increased ability to advocate for self and family.

Partners

CNHP: The CHNP has been working with the target community for seven years and has a proven track record for successful programs in the targeted community in close collaboration with community leaders and the local school district.

Math Forum: The Math Forum will adapt its award-winning online services to help participating students develop their mathematical problem-solving skills and reinforce some of the math concepts and techniques found in the project curriculum. These online services and resources will provide continuity for the students and academic support between project events.

IST: Drexel IST will research technology transfer procedures for adapting software used at the university to local after-school settings in low-income Philadelphia neighborhoods, and will provide on-going research, development and evaluation services, partnering where appropriate with the School of Education and the Math & Computer Science Department.

John C. Ford Program: The Ford Program is a successful educational initiative that involves a unique blend of elements: neighborhood-based Inner-City Telecommunication Centers; a non-academic, real-world business format and curriculum with a focus on science, math, business and technology; strong support from corporate partners; a multimedia network that uses interactive videoconferencing with an innovative protocol to attract, engage and train low-income youth and adults; training and education for the whole family in low-income communities; and state-of-the-art technology that allows the program to tap into available learning resources. This program is now gearing-up for a national scaling initiative for dissemination.

Pilot Implementation

Curriculum: We will begin in Winter 2003 with after-school programs at Harrison Community Center in lower North Philadelphia to capitalize on the national scaling effort of the John C. Ford Program's Global Tele-Communities Education Initiative. This one-year phase will use curriculum already proven successful in low-income neighborhoods in Houston. We will adapt the Ford Program curriculum – which focuses on science and business skills – for our target population. Initial offerings will include: "Science, Math and Technology" curriculum developed in cooperation with the Ford Program, Space Center Houston and the Math Forum. Other offerings will be pre-SAT "Language Arts" and "Math Crafts" curricula from the Ford Program.

In the second year, we will offer "Healthy Habits", a health literacy and self-efficacy curriculum developed by the College of Nursing. The prototype for this curriculum is currently under development as part of two studies in the College of Nursing; the HTN Study and the Asthma Education Program. The pilot project will provide needed experience and outcome data to enable us to design a more complete program and to seek federal funding.

Mentoring: Through telecommunicated simulations and online interactions students will receive learning support from experts in the field and higher education students and faculty, thus forming relationships that encourage students to expand their horizons and set higher expectations for academic performance.

Modeling: The business and science curricula enable the program to model problem-solving, teamwork and other strategies for success in academic and work environments.

Recruitment: We plan to publicize this opportunity through schools, the local community center and guidance counselors. The program will be open to all interested individuals, on a first-come, first served basis. There will be clear behavior and performance expectations with clear consequences and replacement strategies.

Resources: The Harrison Community Center, located in lower North Philadelphia public housing, is a hub for community activity. The center is operated by a very active and deeply committed resident council which strongly supports this initiative. The council has, for the past seven years, sought out opportunities and partnerships that encourage and support families in the pursuit of education and training as a means to a better life. The Harrison Computer Resource Center (HCRC), a modest computer lab, was established to provide area residents access to educational opportunities and to build skills for jobs that provide a living wage. The HCRC provides a vital service to area residents in providing access to technology, which is now considered a 'life-skill' essential for success in today's work and school environments. The commitment by the community and community leaders make the HCRC a logical partner in this project.

Evaluation: We will assess effectiveness of the Pilot Implementation phase from data collected using the following methods:

- Youth Risk Inventory administered as the program begins and at the end.
- Pre- and post- inventories measuring attitudes toward substance abuse and other risky behaviors, school, work, and goal setting.
- Administration of inventories at the start of the program and at the end that assess and monitor self-efficacy, health status, and health behaviors.

- ❖ Monitoring of computer-based activities.
- ❖ Analysis of computer interaction logs.
- ❖ Student school performance (report cards, attendance).
- ❖ Program participation and retention records.
- ❖ Parent/guardian involvement records.

Scaling Up Process

As university educators and researchers, our priorities include the involvement of our own university students to:

- ❖ Develop a workable curriculum that involves at-risk youth and their families in developing self-efficacy.
- ❖ Develop a workable curriculum that involves at-risk youth and their families in developing healthy attitudes and knowledge about risky behaviors such as substance abuse, cigarette smoking, poor diet, early engagement in sex, etc.
- ❖ Develop a workable technological infrastructure to be used in low-income neighborhoods for learning and sharing healthy attitudes.
- ❖ Develop pedagogical and curricular approaches that are successful at involving at-risk youth and their families in educational online communities.

As we succeed in these areas, we will increase the number of sites in low income Philadelphia neighborhoods offering after-school online educational communities and we will diversify the curriculum offerings at these after-school programs.

Request

We are requesting $88,000 for calendar year 2003. This will cover faculty and teacher release time for staffing the after-school program and small amounts for supplies and overhead. Because we need to start up the Pilot Implementation program in early 2003 to coordinate with the Ford Program, there is insufficient time to request federal funding. Furthermore, the pilot will provide us with extensive hands-on experience setting up and working with this type of after-school program to support a major research and implementation proposal. Foundation funding for an initial pilot project year will thereby leverage substantial longer-term funding that can have a sizable impact on the at-risk population in Philadelphia.

Budget for one-year pilot project

$28,000Project Management (20% release time for McGrath & Cornelius)

$24, 000 Project Instruction (2 certified teachers * 10 hrs/wk *30 wks * $40/hr)

$ 6,000 Software

$ 6,000 Hardware

$ 5,000 Travel (to Houston, etc.)

$ 5,000 Supplies

$14,000Indirect (20%)

$88,000Total

Supporting Documents

Letter of support from after-school program

Letters of support from local schools

Letter of support from the John C. Ford Program

One-page biographies of Principal Investigators

Part III: Grants Awarded at the University of Colorado

New Media to Support Collaborative Knowledge Building: Beyond Consumption and Chat

Executive Summary

The Center for LifeLong Learning and Design (L3D), directed by Gerhard Fischer, is an interdisciplinary research and teaching center within the Department of Computer Science and the Institute for Cognitive Science. It has long focused on developing theoretical frameworks and prototype technologies for supporting high-functionality, collaborative, creative tasks with computational media. In recent years, it has explored models of Web-based communication that foster interaction and the collaborative construction of shared knowledge.

The proposed project is situated within an advanced interdisciplinary seminar that brings together faculty and graduate students to research the role of computational cognitive artifacts and innovative Web-based media in collaborative learning and education. Much of the seminar activity takes place through WEBGUIDE, a knowledge-building environment being developed by Gerry Stahl, the project Principal Investigator. WEBGUIDE is an experiment in dynamically structuring hypertext communication according to group and personal perspectives.

The requested seed grant will allow the further development and evaluation of WEBGUIDE during the duration of the seminar. WEBGUIDE will become a central theme of the seminar as an example of a computational artifact that seminar members learn to use. New functionality will be added to WEBGUIDE incrementally as suggested by its use. The adoption, usability, benefits and limitations of the technology will be evaluated and reported.

L3D has always pursued interaction with industry. WEBGUIDE and related models and technologies developed at L3D have been used in a number of classroom settings, and will soon be ready for exploration in commercial settings.

Technical Description

The L3D Center

The Center for LifeLong Learning and Design (L3D) emerged from Gerhard Fischer's research group on Human-Computer Communication. That research group established a reputation for developing ideas and systems to support high-functionality, collaborative, creative tasks with computational media. A central theme in the late 1980's and early 1990's was computational design environments to support designers in various fields (e.g., design of kitchens, voice-dialog systems, LANs, habitats in outer space. Most current L3D faculty were involved in these efforts, and approaches from it influence on-going research.

An important focus in the early work was on supporting "lifelong learning," "just-in-time learning," or "learning-on-demand". The design environments were always "domain-oriented," that is, they were built around knowledge-bases of domain knowledge. A distinctive feature of L3D's research was a concern with the evolution of these knowledge-bases through use. It was seen as critical that designers not only have access to domain knowledge as they work, but that they can grow the knowledge-base by contributing to it and reorganizing it. This concern broadened the research interests from HCI (human-computer interaction) and AI (artificial intelligence) to CSCW (computer supported cooperative work) and CSCL (computer supported collaborative learning) (Arias et al., 1999; 2000; Fischer, 1994; 1998).

With the advent of the Web, L3D research shifted to exploiting the promise of the Web as an infrastructure for sharing knowledge and collaborating on design. Here it was important to distinguish distinct models of Web use: (model 1) the Web as a read-only repository of information; (model 2) the Web as a place where information may be submitted to webmasters who mediate its dissemination; (model 3) the Web as a communication medium in which users interactively grow shared knowledge. Of course, each of these models is appropriate for certain classes of use and model 3 raises a variety of special issues which we are currently investigating.

Much of L3D's work recently has tried to identify limitations of popular models of the Web and to explore ways of overcoming these limitations. To allow users to move from the role of passive consumers of information to active producers of shared knowledge, we developed a number of prototypes and then deployed them in courses. For instance, a series of interlocking dynamic websites were created in which users could interactively build glossaries of technical terms, bibliographies of literature sources and threaded discussion of topics (see DYNAGLOSS, DYNASOURCE, DYNACLASS: http://www.cs.colorado.edu/~ostwald/dynasites.html).

We observed through analysis of entries in threaded discussions that these media, though interactive, were generally limited to relatively superficial chat or exchange of personal opinions. WEBGUIDE was developed to explore support for activities of knowledge-building that go beyond both consumption and chat to dialog, merging of perspectives, clarification of meanings, theory building, shared knowledge, crystallization of ideas in cultural artifacts, etc. (Stahl, 1999b; 1999c; 2000b).

Other L3D projects address the limitations of purely digital communication by allowing interaction with physical objects that have computational implications. Another major concern is that today's technology excludes both people without access to equipment and also many people with physical or mental disabilities. L3D has begun a major effort – in association with industry – to develop technologies that address the special needs of these populations.

The Project Environment: Teaching & Research

The proposed project is situated within an advanced interdisciplinary seminar on "Perspectives in Computer Supported Collaborative Learning" (http://www.cs.colorado.edu/~gerry/readings/). The seminar brings together faculty and graduate students from Computer Science, Communication, Education, Psychology and Philosophy to research the role of computational cognitive artifacts and innovative Web-based media in collaborative learning and education. A variety of theoretical approaches are reviewed through discussion of seminal texts and collaborative micro-ethnographic analysis of videos from a middle school classroom. Video clips, log and transcripts are available through WEBGUIDE, which also provides the medium for communication and group theory building. Several seminar participants interact solely through WEBGUIDE from other universities and even from other countries.

WEBGUIDE is an experiment in structuring hypertext communication according to group and personal perspectives. Seminar participants each have their personal "perspective" or digital workspace in which they have complete control over editing, arranging and managing their own mix of shared and private notes (short texts, graphics, Web links). There is also an official class perspective with topic headings, class minutes and agreed upon notes. Contents of the class perspective are automatically inherited (included, subject to editing) in each personal perspective. Further, it is possible to create subgroup perspectives that reflect the work of teams or topics within the class. For instance, participants from a particular other university, from a specific academic discipline or those especially interested in one of the authors being read could set up a workspace reflecting their joint perspective on the seminar. Again, contents would be inherited from class to subgroup to selected personal perspectives. What appears in a Web browser at any given moment is a dynamic, personalized selection from the shared, interactive knowledge base (Stahl, 1999a; 2000a; Stahl & Herrmann, 1999).

WebGuide has been piloted in a middle school and a graduate school course. The results of these trials have been presented and well received at the major related conferences (see http://www.cs.colorado.edu/~gerry/webguide/publications.html). Many of the problems and limitations of previous trials will be addressed in the current semester, where a substantially revised version (WEBGUIDE 2000) will be used for the first time. This seminar is likely to produce much more meaningful data, particularly if several known problems can be addressed through the proposed project.

Description of the Project

The requested seed grant will allow the further development and evaluation of WEBGUIDE during the duration of the Fall 2000 seminar. By providing 50% funding for the PI, the grant will allow system development work, addition of new utilities, rapid fixes of bugs, evaluation of patterns of use, and timely assessment and reporting of successes and limitations. In addition to freeing up the PI to work on the software directly, the seed grant will let him supervise student projects related to WEBGUIDE, coordinate explicit reflection on the software by seminar participants, and prepare funding proposals to continue this research.

One major planned component of WEBGUIDE has not yet been implemented, although the technical infrastructure for it is mainly in place. That is a negotiation process whereby the group of users decide what notes should be promoted to the class perspective (or to a subgroup). A student project last semester designed this component, but it has not yet been implemented.

A major improvement to the WEBGUIDE architecture would be to convert the client/sever interface to communicate using XML data rather than Java objects. This would greatly improve the ease of developing alternative interfaces to WEBGUIDE, for instance simple HTML or Perl displays and forms. It is possible to involve a student project from an XML course this semester in working on this. The PI also has an undergraduate research apprentice who could work on this, given grant funding.

L3D is increasingly developing expertise in evaluating the success and character of online interaction. In part this is through developing methods of analyzing the structure and semantic or interaction content of discussion threads. In part it is by practicing micro-ethnographic methods of human-computer interaction analysis using digitized video recordings and computer logs. With seed grant funding, these approaches will be applied to assessing the use of WEBGUIDE and related materials in the seminar. The findings will be published and will also be used as the basis for funding proposals to the ROLE, CSS and ITR programs at NSF to continue this research. Collaboration with industry would also be appropriate and welcome at this point.

Relation to New Media Lab Mission

L3D has always pursued interaction with related industry, including NYNEX, US West, IBM, Johnson Engineering, Athenaeum International, BEA, PFU, SRA. L3D's philosophy has been to address real-world problems and to test its ideas in real-world settings. This distinguishes it from alternative approaches oriented to abstract theory or to laboratory research.

L3D is focused on innovative research and teaching concerned with human interaction within the increasingly digital environment, whereby that environment is seen as a potential with both advantages and limitations – a future that is in the throes of being invented, and whose invention we can influence.

L3D strives to integrate teaching and research, with a strong project-based orientation in its classes and a dominant involvement of undergraduate and graduate students in its research. Vertical integration is a way of life here. Relations between L3D and industry have historically included both long-term placement of students on site and substantial visits by industry scientists on campus, in order to build lasting, meaningful relationships and deep shared understanding.

The proposed project fits nicely within the Lab for New Media's theme of "Perception and Persona in the Digitally-Mediated Environment." The perspectives mechanism in WEBGUIDE is designed to represent the intellectual persona of participants and to allow these persona to be perceived dynamically.

The project falls under Technology Research, involving directly the design, implementation, use and assessment of middleware in support of collaborative interaction. At the same time, in the seminar setting it is used to explore the strategic integration of face-to-face and computer-mediated interaction. Finally, within the tradition of work at L3D and by the PI, it involves the dynamic configuration of text and graphics from a shared, interactive knowledge base into a hypertext narrative structure personalized to the user's changing interests.

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Interoperability among Knowledge-Building Environments

Abstract:

A number of software environments have been developed to support collaborative knowledge building, typically incorporating a persistent discussion forum. Despite striking similarities and interesting differences among these community learning tools, there has been little direct interchange of ideas, designs, experiences and data among the developers. A first step toward increasing collaboration in this research community is to define a mark-up language to represent, archive and translate the data captured in these systems. This will help us to understand the design space of such knowledge building environments, to share software tools and to archive data for analysis. This project brings together representatives of research groups building related tools and evaluating the learning supported by those tools.

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Objectives and Significance:

The goal is to start a collaboration among research groups and individuals who are designing, implementing, testing and evaluating innovative learning technologies that support collaborative knowledge building. A number of similar software knowledge-building environments (KBEs) have been created, generally including a discussion facility that renders student argumentation persistent. This project will define a common data mark-up format that these KBE systems can export their discussions to. This will allow interchange of data and the display of data in shared formats to facilitate comparison and research. For instance, it will facilitate the archiving of discussions from different systems in CILT's Knowledge Network.

Project and Partners:

This project will bring together researchers working within a genre of collaborative learning technology that is prominent in the larger field, but has not been identified or conceptualized as such. The effort to make the data in these KBE systems exchangeable will raise issues of software design that will lead to sharing of expertise and technical advances. This is similar to the Dexter conference that defined a software model of the major hypertext systems in 1988 and clarified directions for their future development [CACM, 37, 2]. We hope to start with KBE researchers at Toronto, Georgia Tech, Colorado, Swarthmore, Berkeley, Stanford, SRI and elsewhere. The time they contribute to this project is likely to total in excess of 400 hours during the year: drafting documents, corresponding and attending workshops. The partner groups include several people with XML experience who are willing to share knowledge of this important new technology within the KBE community. A number of groups are already working on XML representations specific to their systems, and others will soon begin to do so as a result of this project. The PI (Stahl) will be leading an interdisciplinary graduate seminar on KBEs in the Fall, with students doing research directly supportive of the proposed project. As a direct consequence of the planning of this project at CILT '99, a parallel project has been launched for research groups in the cognate field of CSCA (computer supported collaborative argumentation / design rationale), with an initial draft XML DTD already (within a week of the CILT conference) posted to a KBE for discussion. All of these activities will be represented and coordinated in the proposed project.

Expected Outcomes:

KBEs are considered important learning technologies, yet their widespread adoption remains problematic. This project will begin to bring together a community of people deeply involved in the KBE sub-field to share data, designs and experiences. Data interoperability will facilitate the development of shared tools for analyzing, visualizing and comparing student learning within various KBEs. When data is stored in an XML file, it can be interchanged between different KBE systems or different versions of the same system, archived for flexible future use and displayed on the Web with metadata search capabilities. The definition of an XML DTD for threaded discussion and related information in KBEs is explicitly viewed as just a first outcome. The KBE-ML will include a minimal model of KBE storage, a full-featured ideal model and extensions for specific systems. If accepted, workshops proposed for CSCL '99 and elsewhere will relate this work to the broader educational issues surrounding KBEs. This project will lead to a clearer understanding of future stages of collaboration for subsequent funded projects.

Deliverables:

A number of participating groups have already started to work with XML representations of their own systems, so development is likely to proceed through iterations punctuated by communication and consolidation, with "standards" being repeatedly revised to support new concerns. The following milestones are targets for reaching consensus and producing semi-stable documents:

- Requirements specification for an XML DTD based on several specific KBE systems. (Month 2)
- Draft of a full-featured KBE-ML Document Type Definition for KBEs and a minimal subset to define compatibility. (Month 4)
- Development of export/import procedures between XML data and specific KBE systems. (Month 6)
- Organization of a workshop at CSCL '99 (assuming acceptance) on issues related to this project and the learning goals of KBEs. (Month 7)
- Development of Web display style sheets for the KBE-ML formatted data. (Month 9)
- Development of simple data analysis tools for the KBE-ML formatted data. (Month 11)
- Submission of funding proposals for future work. (Month 12)
- Preparation of project status updates and summary report. (Month 12)

Organization:

A set of four co-PIs will share primary programmatic and financial responsibility. They will decide how funds should be allocated as needs arise. Funds will be administered through the University of Colorado, but will be used to cover expenses at any participating institutions, such as the hiring of students working specifically on this project or the travel expenses of a participant who needs a subsidy to collaborate or attend meetings or workshops specifically as part of this project. An Executive Committee consisting of representatives of primary KBE systems will ensure the involvement of the research groups involved with those software systems. A Project Membership list of individuals will be used for the circulation of all project documents in order to build broad consensus.

Period of Performance:

12 months starting June 1, 1999.

Conceptual Frameworks and Computational Support for Organizational Memories and Organizational Learning

PROJECT SUMMARY

This project will investigate computer support for learning, working, and collaborating in information-intensive organizations. It will focus on communities of practice (such as local area network managers, research teams) as subgroups within and across organizations. We will work with specific communities to design, test, and reflect upon organizational memories to support organizational learning.

Organizational learning is a process by which knowledge that is created or made explicit during work on tasks is captured, structured, maintained, and evolved so it can be accessed and delivered when needed to inform future tasks. Organizational memories can facilitate organizational learning by supporting communication within communities of practice, delivering information relevant to their tasks, letting them "grow" their own information spaces, and allowing them to collaborate using the World Wide Web (WWW).

The project will work with specific communities of practice to study their actual and potential learning processes. Based on the interpretation and assessment of these observations, and theories from the research literature or from our own previous work, we will develop and articulate a new conceptual framework for computational support of organizational learning. To assess and develop this framework, organizational memories will be prototyped in collaboration with the communities and assessed in naturalistic settings.

The organizational memory software (building on emerging WWW technologies and prior research on domain-oriented design environments) will extend our currently existing prototypes with innovative mechanisms for capturing, structuring, as well as delivering information. It will incorporate computational support to reduce the burden on users as well as end-user controls to empower users to adapt the memory to rapidly evolving needs. It will integrate the various software mechanisms into a coherent architecture and a system of meaningful user interactions for supporting effective organizational learning.

Research Issues. We will focus our research on: (1) how to capture knowledge and integrate the contexts of work; (2) how to sustain the timeliness and utility of

evolving information; and (3) how to deliver relevant information actively and adaptively.

Approach. We will develop a conceptual framework for integrating working and learning in communities of practice. We will create organizational memories that include mechanisms to capture and represent task specifications, work artifacts, and group communications; facilities for practitioners to reorganize and sustain the usefulness of the memory; and techniques for access and delivery of knowledge relevant to current tasks. We will extend emerging WWW technology with structured web site interactivity, version control of evolving information, software critiquing agents, and end-user programmability.

Assessment. We will ground our designs and technical innovations in an assessment of the informational needs and organizational barriers to learning within communities of practice. We will focus our research by working specifically with communities of practice such as local-area network (LAN) designers and managers, the group of researchers working in our center, students in classes, neighborhood communities, and industrial work groups.

Expected Results. The proposed research will create (1) at the conceptual level: a unifying framework for organizational memory and organizational learning; (2) at the computational level: a generic architecture for organizational memories based on our prior domain-oriented design environments and prototypes for specific domains; (3) at the assessment level: a body of empirical results based on evaluations of the systems and the underlying theory in concrete organizational contexts.

PROJECT DESCRIPTION

Section 1. Results from Prior NSF Support

Prior NSF Awards:

- Grant #IRI-8722792: G. Fischer, W. Kintsch, C. Lewis, P. Polson: "Design Principles for Comprehensible Systems" (group grant), 1988-1991, amount: $1,171,246.
- Grant #IRI-9015441: G. Fischer and R. McCall: "Supporting Collaborative Design with Integrated Knowledge-Based Design Environments," 1990-1993, amount: $700,000. For information see: http://www.cs.colorado.edu/~l3d/grants_projects.html#CollDes.

- Grant #RED-9253425: G. Fischer, M. Eisenberg, H. Eden: “Mastering High-Functionality Computer Systems by Supporting Learning on Demand” including an NIE supplement “Learning on Demand—Using Networks for Integrating School and Workplace Learning,” 1992-1995, amount: $1,504,238. For information see: http://www.cs.colorado.edu/~l3d/grants_projects.html#LOD.
- Grant #IRI-9311839: G. Fischer: “Human-Centered Intelligent Agents Supporting Communication and Collaboration in Domain-Oriented Design Environments,” 1994-1997, amount: $210,000. For information see: http://www.cs.colorado.edu/~l3d /grants_projects.html#IntAg
- Grant #REC-9553771: G. Fischer, M. Eisenberg, A. Repenning, H. Eden: “Learning by Design: Environments to Support Reinventing and Reengineering Education as a Lifelong Process”, 1995-1996, amount: $398,482. For information see: http://www.cs.colorado.edu/~l3d/ grants_projects.html#LOD.
- NSF Proposal #CDA-9529549: E. Arias, H. Eden, G. Fischer “Shared Interaction in Support of Design, Learning, and Planning,” 1996-1997, Program: CISE Instrumentation, requested amount: $91,950 ($61,300 NSF, $30,650 University Matching); recommended for funding by NSF program director.
- Grant #REC-9631396: G. Fischer, M. Eisenberg, A. Repenning, H. Eden “Lifelong Learning – Bringing Learning Activities to Life,” 1996-1997, amount: $619,617.

Grants 2 and 4 are described below because they are most directly relevant to this research proposal.

Grant 2. Supporting Collaborative Design with Integrated Design Environments

Summary of Completed Work. This research addressed computational support for collaboration among members of design teams when direct communication among the members is impossible, impractical, or undesirable. The grant focused on the long-term, indirect communication needs of project teams rather than the needs occurring in face-to-face synchronous communication such as project meetings. Novel approaches and mechanisms were developed to capture design rationale and to associate it with the artifact to which it referred. The accumulated information was largely informal, meaning that the system was unable to perform operations on it. Techniques of incremental formalization were developed to address this problem. Incremental formalization tools were designed, implemented, and assessed that allowed system-interpretable attributes to be added to the accumulated information.

The research results of this grant were presented at major conferences in the research areas explored by the grant (e.g., CSCW, CHI, AAAI) and published in major journals in the research area (e.g., Human-Computer Interaction Journal, Applied Intelligence Journal, ACM Transactions of Information Sciences Journal). Our work has led to an increased attention in the Coordination Theory and Collaboration Technology (CTCT) and CSCW communities for long-term, indirect communication and collaboration, and design environments have been developed at numerous other places.

Limitations Exposed by the Grant. (1) Designers rarely capture their design rationale because it involves a lot of work and the benefits seem remote. (2) Information spaces quickly become out-of-date and disorganized. (3) Designers are not always aware that they are in need of additional information, so they make no attempt to search for information whose existence is unknown to them – hence passive information repositories are inadequate for supporting ongoing, collaborative design. These limitations motivate the proposed project emphasis on automated information capture, end-user information maintenance, and active knowledge delivery.

Development of Human Resources. Two members of the project are now faculty members (Scott Henninger, University of Nebraska; David Redmiles, University of California at Irvine). The graduate research assistants were offered summer fellowships at prestigious industrial research laboratories (e.g., Xerox-Parc, NYNEX S&T, and Siemens). Two Ph.D.s were awarded (Reeves and Shipman). REUs allowed several undergraduate research assistants to be exposed and integrated into research activities.

Five Most Important Publications:

G. Fischer, R. McCall, J. Ostwald, B. Reeves, F. Shipman. "Seeding, Evolutionary Growth, and Reseeding: Supporting Incremental Development of Design Environments," Human Factors in Computing Systems, CHI'94 Conference Proceedings (Boston, MA), 1994, pp. 292-298.

G. Fischer, A. C. Lemke, R. McCall, A. Morch. "Making Argumentation Serve Design," Human Computer Interaction, special issue on design rationale, Vol. 6, No. 3-4, 1991, pp. 393-419.

G. Fischer, K. Nakakoji, J. Ostwald, G. Stahl, T. Sumner. "Embedding Critics in Design Environments," The Knowledge Engineering Review Journal, Vol. 8, No. 4, December 1993, pp. 285-307.

B. N. Reeves, F. Shipman. "Supporting Communication between Designers with Artifact-Centered Evolving Information Spaces," Proceedings of the

Conference on Computer-Supported Cooperative Work (CSCW'92), ACM, New York, November 1992, pp. 394-401.

G. Fischer, J. Grudin, A. C. Lemke, R. McCall, J. Ostwald, B. N. Reeves, F. Shipman. “Supporting Indirect, Collaborative Design with Integrated Knowledge-Based Design Environments,” Human Computer Interaction, special issue on CSCW, Vol. 7, No. 3, 1992, pp. 281-314.

Grant 4. Human-Centered Intelligent Agents Supporting Communication and Collaboration in Domain-Oriented Design Environments

Summary of Completed Work. This project extended the research work and the prototype system developed in Grant 2. It explored the embedding of intelligent agents into domain-oriented design environments with the goals of reducing the cognitive load on designers through active behavior and improving the quality of the designed artifact. The project began to investigate the World Wide Web.

Limitations Exposed by the Grant. The project illustrated that large information repositories should not simply be built and used, but that they have to evolve by their users. This created the view that such systems should not be created by a few people doing lots of work, but should be ìgrownî by many people incrementally contributing small amounts of additional information and knowledge.

Development of Human Resources. The relatively small research grant contributed to two Ph.D.s (Christoph Thomas and Jonathan Ostwald). The graduate research assistant (Lindstaedt) worked with NYNEX on the development of the GIMMe system.

Five Most Important Publications:

G. Fischer, C. Thomas, “Using Agents to Personalize the Web,” Proceedings of the 1997 International Conference on Intelligent User Interfaces (Orlando, Florida), ACM, New York, NY, 1997, pp. 53-60.

G. Fischer, S. Lindstaedt, J. Ostwald, M. Stolze, T. Sumner, B. Zimmermann, “From Domain Modeling to Collaborative Domain Construction,” In Proceedings of DIS’95, Symposium on Designing Interactive Systems, Ann Arbor, MI, 1995, pp. 75-85.

G. Fischer, S. Lindstaedt, J. Ostwald, K. Schneider, and J. Smith, “Informing System Design Through Organizational Learning,” Proceedings of the Second International Conference on the Learning Sciences, July 1996, Northwestern University, Evanston/Chicago, published by: Association for the Advancement of Computing in Education, pp. 52-59.

G. Fischer, “Seeding, Evolutionary Growth and Reseeding: Constructing, Capturing and Evolving Knowledge in Domain-Oriented Design Environments,” Proceedings of IFIP WG 8.1/13.2 Joint Working

Conference, In A. Sutcliffe, D. Benyon, F. van Assche (eds.), Domain Knowledge for Interactive System Design, IFIP Series, Chapman & Hall, London, Geneva, Switzerland, May 1996, pp. 1-16.

G. Fischer, "Distributed Cognition, Learning Webs and Domain-Oriented Design Environments," Proceedings of the Conference on Computer Supported Collaborative Learning (CSCL'95), Indiana University, October 1995, pp. 125-129.

Relation of Prior NSF Work to the New Proposal

In our previous grants we have explored collaboration theory and technology in the design and use of high functionality software systems to support the work of individuals and small design teams. We have developed conceptual frameworks concerning (1) multifaceted architectures for domain-oriented design environments and computational support for lifelong learning integrated with work processes [Eden et al., 1996]; (2) the maintenance and evolution of growing information bases through seeding-evolution-reseeding [Fischer et al., 1994]; (3) embedding communication in and routing work through design environments [Reeves & Shipman, 1992]; and (4) providing knowledge delivery with critiquing and other agent mechanisms [Nakakoji & Fischer, 1995].

Our research in domain-oriented design environments explored the shortcomings and limitations of generic systems and integrated different aspects of design support environments [Fischer, 1994]. Aspects investigated included active help delivery systems [Fischer et al., 1984]; critics [Fischer et al., 1991]; information filtering [Fischer & Stevens, 1991]; adaptive and adaptable systems [Fischer, 1992; Rausch, 1996]; end-user modifiability [Fischer & Girgenson, 1990; Girgensohn, 1992; Stahl, 1993a]; and incremental formalization of large information spaces [Shipman, 1993].

The major new aspect of this proposal is to move from a primarily individual perspective (e.g., individual lifelong learning) to an organizational perspective. In our proposed project, we will develop and study a form of organizational memory based on our model of domain-oriented design environments.

In order to gain a deeper and broader understanding of the research issues associated with this shift, we organized a research symposium in May 1996 entitled "Computational Support for Continually Evolving Organizational Knowledge Bases," which brought together a dozen of the leading researchers in organizational memory and organizational learning (for details, see: http://www.cs.colorado.edu/~ostwald/symposium/symposium.html) and we participated in a workshop at the CSCW'96 conference entitled "CSCW and Organizational Learning" [Lindstaedt, 1996b].

The proposed project builds on ideas and technologies from prior work. It expands them by focusing on organizational issues and by exploiting and redirecting the emerging WWW support mechanisms for organizational learning and organizational memories. The move to the WWW is a response to the limitations of our past closed systems, and the emphasis on practitioners sustaining information evolution is a response to the short lifetimes of our domain-oriented knowledge bases. In other, related prior NSF research (see list at the beginning of this section) we have established ongoing collaborations of our research center with community organizations, industrial partners, and interdisciplinary academic departments in Boulder as well as world-wide; the proposed project will deploy and assess our research within these organizations.

Section 2. Conceptual Framework

Our approach to organizational memories and organizational learning focuses on communities of practice as the unit of analysis, for reasons discussed in this section. We will analyze interdisciplinary sources to provide a basis our theoretical framework, including educational theory (constructivist learning, e.g., [Harel & Papert, 1991]); design methodology (design rationale [Moran & Carroll, 1996]); cognitive psychology (distributed cognition [Norman, 1993]); social theory (activity theory [Nardi, 1993]); anthropology (situated action [Suchman, 1987]); philosophy (epistemology [Dreyfus, 1991]); sociology (communities of practice [Lave, 1988]); management science (organizational learning [Senge, 1990]); and computer science (intelligence augmentation [Bush, 1945]).

The concepts introduced in this section will be used to guide our proposed project and to assess its accomplishments. This framework suggests issues to explore, needs to support, approaches to try, and questions to evaluate. Within this context, we will design and prototype software systems to support work, learning, and collaborating in specific domains. To ground our research in the domains, we will work closely with practitioners from relevant disciplines, observing their work patterns, joining in participatory design with them, and having them try out our prototypes.

Communities of Practice

A community of practice is a group of people who share a set of activities and who interact to achieve shared objectives and to maintain their community [Lave & Wenger, 1991]. Unlike an organization, which has well-defined bureaucratic structures, a community of practice is often an informal network of people who share expertise, war stories, and practical advice [Orr, 1990]. Such communities typically form through personal ties in order to help each other keep up with new organizational or technological developments that impact their ability to get work done. These groups have a life of their own that helps them accept newcomers and survive when old-timers leave. Because of their unofficial status, communities of practice often go unrecognized and unsupported. As the role of these communities grows – particularly in information-intensive settings – it becomes increasingly important to understand them and to provide computer tools to support their functioning.

We have begun to work with local-area computer network (LAN) designers and managers at the University of Colorado in order to understand their needs for computer-supported organizational memory. This community exists within a larger organizational structure and cuts across official boundaries based on practical needs to interact and to share information. Their information needs include technical knowledge of their work domain (e.g., what are the latest routers on the market and what are their costs, capabilities, problems, etc.), local lore (the manager of LAN x is a UNIX guru), and specific arrangements (the print server in LAN x is configured as y for reason z). The fact that most of this information is kept in the minds of individuals makes it difficult for other community members – particularly newcomers who do not yet know who has what information and have not established personal relations – to do their jobs.

We understand practice as situated activity in which practitioners pursue activity within concrete physical, technical, cultural, and interpersonal circumstances [Giddens, 1984; Lave, 1993; Suchman, 1987]. Rather than modeling practice as the execution of explicit goal-oriented procedures, we are interested in the established, generally unstated practices of a community that determine how things are done by its members – what Bourdieu calls the habitus or the tacit culture of the community [Bourdieu, 1972].

The daily practice of a community not only produces the community's work products, it also reproduces – more or less effectively – the preconditions for the future of the community. New members learn community practices as they engage in them actively, not necessarily through didactic instruction [Schön, 1983]. As the community practice produces learning, it reproduces its own future. Because much of what needs to be passed on is never articulated explicitly, education takes place through apprenticeship relationships and training of reflective practitioners [Brown & Duguid, 1992]. This learning can be facilitated by a group memory that includes evolving artifacts of communal practice [Fischer et al., 1996b; Lindstaedt, 1996a; Ostwald, 1996].

The theory of practice addresses a number of problems that have arisen in the human-computer interaction community [Kuutti, 1996; Nardi, 1996], and that have implications for organizational memory and organizational learning. It broadens the analytic scope to take into account the social context in which people use computers [Hutchins, 1993]. The social context of a community of practice provides motivation to pass knowledge from old-timers to newcomers as everyone tries to increase their participation and reproduce the community [Lave & Wenger, 1991]. It ties working and learning together into a single framework. The introduction of new computational memories into this process will transform the social fabric, the cycles of learning, the interpersonal needs of the group [Ehn, 1989]. The design of organizational memories must take such implications into account.

Finally, the theory of practice provides a perspective on work in which sustainability means not maintaining the status quo, but rather maintaining a constant flux of new members and new knowledge. Computational environments for communities of practice must support this sustainability by allowing members to extend, update, and restructure organizational memory continuously. They must also make it easy to redefine who has access to what information in response to continual shifts in roles, assignments, and understandings. Sustainability of organizational memory means keeping it tuned to the changing needs of individuals because organizational learning takes place in parallel with the lifelong learning of community members [Senge, 1990].

Organizational Learning

Our vision of organizational learning focuses on recording knowledge gained through experience (in the short term), and actively making that knowledge available to others when it is relevant to their particular task (in the long term) [Fischer et al., 1996b]. A central component of organizational learning is a repository for storing knowledge – an organizational memory. However, the mere presence of an organizational memory system does not ensure that an organization will learn [Argyris & Schon, 1978]. Today, information is not a scarce commodity; the problem is not just to accumulate information, but to deliver the right knowledge at the right time to the right person in the right way. Organizational learning happens only when the contents of organizational memory are utilized effectively in the service of doing work [Dodgson, 1993].

Traditionally, people went to school or attended training seminars or studied books to learn facts that might be needed for later work. When working and learning are integrated in the process of organizational learning, information needed for a current task is available just-in-time [Fischer, 1991].

For sustained organizational learning, three seemingly disparate goals must be served simultaneously. Organizational memory must:

- be extended and updated as it is used to support work practices;

- be continually reorganized to integrate new information and new concerns; and
- serve work by making stored information relevant to the new task at hand.

We envision organizational learning as a continuous cycle in which organizational memory plays a pivotal role:

- Individual projects serve organizational memory by adding new knowledge that is produced in the course of doing work, such as artifacts, practices, rationale, and communication.
- Organizational memory is sustained in a useful condition through a combination of computational processes providing information (e.g., [Hill et al., 1992]) and people actively contributing [Girgensohn, 1992].
- Organizational memory serves work by providing relevant knowledge when it is needed, such as solutions to similar problems, design principles, or advice.

The intimate relation between organizational memory and work practice implies that the contents of organizational memory must be easily accessible within the context of work. Computational support for organizational learning, therefore, must tightly integrate tools for doing work with tools for accessing the contents of organizational memory.

Through everyday work, a community of practice generates knowledge that may be critical in its future [Brown, 1991]. The communityís practices are generally tacit, not written down or expressed in words [Polanyi, 1966]. Often, the only time that the knowledge exists in explicit form is when it is being actively reflected upon and used to do work [Stahl, 1993a]. By capturing this knowledge as it arises and storing it in repositories of organizational memory, a community can preserve information that is otherwise lost. Rather than building organizational memories by interviewing experts to formulate rules for expert systems, we will study the practices by which organizations do their work and communicate knowledge, and to capture the knowledge as it is articulated during work. We want to create "living" organizational memories [Terveen et al., 1995] – information spaces that are sustained and managed by the people who use them in their work, rather than by people in other parts of the organization who may have requisite technical expertise but are not intimately involved in the actual work practices [Stahl et al., 1995a; 1995b].

A principal challenge for organizational learning is to capture a significant portion of the knowledge generated by work done within a community. Experience with organizational memories and collaborative work has exposed two barriers to capturing information:

- ❖ Individuals must perceive a large enough direct benefit in contributing to organizational memory to outweigh the effort [Grudin, 1992].
- ❖ The effort required to contribute to organizational memory must be minimal so it will not interfere with getting the real work done [Carroll & Rosson, 1987].

The consequence of these barriers means that processes of information capture, structuring, and delivery must be computationally supported as much as possible or they will simply not get done.

Organizational Memory

Organizational memories are information systems that are used to record knowledge for the purpose of making this knowledge useful to individuals and projects throughout the community of practice and into the future [Ackerman, 1994]. Ideally, an organizational memory allows individuals within the community to benefit from the experiences and insights of others, by actively informing work practices at the point when the information is actually needed [Fischer et al., 1996a]. That is, an organizational memory should not be simply a passive repository of information, but an interactive medium within which collaborative work can actually be conducted and through which communication about the work can take place and be situated.

It is often assumed that the Internet solves the problem of organizational memory. While the World Wide Web (WWW, web) on the Internet functions primarily as a broadcast medium and therefore lacks the interactivity needed, intranet structures can indeed be designed to implement organizational memories. An intranet is a small version of the web, in which access is restricted to a particular community. It uses the same technology standards (e.g., TCP/IP, HTTP) as the global web. Generally, intranet information is stored in a database rather than in fixed HTML documents, so it can be displayed dynamically to use the latest information and to respond to unique queries. Intranets are rapidly replacing traditional client/server systems as the preferred technology for computer-based organizational memories. Intranets make more flexible organizational memories because users can access them with a web browser on any computer and because the computation of the client display logic, the organizationís business rules, and the database query logic can execute on different computers.

All the major software companies are rushing to support the building of intranets. Microsoftís Office 97 applications, for instance, can publish web documents directly. Database environments are beginning to support live data editing through forms on the web (using ODBC and JDBC database connection standards). Special environments such as Tango allow a developer to design web data entry forms quickly using visual drag-and-drop tools. Finally, an extraordinary wave of sophisticated development environments incorporating scripting languages are appearing (at least in beta or vapor ware): Borlandís IntraBuilder, IBM/Lotusís Notes/Domino, Netscapeís LiveWire, Microsoftís FrontPage, Oracleís InterOffice, Novellís GroupWise, PowerBuilder, Cold Fusion, SuperNova, etc.

Intranet technology seems to offer a promising approach and substrate for building organizational memories. However, these environments do not by themselves suggest how to integrate work and learning, how to capture new information, how to support information evolution, how to deliver relevant knowledge, or how to computationally support these processes under user control. Yet, that is precisely what is needed. We maintain that systems to support organizational learning should take an analogous approach to our domain-oriented design environment support for informing collaborative design work. We propose to explore organizational memory that does this, using commercially available intranet technology as an enabling technology .

Section 3. A Scenario of Organizational Learning Using Organizational Memory

To address the issues reviewed in the previous section, we propose to prototype an organizational memory system named WebNet that explores these issues within concrete work contexts. One community of practice with whom we plan to collaborate in designing and assessing WebNet is local-area network (LAN) designers and managers at the University of Colorado. Following is a vision of how WebNet might be used by this community. The scenario illustrates how WebNet integrates working, learning, and collaborating. The purpose of the scenario is to present concrete examples of the kinds of information and mechanisms that WebNet will include, as a background to the discussion of computational support in the following section.

Kay is a geography graduate student who works part-time for network services. Kay logs into WebNet through her web browser, and WebNet responds by displaying Kay's WebNet home page. Kay had designed this page to include information sources she needs to check regularly; it delivers information that is related to her LAN and to her job responsibilities. Kay's WebNet home page contains a message list (with email and comments directed to Kay from co-workers and clients), a to-do list for tracking her current projects, and a community-wide task list of jobs that need to be done.

Integration of the Work Situation. Kay notices that she has a message from Ray, her supervisor, suggesting a new task for her. Kay selects the Geology job from the task-list and WebNet displays a task specification page (see Figure 1-A). The task specification says that a new Windows NT Server and three Macintosh PowerPC workstations are to be connected to the Geology Network in room 214. Kay's task is to prepare a logical design, parts list, and price breakout for the new installation. The task specification also provides a budget and contacts within the Geology Department. Kay clicks on "reserve task" to inform her co-workers and WebNet that she will take care of the task.

When Kay clicks on "Geology Net" in the task specification, WebNet displays a logical map of the current Geology LAN in the knowledge-based construction tool for LANs. The construction tool provides a work area, a tool bar, and a palette of network design elements that can be selected with the mouse and placed in the work area (see Figure 1-B).

Kay begins to plan the installation of new equipment by adding the purchased equipment to the existing logical network using the construction tool. She selects the Macintosh icon from the palette and places three workstations into room 214. Then she selects a Windows NT icon and places it. Finally, Kay connects the new equipment by dragging the cable to reach from the existing network to each of the new machines.

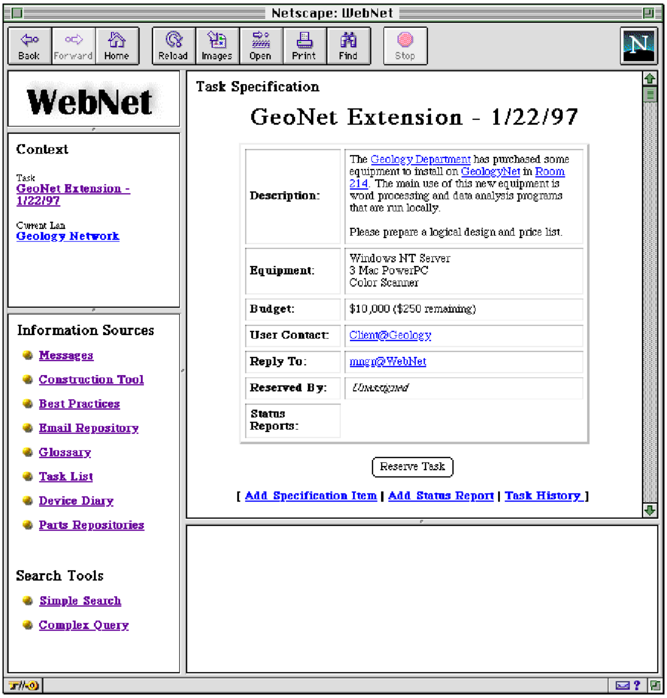
Information Delivery. When Kay has connected the machines to the network, WebNet beeps and places a blinking router icon at the junction between the existing network and the portion that Kay has added. A critic message appears in WebNet's lower pane, indicating that the configuration she has specified requires a router. Kay knows what a router basically does and why a router is needed in this configuration. However, she doesn't know what specific router is needed or how much the needed router should cost.

Kay selects the link to "router" in the critic message, and WebNet brings up a new page containing information about routers (see Figure 1-C). The router information page contains a short description of routers from the WebNet glossary, a collection of definitions for common networking terms.

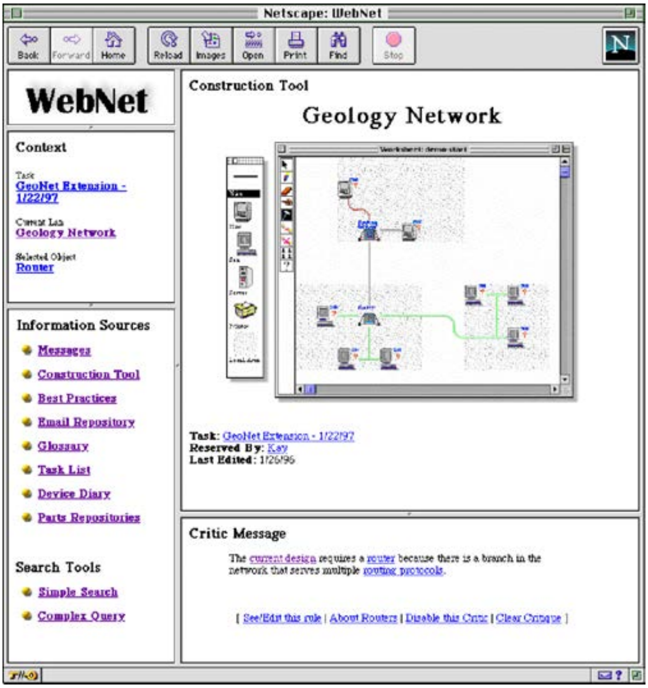
Kay finds that this definition is also too general so she decides to check out some displayed bookmarks. Bookmarks consists of a catalog of URLs that previous WebNet users had found helpful and had added. WebNet has displayed the bookmarks that are relevant to the current design. To Kay's disappointment, the bookmarks point to router manufacturersí pages, which contain detailed specifications about the routers, but not the type of information that Kay needs.

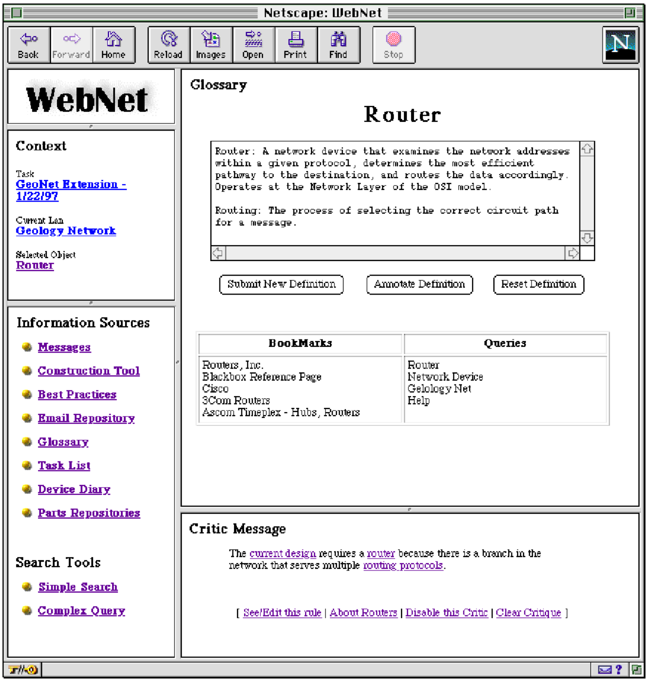
Kay decides to search WebNet's information space. WebNet supplies a default query based on the current LAN design context: "list all information about routers". Kay can use this default to search WebNet, or she can modify the default query by simply typing in more words to the query box. More sophisticated searches may be performed by selecting the "more choices" button, which brings up a query window containing an interface for constructing queries involving particular information sources within WebNet, author, dates, and specific networks, in addition to the search string.

Kay begins her search by selecting the "Search Now" button. WebNet displays links to many pieces of information, ordered by their relevance to the query string. Overwhelmed by the amount of information, Kay decides to refine the query. She selects “more choices” and restricts her search to email written in the past six months and modifies the query to "list emails about routers for small networks" (see Figure 1-D).

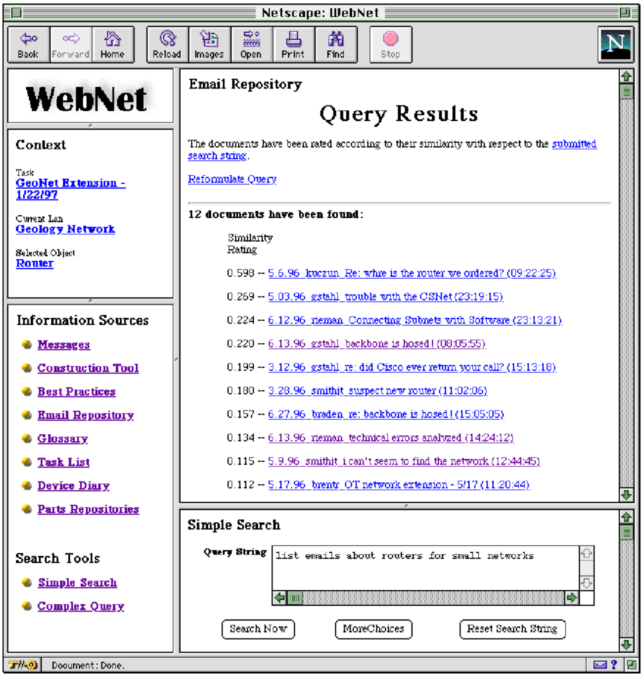


A.

B. 
Netscape: WebNet
Back
Forward
Home
Reload
Images
Open
Print
Find
Stop
WebNet
Context
Task
GeoNet Extension - 1/22/97
Current Lab
Geology Network
Selected Object
Router
Information Sources
Messages
Construction Tool
Best Practices
Email Repository
Glossary
Task List
Device Diary
Parts Repositories
Search Tools
Simple Search
Complex Query
Construction Tool
Geology Network
Task: GeoNet Extension - 1/22/97
Reserved By: Kay
Last Edited: 1/26/96
Critic Message
The current design requires a router because there is a branch in the network that serves multiple routing protocols.
[See/Edit this rule | About Routers | Disable this Critic | Clear Critique]


Netscape: WebNet
Back
Forward
Home
Reload
Images
Open
Print
Find
Stop
WebNet
Context
Task
GeoNet Extension - 1/22/97
Current Lan
Geology Network
Selected Object
Router
Information Sources
Messages
Construction Tool
Best Practices
Email Repository
Glossary
Task List
Device Diary
Parts Repositories
Search Tools
Simple Search
Complex Query
Glossary
Router
Router: A network device that examines the network addresses within a given protocol, determines the most efficient pathway to the destination, and routes the data accordingly. Operates at the Network Layer of the OSI model.
Routing: The process of selecting the correct circuit path for a message.
Submit New Definition
Annotate Definition
Reset Definition
BookMarks
Queries
Routers, Inc.
Blackbox Reference Page
Cisco
3Com Routers
Ascom Timeplex - Hubs, Routers
Router
Network Device
Gelology Net
Help
Critic Message
The current design requires a router because there is a branch in the network that serves multiple routing protocols.
[See/Edit this rule | About Routers | Disable this Critic | Clear Critique]

C.


Netscape: WebNet
Back
Forward
Home
Reload
Images
Open
Print
Find
Stop
WebNet
Context
Task
GeoNet Extension - 1/22/97
Current Lan
Geology Network
Selected Object
Router
Information Sources
Messages
Construction Tool
Best Practices
Email Repository
Glossary
Task List
Device Diary
Parts Repositories
Search Tools
Simple Search
Complex Query
Email Repository
Query Results
The documents have been rated according to their similarity with respect to the submitted search string.
Reformulate Query
12 documents have been found:
Similarity Rating
0.598 -- 5.6.96 kuczun Re: whre is the router we ordered? (09:22:25)
0.269 -- 5.03.96 gstahl trouble with the CSNet (23:19:15)
0.224 -- 6.12.96 neman Connecting Subnets with Software (23:13:21)
0.220 -- 6.13.96 gstahl backbone is hosed! (08:05:55)
0.199 -- 3.12.96 gstahl re: did Cisco ever return your call? (15:13:18)
0.180 -- 3.28.96 smithjt suspect new router (11:02:06)
0.157 -- 6.27.96 braden re: backbone is hosed! (15:05:05)
0.134 -- 6.13.96 neman technical errors analyzed (14:24:12)
0.115 -- 5.9.96 smithjt i can't seem to find the network (12:44:45)
0.112 -- 5.17.96 brentr OT network extension - 5/17 (11:20:44)
Simple Search
Query String
list emails about routers for small networks
Search Now
MoreChoices
Reset Search String
Document: Done.

D.

Figure 1. WebNet Scenario Pages. A. Task Specification. B. Construction Tool loaded with the Geology Network. C. Information about Routers. D. Query Results in GIMMe.

This query returns just twelve email messages. One describes how Pat used a PC as a router in a small LAN. Pat's email indicates that routing in software can be cheaper and more flexible than through a hardware router, although there is a performance penalty.

Sustaining the Organizational Memory. Kay decides that Pat's solution may also work for the Geology Network. She adds information about her solution to WebNet's glossary, making it available to other members of the network design community. She includes a link to Pat's email message, and also a link to her design, to connect these related pieces of information. Now other designers in Kay's community will benefit from the knowledge Kay uncovered through her work.

Kay returns to the task description page and adds a status report describing her proposed design. She tags the status report to be sent to Ray, to the Geology contact person, and to Pat, asking for feedback on her decision.

Section 4. Computational Support

The conceptual framework presented in Section 2 implies that organizational memory systems supporting organizational learning must be tightly integrated with tools for doing work in order to capture new knowledge, to allow the community to sustain it, and to actively deliver information when needed. Only if the organizational memory includes representations of the work context can it decide what information is relevant to the current task. This project will explore mechanisms for the software to make such determinations. The scenario showed a simple example of one person interacting with such an organizational memory.

This section presents our technical approach. Our approach extends prior work by us and by others; it also takes advantage of emerging intranet technologies. The significance of this project is to integrate the techniques in a theoretically motivated way and to assess how well they can address the practical issues confronting communities of practice in the information age. After reviewing our prior work and the work of others, this section will discuss some mechanisms for addressing our core research issues:

1. How to capture knowledge and integrate the contexts of work.
2. How to sustain the timeliness and utility of evolving information.
3. How to deliver relevant information actively and adaptively.

Relation of Our Prior Work to Proposal. We have created and assessed design environments for the following domains: kitchen design [Nakakoji, 1993], programming [Mastaglio, 1991], user interface design [Lemke, 1989], voice dialog design [Sumner, 1995], simulation design [Repenning, 1993], lunar habitat design [Stahl, 1993a], service provisioning [Ostwald, 1996], and LAN design [Reeves, 1993; Shipman, 1993; Sullivan, 1994]. In particular, we investigated how such systems could support the location [Henninger, 1993], comprehension [Redmiles, 1992], modification [Girgensohn, 1992], querying [Fischer & Nieper-Lemke, 1989], filtering [Stevens, 1993], and sharing [Rausch, 1996] of information in large information spaces of domain knowledge.

This prior work has contributed to a prototypical architecture for domain-oriented design environments, which integrates working and learning with components for: (a) construction of the design artifact, (b) a knowledge base of design rationale and artifact designs, and (c) computational critics that actively deliver relevant knowledge. The proposed project will generalize from this prototypical architecture to one having the following general functions: (a) representations of the work/collaboration context, (b) a rich, sustainable information space, and (c) mechanisms to map from the work context to relevant information for delivery.

Just as our work on design environments involved the interplay of multiple software components (e.g., construction, simulation, specification, gallery, catalog, rationale, critiquing, etc.) to deliver relevant design rationale, the proposed project will investigate mechanisms that deliver timely knowledge to practitioners by retrieving items from the information space that are related to the current work context. We will discuss our approach to implementing these mechanisms in the remainder of this section, after we relate our approach to that of others.

CSCW and Distributed Artificial Intelligence. Our approach distributes work and control between human practitioners and computational agents embedded in organizational memory. Our paradigm shares a large number of research issues with two related areas: (1) Computer Supported Cooperative Work (CSCW) [Greif, 1988], which emphasizes communication and collaboration among humans mediated by computer; and (2) Distributed Artificial Intelligence (DAI) [Bond & Gasser, 1988], which emphasizes communication and collaboration among computational agents. In order to enrich CSCW environments with computational agents, the information content must be at least semi-formal. By studying systems with no humans directly involved, DAI [Durfee, 1992; Gasser, 1991; Palaniappan et al., 1992] focuses on related but primarily different research issues, and it is not faced with some of the challenges unique to human-centered agent-based systems.

Semi-formal Systems. Our approach to formalizing information in the organizational memory attempts to avoid the need for complete formalization without placing an unmanageable burden on the people who use the system. By representing the contexts of work, we establish a shared understanding of that context by the system and its users. By combining automatic capture of information, incremental formalization of stored knowledge, and end-user control over structure, we try to facilitate a workable balance. Related work on semiformal systems indicates that formalization need not be complete to be useful in aiding communication and collaboration [Bobrow, 1991; Malone et al., 1988; Malone et al., 1992; Winograd, 1988].

Workflow Systems. Our approach to organizational memory can be contrasted with workflow systems [Ellis, 1991] and other systems that are established by an organization to structure and regulate work processes. Workflow systems may be appropriate to coordinate regular and predictable interactions among different work groups, but they are not appropriate to support the situated and often ad hoc work within communities of practices, where innovation and change are ubiquitous. Similarly, systems to support ISO 9000 often try to incorporate organizational memory about work procedures in client/server or intranet systems. However, they center on a hierarchy of documents and fail to capture the implicit practices, tacit background knowledge, and changing circumstances that are critical to organizational practice. Organizational memory systems for communities of practice should empower users to cope with vague problems and unexpected breakdowns, and to share innovative solutions and work practices with their peers.

Design Rationale. Our approach also contrasts with design rationale schemes such as gIBIS [Conklin & Begeman, 1988] that require designers to interrupt work to articulate justifications for their design moves [Fischer et al., 1996a; Reeves & Shipman, 1992]. Designers are often unwilling to invest the extra effort to provide rationale [Grudin, 1994]. Similarly, most web-based group memory systems − such as threaded conversations and Frequently Asked Questions (FAQs) − are divorced from work contexts, so they can neither capture knowledge as it is articulated nor target retrieval to work states. Moreover, like many other information systems, these are impoverished in that they cannot contain work artifacts themselves, but only discussions about artifacts.

We postulate that organizational memories need to incorporate tools for working and communicating within the system. This is something that workflow, ISO 9000, design rationale, and similar support systems fail to do. By including software components for design, analysis, communication, etc. in which community members can carry out some of their work and through which they can collaborate with each other, organizational memories can address their central tasks: to capture, sustain, and deliver information.

1. How to capture knowledge and integrate the contexts of work

We will combine several mechanisms for embedding work and communication in a computational information system that we implemented and assessed in our previous NSF grants. In Janus [Fischer et al., 1989] and similar design environments, the construction of a design artifact takes place in a construction component that uses a palette of domain items so that the software can track the semantics of the design. In the Remote Exploratorium [Ambach et al., 1995], the domain items in this palette can be exchanged within a virtual community through a web page within the system. In the Indy system for LAN design [Reeves & Shipman, 1992], post-it notes and other annotations can also be embedded in the construction area. The Kid system [Fischer & Nakakoji, 1991] incorporated a specification component to capture and represent design goals. EVA [Ostwald, 1995] routed design ideas through a shared computational repository. In GIMMe [Lindstaedt, 1996a] email is sent through and archived in a group memory. These mechanisms can all be used in organizational memories. The scenario illustrated several. Kay worked on designing the extended LAN within a construction/simulation component and she found critical information in an email component based on GIMMe.

Our organizational memory systems will generalize the notion of representing the contexts of design. In addition to representing the layout of an artifact or its specification criteria, a system can, for instance, represent the people involved – either as individuals or as workers in certain organizational roles. The Hermes design environment [Stahl, 1993a] explored a perspectives mechanism that tagged versions of information as belonging to different perspectives: different system users chose to retrieve information according to their profession (e.g., plumbing or electrical); domain (residential, commercial, industrial habitats); or organizational role (designer, supervisor, manager). Situating knowledge delivery within Janus, Kid, or Hermes-type contexts – constructions, specifications, perspectives – can facilitate the selection of relevant information.

In the context of LAN design and management, WebNet representations of the problem context will include: physical layout of equipment; logical layout of functional components; simulation of major network traffic sources and routers; performance specifications; professional perspectives; organizational business rules; problem reports; and email discussions. Each context representation will require its own user interface to allow people to modify the characteristics and effects of the representation as well as to instantiate representations of specific tasks. Each representation will affect the selectivity of the system's knowledge delivery.

We will use mechanisms for communication capture such as those we used in the GIMMe email archive. GIMMe [Lindstaedt, 1996a] works this way: a community establishes an email alias for all communication of general interest to the group. In addition to members getting the email, it is also sent to a group memory archive. Here it is indexed for full-text search (using latent semantic indexing, described below) and made available for searching and browsing by community members. Members can also reorganize the mail by categories. Not only can members stop reading their daily group email and periodically scan GIMMe by categories of interest, but new members can learn the groupís history, and all members can retrieve prior discussions and decisions. GIMMeís functionality will be incorporated in WebNet, where it will be enhanced with tools to sustain its evolution and to actively deliver relevant contents based on work contexts.

2. How to sustain the timeliness and utility of evolving information

The approach to sustaining information is based on an extension of our model of system evolution (ìSERî). We want to empower practitioners to evolve their own information spaces in a sustainable way. This requires making the web interactive (with ìDynaSitesî) so information can be changed as it is used. It also requires structuring mechanisms (such as ìperspectivesî) for organizing changing information.

Sustainable Evolution. In evaluating our domain-oriented design environments, we observed that the information stored in the knowledge bases soon became obsolete, as did the system functionality itself. Our seeding, evolutionary growth, and reseeding (SER) model [Fischer et al., 1994] is an attempt to see how community members can evolve their information systems [Henderson & Kyng, 1991]. The model distinguishes three categories of professionals involved in creating, maintaining, and using an organizational memory:

- Substrate producers. These are the people who create the underlying technology. For our project, these are the producers of intranet development environments and other substrates.
- Memory designers. These are the people who design and implement an organizational memory. For our project, these are members of our research group.
- Practitioners. These are the people who use the organizational memory in their work practices. For our project, these are the communities of practice that collaborate with us and try out our prototypes.

The SER model consists of the following three processes:

- Seeding. In the seeding process, memory designers and practitioners work together to instantiate an organizational memory seeded with domain knowledge and local information.

- ❖ Evolutionary Growth. In the evolutionary growth process practitioners add information to the seed as they use it to do work. Work artifacts and communications accumulate in the organizational memory, resulting in growth of memory contents. In addition, new work produces needs for new system functionality and structures.
- ❖ Reseeding. In the reseeding process, memory designers and practitioners reorganize and reformulate information so it can be reused to support continuing tasks.

In the proposed project we want to investigate the possibility of going beyond our prior reseeding model by providing mechanisms for communities of practice to sustain the growth of their organizational memories without a distinct reseeding phase. Organizational memories should be able to evolve in symbiosis with their communities of practice like biological species evolve with their environments – with no interventions needed from outsiders. Incremental formalization techniques [Shipman, 1993] can be used to automatically add computationally interpretable attributes to information that has accumulated during the evolutionary growth. Formalization of information increases the system's ability to structure and retrieve the information, and thereby generalizes the information content beyond the specific context in which it was originally added. Empirical evidence shows that, within communities of computer users, technically proficient ìlocal developersî emerge who are willing and able to perform many system modifications [Nardi, 1993]. WebNet will include mechanisms for communities – especially their power-users – to use to sustain the usefulness of the organizational memory continuously, thus reducing the need for a separate, disruptive reseeding phase that requires the memory designers to return. We have begun to explore this possibility with GIMMe, which allows members to reorganize as well as search and browse its email repository. We will make use of open industry standards so we can take advantage of future technological advances to increase substrate functionality, too, with minimal disruption.

Interactive Web Sites. Technologies for intranets are proliferating. However, these commercial products are very generic enabling technologies. They provide tools for building organizational memories but do not by themselves solve the complex issues of capturing, structuring, and delivering information.

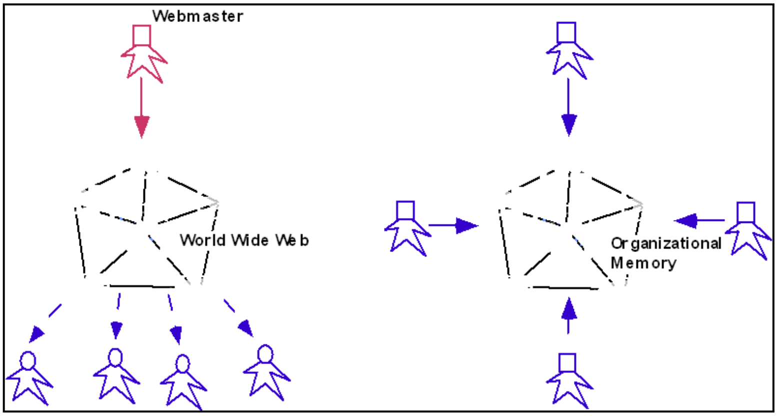


Figure 2. The web as (a) broadcast medium and the web as (b) interactive organizational memory.

WebNet will address current limitations of the web for supporting the kind of interactions required for communities of practice to use and sustain their organizational memories. As typically used, the web is a broadcast medium; people can find some information there, but they cannot easily modify, update, restructure, or contribute to the information source (see Figure 2). This model of the web suffers from one-way communication, poor coverage, poor reliability, low relevance, static format, and rapid obsolescence. These are serious problems for organizational memory. We propose an interactive model of the web, designed to solve each of these problems [Ambach et al., 1997; Fischer & Thomas, 1997; Stahl, 1997].

WebNet will use what we call "DynaSites" to create a rich, interconnected, searchable, and browsable organizational memory that is easily updated and annotated. DynaSites are dynamic web sites. The HTML pages viewed in standard web browsers are created on-the-fly by a commercial intranet builder from data stored in a relational database. Wherever appropriate, the pages include forms for viewers to make changes to the content, subject to a system of permissions that can be configured for each DynaSite. These forms update the underlying database (and thereby the content of future web pages) without requiring any database or web technical knowledge by the users. The structure and other characteristics of a DynaSite can be set up in advance by memory designers or defined and modified by practitioners with appropriate authorizations.

The specific content of DynaSites in a given system will depend upon the domain and the community being supported. Initial DynaSite structures will arise through a participatory design process in which we work closely with community members. Based on our initial explorations of DynaSites for local area network managers, their information space will include a glossary of technical terms and local terminology; a repository of all group email; the current queue of trouble reports and its history; a table of configuration data for each host on a LAN; a diary of changes made to each machine; an on-line manual of approved methods and procedures; LAN design rationale; a FAQ (Frequently Asked Questions about local LANs); threaded discussions among group members; and a directory of external pages of equipment vendors and other external web sites of interest.

Perspectives. In prior work we have explored a "perspectives" mechanism [Stahl, 1993b; 1997] that will be adapted to DynaSites. Perspectives are important for sustaining evolution in collaborative information spaces [Boland et al., 1992]. They allow different changes to the information to be maintained simultaneously in different perspectives. This way, people can make successive changes to the content or organization of information without negating the effects of previous changes. For instance, if one design group has completed an artifact that satisfies all relevant critic rules and saves the artifact in their group perspective, then later changes to the critic rules by another group will not affect the subsequent evaluation of the artifact within its original perspective. In such cases, perspectives provide a versioning system for organizing and sustaining a memory system that evolves over time.

Perspectives can also be used to make knowledge delivery relevant to subgroups of a community. For example, everyone who maintains a given LAN or set of LANs can use the same perspective; there can be a perspective for Macs, one for PCs, and one for UNIX management; perspectives can correspond to the chart of organization, with supervisors having more modification permissions and oversight over certain DynaSites. Perspectives inherit from each other hierarchically [Bobrow & Goldstein, 1980], determining what information is retrieved, how it is displayed, and what modification permissions are granted.

3. How to deliver relevant information actively and adaptively

The standard mechanisms for retrieving information from the Internet or from intranets yield frustrating results [Berghel, 1997]. Indexers and search engines such as Yahoo and Alta Vista work best when information is structured – but the web is not. Typical first searches return hundreds of thousands of hits, with follow up queries returning either still unmanageable thousands or none at all. Attempts to ìpullî down information of interest automatically using software agents (bots) is not yet practical – there are still too many unresolved issues involving how to specify relevance through end-user programming or otherwise. While there is much current work on software agents as a means to aid users in locating information in large information spaces (e.g., [Fischer & Thomas, 1997; Maes, 1994]), most of this work either relies on the user to explicitly formulate a query or relies on an implicit user model. ìSolicited pushî [Wired, 1997] through subscription to specialized or reliable information services is likely to be a popular solution for receiving domain news, but it does not meet the needs of just-in-time learning. Once more, none of the generic solutions integrate information delivery with work.

In our prior work, we have addressed the retrieval problem with query by reformulation [Fischer & Nieper-Lemke, 1989], filtering [Fischer & Stevens, 1991], and critics [Fischer et al., 1991]. In organizational memories, we want to empower practitioners to take maximum advantage of shared knowledge. However, we do not want users to have to formulate database queries as such – that requires professional training and knowledge of data storage structures. We are interested in providing as much software support as possible in formulating initial queries, letting users select from catalogs of queries, and helping people to reformulate queries at a level of abstraction corresponding to how they think about their work tasks. This means integrating the information delivery process with the work context with mechanisms like critics. Another mechanism for doing this is suggested by latent semantic indexing (LSI). Finally, we propose to develop an end-user scripting language for practitioners to reformulate queries.

Critics. Our domain-oriented design environments used the context of constructed artifacts, specified design goals [Nakakoji & Fischer, 1995], and selected perspectives [Stahl, 1993a] to guide retrieval[Fischer et al., 1993]. Computational critics in these systems are agents that monitor the changing work context and identify potential information needs; when such a situation is identified the critic offers to deliver relevant information. Specifications can be used to select different sets of critics, and perspectives can reinterpret the behavior of the critics [Fischer et al., 1993]. Critics remain an important mechanism for organizational memories, but we want to find additional mechanisms to map from representations of the work context to relevant information.

LSI. To combat the brittleness of keywords in searches, we use latent semantic indexing (LSI) [Dumais et al., 1988; Landauer & Dumais, 1997]. We have experience using this with GIMMe, where it provides the primary access to archived email. LSI works by building a multidimensional scaling space through a statistical analysis of all the vocabulary in a textual corpus such as an organizational memory. Using this, LSI can locate items that are closely related to a given word or a longer phrase; it is not restricted to items that contain the exact keyword. LSI nicely augments the use of an embedded work context to help locate relevant information. For example, a textual problem report or a specification document can be used directly as an LSI query to retrieve stored documents that are semantically related (i.e., that deal with the same problems or with related machines and people). In this way, a document in the work area, such as a task description or a problem report, can be used by LSI to find other documents (emails, procedure manuals, previous problem reports) that are related and could prove helpful.

Scripting Language. Because information-intensive work is creative and communities of practice are dynamic, the retrieval of needed information must be under the control of the users. An organizational memory should allow practitioners to modify the information retrieval processes themselves. We will include an end-user scripting language to allow non-programmers to formulate and modify queries. We developed similar scripting languages in our Hermes [Stahl, 1993a; Stahl et al., 1992] and Agentsheets [Repenning, 1995] design environments. The syntax and vocabulary of the language will reflect the structures of the DynaSites database schema and representations of the work contexts, but a drag-and-drop interface to the language will shelter the user from worrying about these matters. In the scenario, for instance, Kay formulated the query, "list emails about routers for small networks."

Section 5. Assessment in Practice

Our project approach incorporates ongoing assessment of our conceptual framework and computational mechanisms. The framework suggests important requirements and mechanisms; our success in designing the mechanisms and the results of assessing them in use will reflect back upon the theory, highlighting important issues for organizational memories and the communities that use them.

We will assess our conceptual frameworks and prototypes in a variety of settings for organizational learning, such as those discussed below. In each of these settings, efforts to enact organizational learning will focus on reconceptualizing the use of technology for organizational learning, rather than simply “gift-wrapping” traditional frameworks with new technologies.

LAN Design Community. The domain of LAN design and management is appropriate because work is done by a community of practice; LANs are not designed once and for all but evolve over time; LAN design relies upon an enormous and rapidly changing information base; and LAN managers do much of their work on computers. Within this setting we will assess the integration of working and learning, new forms of collaboration enabled by our systems, and the ability of the community to sustain their computational environment over time.

Boulder County Healthy Communities Initiative. BCHCI is a community-based effort (of approximately 500 citizens coming from different backgrounds) to identify major trends and implement positive change on issues that affect the long-term health, quality of life, and sustainability of Boulder County. The concerns of BCHCI are (1) to engage citizens as self-directed learners who understand sustainability and can actively participate in design solutions, and (2) to turn BCHCI into a learning community that benefits from citizen input. Our relationship with BCHCI provides a unique opportunity to establish an organizational memory and study organizational learning within a community setting.

NYNEX University. We will build upon our ten-year relationship with NYNEX to reconceptualize organizational learning in industrial settings. NYNEX is the regional telephone company for the New York/New England area, with about 50,000 employees. NYNEX has made an unprecedented commitment to lifelong education of its front-line workers by establishing NYNEX University campuses throughout its operating regions. GIMMe technology is used as part of this effort, aimed to train workers to keep up with the rapid changes in their field through (1) a deeper understanding of emerging technologies, (2) competence with computational tools for finding and communicating new knowledge, and (3) a new emphasis on peer-to-peer learning in the workplace.

L3D Center (including the proposed project). Our research center aims to develop computational support and conventions of use that enable us to be a learning research community. We will create organizational memories for our center, as well as for the proposed project. This self-application of our theories will give us first-hand experience with the strengths and limitations of our conceptual framework and technology.

University of Colorado Courses. University courses have traditionally been based on instructionist educational strategies, emphasizing fixed curricula, memorization, and decontextualized learning. The proposed project will continue our standing commitment to exploring new models of education that emphasize peer-to-peer learning through projects and discussion-oriented classrooms. We will use project prototypes in our own classrooms, where students will explore and reflect upon innovative applications of organizational memory.

Section 6. Work Plan

Year 1. Our initial focus will be on careful analysis of the current practices of the LAN design community at the University of Colorado and our own research group. We will work with an anthropologist to understand the existing practices of communities we collaborate with. Our goal will be to extend the unit of analysis from an individual working and learning to an organizational focus. System-building efforts in the first year will focus on the implementation of a core WebNet system. We will employ available technologies and our prior system mechanisms and extend them as needed.

Year 2. In the second year our emphasis will be on envisioning and enabling new ways of working, learning, and collaborating. We will work closely with several communities to create organizational memory seeds. The seeds will define initial community-specific organizational memories. The seeding process will be grounded by the creation and collaborative assessment of prototypes, with communication about the prototypes captured within the organizational memories. This approach will interleave system-building and assessment, and capture a history of the seeding process that will serve project assessment as well as the ongoing evolution of the systems. We will embed logging mechanisms in the organizational memories to facilitate tracking of the evolution of both information content and structure. In this year we will extend our system functionality with perspectives and a scripting language.

Year 3. The final year of the project will have two primary foci: (1) the use and sustainability of organizational memories by the communities of practice, and (2) an integrative framework for organizational learning in a variety of settings. Assessment of organizational learning in communities will be both quantitative and qualitative. Logs of information use and evolution will provide data about the mechanisms most used and about the dynamics of the organizational memory. By analyzing the usage logs in conjunction with user interviews, we will assess how well the mechanisms and systems supported the sustainability of these information spaces as useful sources of organizational memory under changing conditions. Our assessment of organizational learning in the research settings will lead to an integrated conceptual framework for organizational memories and a generic architecture of computational support for organizational learning.

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Allowing Learners to be Articulate: Incorporating Automated Text Evaluation into Collaborative Software Environments

Proposal to the McDonnell Foundation

A joint project of the Institute for Cognitive Science and the Center for LifeLong Learning and Design at the University of Colorado

1. Abstract

We have been developing software environments that allow teachers or students to build educational simulations to foster collaborative learning. In particular, our WebQuest adventure games motivate players to explore subject matter topics on the World Wide Web as part of classroom research projects. Our goal is to explore how "edutainment" software (like Where in the World is Carmen Sandiego?) can support the construction of personal knowledge and the articulate self-expression of learners. In this effort, we have confronted a problem that is quite pervasive in educational software: the challenges posed to game players by games like WebQuest are currently restricted to questions having well-defined factual answers that can be checked by the software. In order to promote and evaluate the construction of deeper knowledge the software needs to be able to make computational judgments about the content of unrestricted essays that the students write.

A new mathematical technique being developed as part of a cognitive theory of text comprehension—latent semantic analysis, or LSA—promises to provide the necessary computational ability. LSA computes the semantic relations within a corpus of literature on a given subject matter and then uses this information to judge the semantic similarities among submitted written responses. Although LSA has been found to be almost as reliable as human readers in several laboratory tests, it has yet to be applied in classroom settings. The proposed project will incorporate LSA in a variety of ways within our educational software in order to explore a range of theoretical issues related to how computer-based media can help students learn.

We will develop several of our current software prototypes (WebQuest, Remote Explorium, Teacher's Curriculum Assistant) further by extending them with LSA mechanisms and by working with teachers and students in the classroom.

Development will be guided by cognitive theory concerning text comprehension, research techniques for educational software, and evaluation of various applications of our software in educational practice. The software will be extended to allow students to design and create their own games for fellow students to play. Both questions and answers will be in text format, evaluated automatically by the software using LSA. Classes can select themes, create multiple games incorporating summaries of group knowledge, critique the games, and share the games with other schools over the Internet. Ultimately, LSA can be used to match the most appropriate versions of games or information sources on Web sites to different classrooms or to individual students by evaluating the students' written products and comparing them to alternative sources of background information.

The project goal is to explore computer-based tools for supporting the collaborative construction of knowledge in classrooms and the articulate self-expression of individual learners without over-burdening teachers. Automated text evaluation mechanisms will be investigated to allow fact-centered questions to be replaced with open-ended, question-answer interactions, without requiring continuous teacher intervention. More generally, the project will address how software environments can help students to learn in an information-intensive, technologically mediated world by matching individual competencies to appropriate resources.

2. Instructional Problem

The Center for LifeLong Learning and Design at the University of Colorado has been working with classrooms and teachers in the Boulder Valley School District to conduct research in educational software. Specifically, our WebQuest software presents students with an adventure game that teaches students research skills involving the Internet. (See Figure 1.) Each time a student confronts an obstacle in the game, the student must answer questions using information found on the World Wide Web (WWW or Web).

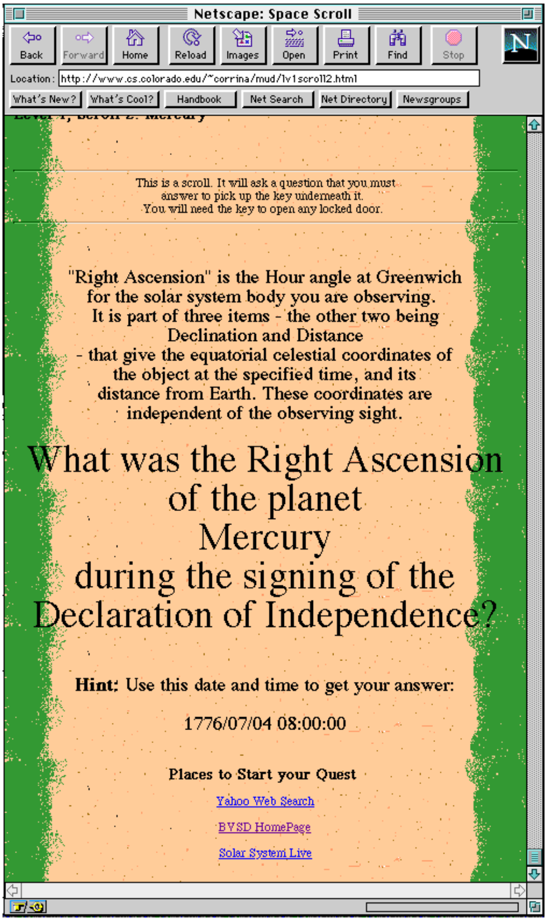

Figure 1. A scroll in WebQuest and a WWW page it suggests for finding the answer. The scroll is presented when a WebQuest player encounters a challenge. The player must conduct research to answer the question. The scroll suggests Web sites or search engines to guide the player to relevant pages on the Web.

Students are enthusiastic about playing the game and surfing the Web. Although WebQuest was just recognized as the "best innovative application of the WWW for education" at the international WWW5 conference in Paris, we think we can make it into a much more effective classroom tool. We recognize several major pedagogical weaknesses to our current approach, based on constructivist theories of learning. These weaknesses are endemic to the computer game approach to education, in which one tries to embed learning opportunities within a motivational game context:

❖ The questions posed require multiple-choice or keyword answers, not the articulation of deeper reflection.

- ❖ The investigation of information is guided by an externally imposed game framework, rather than being student-centered.
- ❖ The acquired knowledge is not tuned to the background knowledge and capabilities of the student.
- ❖ The learning process is not social and interactional.

As a first step in overcoming these weaknesses, we have begun to experiment with having students actually author (i.e., design and program) adventure games for their classmates to play. This makes for a much more intense learning-by-teaching experience; it opens up exciting new possibilities for interactions in the classroom. However, the bottleneck of multiple-choice or keyword answers remains. A student authoring a game must reduce any knowledge about a topic to a few atomic facts which students playing the game have to match literally. We want to allow learners to be more articulate than this.

Multiple-choice questions and keyword answers have always been resorted to in education for pragmatic reasons. Teachers simply do not have the time to read and understand answers to open-ended questions for every test and quiz. Multiple-choice questions have been used for standardized tests because of technical limitations to machine processing of answer sheets. We know how stultifying this restriction to keyword answers has been. It forms a major barrier to moving classroom emphases from the memorization of atomic facts and isolated terms to the construction of deeper understanding and fuller self-expression.

The constructivist alternative to multiple choice questions has proven untenable to date because of the burden it places on teachers. Within the context of an NSF-funded research project focused on learning-on-demand (student-centered and task-centered) we found that self-directed, authentic learning activities require substantially more teacher resources than are normally available in K-12 or university classrooms. Teachers must evaluate written reports and portfolios on topics that may be relatively new to the teachers themselves. To be most effective, feedback in response to student attempts at articulating their growing knowledge must be timely. In the context of educational games, the situation is even more extreme: evaluation of answers must be immediate to avoid interruption of the motivational game context.

If educational software could adequately process unrestricted text, then it could provide a medium for students to construct and communicate higher-order understandings of subject matter without placing an impossible burden on teachers. For instance, if WebQuest could automatically evaluate unrestricted text, then authors of new games could define obstacle problems using short essays, and students playing the game could enter brief texts that would be compared with the problem essay. In this way, everyone could express their own understanding in their own terms.

The ramifications of evaluating unrestricted text by educational software are far-reaching. Ultimately, this capability would allow textual presentations of topics to be selected based upon students' background knowledge. For instance, an individual student or a classroom of students could be evaluated by software that analyzes their sample writings. When the software then presents WWW sites for the student to explore, it could select sites whose text is at an appropriate reading level. As the use of such software becomes prevalent, WWW sites, WebQuest games, and other educational resources could be structured to provide versions of texts at different reading levels. In the "articulate classroom" that we envision, students would express their ideas in writing, producing portfolios of text that the software could evaluate to form a model of the students' levels of understanding. This would provide a valuable tool for the teacher to use in guiding students.

The fact that software like WebQuest is currently restricted to multiple-choice questions illustrates a significant and wide-spread problem in education: how to evaluate, score, classify, and otherwise process unrestricted text automatically, without laborious efforts by highly qualified but over-burdened professionals, such as teachers. Adding a free text capability to WebQuest could increase the educational value of the software, in that information of greater complexity could be searched for, and the students' answers would not have to be as narrowly constrained.

We believe that full natural language understanding by computers is not necessary to remove the bottleneck. Certain computationally feasible analyses of text may be sufficient to meet the needs of software like WebQuest for processing essay answers. The proposed research would permit us to explore this possibility, further developing a promising text analysis technique and extending our educational software to overcome its current weaknesses. Moreover, the project would allow us to test and refine our laboratory-based theories of text comprehension within the context of classroom practice.

Specifically, we propose to investigate a new technique of text evaluation known as latent semantic analysis (LSA). We anticipate that LSA can provide a fully automatic computer technique that allows assessing the content of a text by comparing it with other texts, such as books, articles, essays written by students, single sentences or phrases, even single words. The technique has its limitations and is still being developed. Furthermore, we have only begun to explore its implications, both for psychological theories of meaning and for educational applications. Nevertheless, our work has progressed enough to show that further research along these lines is worthwhile and, indeed, highly promising.

The general cognitive issue that we want to focus on with the proposed project is the question of what it means to acquire subject matter knowledge using tomorrow's technologies of large information bases and efficient search methods. The ability of students to benefit from external information sources both relies upon a level of internally assimilated background knowledge and simultaneously transforms the motivations for acquiring and internalizing such knowledge. What content do students have to know for successful searching? Will they learn if they know that they can always easily find answers by searching? How do these factors combine to produce intellectual competence and motivation?

We will explore these issues through a series of five educational interventions in K-12 classrooms:

1. Having students play WebQuest games that have been authored by us or by the teachers.

2. Having students author their own WebQuest games for their peers to play.

3. Enhancing the use of factual questions and keyword answers in WebQuest with open-ended questions and essay answers, evaluated using automated LSA mechanisms.

4. Allowing students to share WebQuest games and game components across the Internet using Remote Explorium software that we have developed.

5. Supporting the creation and sharing of theme-centered sets of WebQuest games and related curricular resources using Teacher's Curriculum Assistant software that we have prototyped.

These interventions and the evaluation of their effects will be described in Sections 4 and 5, following a discussion of the potential of LSA.

3. Cognitive Research

The proposed work is based on constructivist and collaborative theories of learning, broadly defined. The psychological background most relevant to the proposal is the construction-integration theory of text comprehension (Kintsch, 1994) and the latent semantic analysis theory of knowledge acquisition and knowledge representation (Landauer & Dumais, in press). This theoretical framework is complementary to the cognitive theories guiding our design of computer support for learning: breakdown / repair (Fischer, 1994) and situated interpretation (Stahl, 1993). For the most part this background is relatively widely known; since the proposed project centers on the application of a technique that is less well known, we will focus on explaining latent semantic analysis in this section.

What is LSA?

Latent semantic analysis (LSA) is a mathematical / statistical technique for extracting and representing the similarity of meaning of words and passages by analysis of large bodies of text. LSA uses singular value decomposition, a form of factor analysis, to condense a very large matrix of word-by-context data into a much smaller, but still large (typically 100-350 dimensional) representation. (Berry, Dumais & O'Brien, 1995; Deerwester, Dumais, Furnas, Landauer & Harshman, 1990). The right number of dimensions has been discovered to be crucial; with the best values, which can be easily optimized for a domain, LSA yields up to four times as accurate simulation of human meaning judgments as ordinary co-occurrence measures.

The promise of LSA

Several sources of evidence show that LSA validly reflects human knowledge of word meaning and human interpretations of terms in text passages:

- After training on about 2,000 pages of English text, LSA scored as well as average test-takers on the synonym portion of TOEFL (the ETS Test of English as a Foreign Language).
- After training on an introductory psychology textbook, LSA equaled students' scores on a multiple-choice hour exam.
- LSA significantly improves automatic information retrieval in general by allowing user requests to find relevant text on a desired topic even when the text contains none of the words used in the query.
- The semantic similarity of successive sentences as measured by LSA mirrored manipulated variations in coherence in expository texts and accurately predicted their comprehensibility (Foltz, Kintsch and Landauer, 1994).
- Simple averages (centroids) of the words contained in these sentences significantly predicted the semantic priming by sentences of words judged to be related to the sentences' overall meaning (Landauer and Dumais, in press).
- Pilot studies have found promising results of using LSA (a) to predict which of a set of brief texts an individual student will learn most from depending on the student's prior knowledge as expressed in a short essay (research in progress), and (b) to evaluate the content of essays based on their LSA

resemblance to text studied by the student or to pre-scored essays written by other students (Foltz, 1996, and research in progress).

Potential uses of LSA for learning and teaching

In what follows, we mention a number of examples of potential educational applications that appear worth pursuing eventually. Since we are proposing to develop a tool, it is important to form some idea about the possible range of uses for this tool. Of course, we can investigate only certain of these uses in the present project, as we shall describe in Section 4.

We believe that LSA can eventually provide the basis for a spectrum of effective new tools for facilitating and enhancing exploratory, project-based and collaborative learning, and we mostly describe such potential applications. However, we believe that most of the methods could also be applied in conjunction with other educational styles and methods, including computer-based tutoring, independent study, and traditional classroom instruction. In all cases, the goal of the new tools is not to supplant other methods, but to augment and amplify their benefits to learners and to help educators produce more and better learning with the same educator effort.

1. Finding optimal text for learning. Since actually finding relevant sources in a large information base such as a library or WWW is very difficult, the teacher traditionally provides a closed set of resources containing the necessary information. Furthermore, the problem is not merely to find resources relevant to a topic, but to find ones comprehensible to the learner with a particular background knowledge. LSA may be able to enhance a teacher's ability to automatically match educational resources to individual students.

LSA is not only capable of selecting topic relevant materials, but it is able to match individual levels of prior knowledge and terminological sophistication as well. A research project directed by Landauer & Kintsch and funded by DARPA has shown that LSA can be used to choose, from a set of texts on a particular topic, the one text from which an individual student will learn the most. The underlying principle is a notion adapted from Vygotsky (1968), "zones of proximal learning" (Kintsch, 1994). A student learns most from text that, on the basis of prior knowledge, is understood with moderate effort and contains just the right amount of new information. Students are first asked to write short essays on a topic, then the LSA centroid of their essays are compared with those of texts on the same topic but at varying levels of sophistication. Wolfe, Schreiner, Rehder, Landauer & Kintsch (in preparation), using texts about heart function, have shown that LSA-based choice of a text for an individual can result in about 50% more learning than random choice of text.

2. Coherence and comprehensibility measurement. LSA can be used to automatically measure text coherence and comprehensibility, important aspects of thinking and its written expression. Automatic evaluations could be incorporated as a component for a computer tutor in most subjects, or directly serve as an aid for independent learners much like current spelling, grammar or style checkers.

3. Connecting students with each other and with relevant experts. LSA could also be used to match more effectively a particular student to other people with similar interests for conversation, collaboration or consultation. Students could either post messages on the Internet or leave statements of interest with characters in a WebQuest game. A computer-based agent would collect them, make LSA comparisons to match areas of interest or levels of knowledge, then pass on recommendations of people to get together with or automatically initiate interactions.

Potential uses of LSA for educational assessment

LSA can provide automatic ways to objectively evaluate written products and to generate content-customized, objective test items. It appears that it may be feasible to automatically measure, at least approximately, the following:

- The quality and relevance of individual written contributions to group activities.
- How much a student has learned from the materials that only she or he has read.
- The overall correlation of an individual's contributions to the continuous process and final (textual) product of some kinds of collaborative group activities.

The point of such methods would not be to supplant the professional assessment skills and judgment of teachers. Rather, in face of the virtual impossibility of a teacher devising and grading equivalent tests for each student where each has studied a different, unanticipated subject matter, the intent would be to supplement and contribute to teacher judgment of overall achievement. To this end, LSA would be used by the teacher to produce and score a battery of brief assessment instruments individually targeted (a) to the idiosyncratic knowledge being acquired by each group of project participants; and (b) to the different knowledge sources encountered and activities engaged in by each individual.

1. Automatic writing assessment. Evidence that LSA can assess the quantity and quality of learned knowledge contained in a student's writing has come from several kinds of studies. The most direct have been explorations of the use of LSA to automatically assign grades to essay exam questions. Predictions of instructor

assigned grades were quite good, r=.67, and about the same as the correlation of .68 between two human graders.

Concretely, the application of LSA to assessing student knowledge and expression in exploratory and project-based learning might proceed as follows. At the beginning of a project, someone—the teacher, a publisher, a curriculum specialist, an independent student—would collect a large and broad training corpus of text relevant to the overall topic, by assembling electronic text either from textbooks and articles or by an Internet search, followed by some culling and editing, and submit it to LSA. As students found texts they would also be included. To evaluate a student's knowledge and project contributions, an LSA-based program would be invoked by the teacher or student. It could be asked to perform one or more possible actions. For example, it might produce an estimate of the relevance to the overall topic of each text by a particular student (as always, with unusual pieces flagged for teacher attention). It might be asked to determine the similarity of a student's computer-composed summary of research findings (or other communications and contributions to the group effort) to individual or group source material or to the group's final report. It might be asked to score an answer to an essay question posed by the teacher, who might have devised the question after searching on a special subtopic among one or all students' discovered sources. Note also that LSA could be used to detect instances of too much overlap with particular source materials, suggesting over reliance on a select and paste strategy in writing.

2. Choosing or constructing a summarizing sentence or paragraph. LSA may be able to order, and possibly quantify predictively, the quality of every sentence in a text, and thus score a test item consisting of text on a desired topic from which test-takers are asked to construct a summary sentence.

3. Choosing or producing related concepts. LSA could be used to find related sets of words or phrases from a collection of texts on a topic and to estimate their similarity for concept matching or relating tests.

4. Portfolio assessment. It is conceivable that LSA could be applied usefully as a partial or component scoring technique for text-based portfolio evaluation. One idea would be to use LSA to measure the coherence of student generated text by measuring the semantic relatedness of successive sentences, as in the experiments mentioned earlier. Another idea would be to use LSA to measure the degree to which the text produced by students reflects the range of content available in the textual resources with which they have been provided or have selected on their own. Coherence in writing, together with topic relevance in comparison with source texts, not only reflects text-based understanding, but can also be taken as an indication of ability to successfully relate ideas, to reason and to transform knowledge.

We have mentioned here a broad range of conceivable applications of LSA to technology-enhanced education only to suggest the potential richness of the approach. In the next sections, we describe our specific goals for the present project.

4. Educational Intervention

We currently plan the following stages of intervention using our software with LSA in the classroom. Because of our commitment to user-centered design and student-centered activities, we will be responsive to what we observe in the classroom and to the suggestions and interests of students and teachers. Thus, the following plan will serve as a guide to help us focus on our research interests rather than a rigid recipe for our work during the duration of the project:

Stage 1. Students play WebQuest games. We have been exploring this stage in several K-12 classrooms during the past school year. We will continue to work with teachers and students to design new types of games and to use them differently in a variety of classrooms. Games we design can then serve as prototypical models to inspire students to construct their own games. Building different kinds of games also gives us insight into the usability of our software and ideas for new functionality.

Stage 2. Students author their own games for their peers to play. We have just begun to explore this approach and have already found that it makes a great deal of difference. Students not only construct their own knowledge of a topic in order to teach it to peers, they become engaged in a design process to structure the knowledge effectively. We believe that design skills provide important learning capabilities for the information-intensive future. Much of our computer science research has centered on developing computational media to support design, and our educational software takes design as a metaphor for constructivist learning. Thus, we have developed a series of software environments that support learning related to a task at hand (Fischer, Nakakoji, Ostwald, Stahl, Sumner, 1993). When students design games for other students, they engage in authentic, self-motivated tasks, reflect on their own or their peers' learning processes, participate in important social interactions, and interpret domain concepts from different perspectives (Stahl, 1993). Classrooms in which students play each other's games become involved in joint construction of knowledge.

Stage 3. Use of open-ended questions. This is where LSA is needed to create "the articulate classroom". At this stage, game authors define answers to scroll questions by writing brief essays. Players then answer the questions with their own brief written responses. LSA mechanisms compare the two texts and judge whether they are sufficiently similar in content. This allows students to express their understandings in their own words. LSA is particularly effective in matching up different ways of saying the same thing using different vocabulary. Questions that required rote recitation of facts like the names of Jupiter's moons can now be replaced with thought-provoking questions like: What would be the effect of Jupiter's gravity on a space ship that wanted to land on Jupiter? Writing paragraphs on such questions promotes high-level learning processes and develops scholarly communication skills.

Stage 4. Students share games across the WWW. Incorporation of supplementary software we are developing (the Remote Explorium and the Teacher's Curriculum Assistant, described on the following pages) opens up the knowledge-building community to the world. The articulate classroom becomes a global classroom. A student who has developed a game on an esoteric topic can find other students interested in the same topic by distributing the game on the Internet. In this way, WebQuest games will provide yet another communication medium for students on the WWW. The distribution of games also creates a wealth of educational resources for teachers and students to choose from for their group and individual activities. This stage stresses the potential of the Internet to be an active two-way communication medium, rather than just a static repository of information. Students learn to become actors in the scientific community, not merely consumers of external knowledge.

Stage 5. Theme-centered games incorporating written reports. The original WebQuest theme involves knights from the Middle Ages, deriving from the popular dungeons and dragons games. But WebQuest is built on a very general simulation construction substrate, so the visual appearance and the definitions of agents can be readily changed. To build a game on a new theme would be a major undertaking for an individual student. Although some students might want to do this for a theme they have already begun to explore, it makes more sense for a classroom to work together on this. The process might be as follows:

❖ The class selects a theme like the solar system. They begin researching the topic on the WWW to collect interesting WWW sites and stimulating questions.

❖ Students divide up the tasks of constructing background icons, character depictions, agent interactions. For instance, a WebQuest related to the solar system might include icons of the planets, spaceships, astronauts, cosmic ray dangers, space walk challenges, etc. Ambitious students could even build simulations into their games, including, for instance, graphic demonstrations of the effects of different gravitational forces.

- ❖ Individual students or small groups design games incorporating the components of the themes.
- ❖ Students play each other's games and increase their knowledge of the subject matter.
- ❖ Students critique each other's game designs and revise their own games.
- ❖ The class gets together to reflect on the experience, to discuss what they learned about the topic and to compile reports on the theme.
- ❖ The class shares what they have learned by distributing some of their games on the Remote Explorium. They might construct their own WWW site on the theme, including statements of their ideas and pointers to other sites they discovered.

Stage 6. Versions of questions and information sources for people with different background knowledge levels. People construct new knowledge by going beyond their previous understanding and then integrating the new insights into their background knowledge (Kintsch, 1994; Fischer, 1994; Stahl, 1993). Therefore, educational information is most effective for an individual when it falls within the person's zone of proximal learning. LSA allows us to personalize information sources to students by finding texts that most closely match (or slightly exceed) the student's own writings. Rich digital libraries can provide selections of alternative presentations on any given topic. For instance, the Remote Explorium could eventually contain many versions of solar system games. These versions could be rated using LSA and indexed in the database of the Teacher's Curriculum Assistant so that teachers and students could select the most appropriate versions. In addition to selecting entire games, people could find game components such as background features, character agents and question narratives. The Visual AgenTalk programming language used to define character behaviors is user-extensible and students could exchange little subroutines in this language that accomplish interesting interactions. LSA databases could also be exchanged across the Internet. That is, one classroom could collect and author texts on a particular subject, then submit it to LSA to create a database of interrelated terms. These databases can be used by other classrooms to evaluate student essays on the given subject, resulting in ratings of the students' background knowledge and readiness to learn from resources at different levels.

By the sixth stage which we plan to explore in the second half of the proposed project teachers and students have a wealth of resources organized into coherent curricula on interesting themes. The resources are available in alternative versions for people's levels of knowledge acquisition, or as constituent components that students can combine in their own constructions. In addition, there are software environments to support the collaborative construction of knowledge using these resources, including mechanisms for evaluating text and matching it to individual learners automatically. These tools will help teachers in their new roles, freed from some of the tedious evaluation of rote tests. They will have to oversee the progress of students and make sure that LSA ratings stay on track, using this information to judge what kinds of high-level guidance and support to provide. Our research will look at how to make most effective use of both teachers and software in the classroom.

The software we are planning to test and refine in classroom use in order to support "the articulate, global classroom" consists of the following three component systems currently being developed in our labs:

- WebQuest, a software environment for the design of educational games.
- Remote Explorium, a WWW site with WebQuest games and other educational simulations that can be down-loaded by users around the world.
- Teacher's Curriculum Assistant, a software environment for teachers to locate, evaluate, adapt and share educational resources over the Internet.

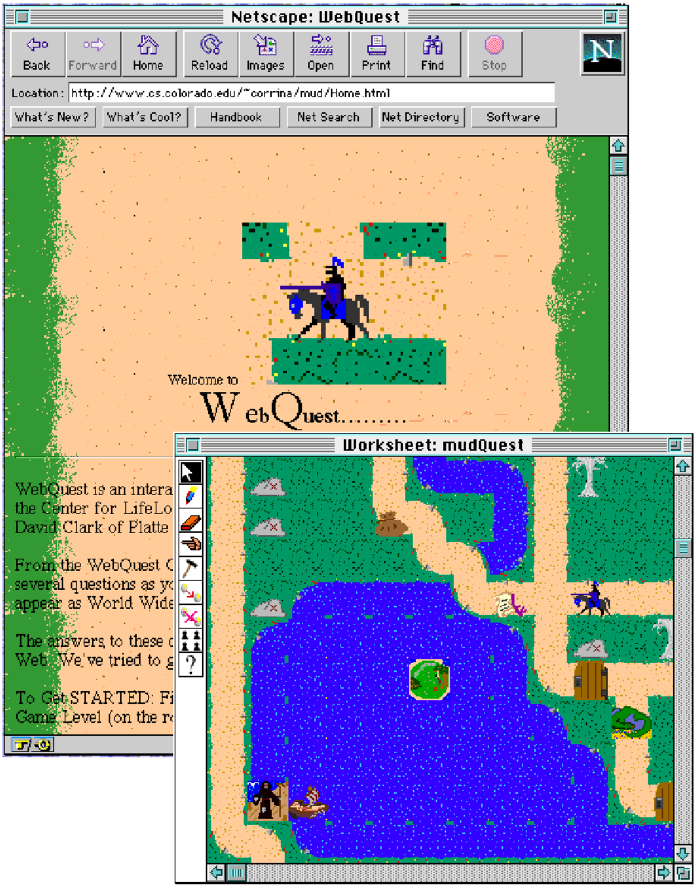

Figure 2. The WebQuest home page on the WWW and a scene from a typical WebQuest game. The game board consists of paths that players like the knight can follow to win treasures by accumulating and articulating knowledge.

WebQuest (Perrone, Clark, Repenning, 1996) is an adventure game development environment we developed to research educational software like Carmen Sandiego. It allows a game author to lay out a graphical scene with fields, paths, lakes, islands, etc. The scene can then be populated with active agents, such as heroes, princesses, dragons, locked doors and buried treasures. (See Figure 2.) Scrolls are defined and associated with game obstacles. The scrolls pose questions that a player must correctly answer to get past a dragon or enter a door. The scrolls may suggest WWW sites to explore to find hints and answers to scroll questions. When a player clicks on a suggested site, the software opens a WWW browser displaying that site. Players can browse the WWW or perform WWW searches using standard search engines.

In a typical WebQuest game, a player might adopt a medieval knight character and be confronted by an anachronistic question like: What are the names of the four largest moons of Jupiter? The student would read a WWW page about the solar system, answer the question and then pursue the dragon. The question might also be one that requires more understanding and research, like: What was the right ascension of Mercury during the signing of the Declaration of Independence? (See Figure 1.)

The WebQuest software has the capability to let students construct original educational games for their fellow students. This creative process allows students to explore information on the WWW in self-directed ways and to embed ideas and facts they discover into game boards that they design. Students learn new information while situated within a context of having to incorporate the new information into the conceptual framework of an educational game they are constructing for their peers. Within a particular classroom, students exchange and play games, learning subject matter that has been organized by their peers and providing feedback to the game creators. Both game players and authors develop research skills using the WWW; they also both reflect on the organization of knowledge and the strategic design of the game artifact.

The authoring capability of WebQuest takes advantage of Agentsheets (Repenning, 1994), the programming substrate that WebQuest is built upon. Agentsheets is a substrate we developed for building educational simulation applications. It allows authors to design the appearance and behavior of their own active agents, as well as creating their own backgrounds with which the agents interact. Agentsheets is programmed by game authors entirely through visual manipulations and requires no traditional programming knowledge. It includes an end-user programming language, Visual AgenTalk (Repenning 1995), which allows students to define the behaviors of their agents. We have begun testing the Agentsheets and Visual AgenTalk authoring capabilities in the classroom with very positive responses. Students are enthusiastic about tools that empower them to construct their own software environments. The proposed project will allow us to pursue this research and to enhance it with the capability to analyze the process of knowledge building as evidenced by students' question and answer formulation.

The Remote Explorium (Ambach, Perrone, Repenning, 1995; Stahl, Sumner, Repenning, 1995) allows game authors to share their artifacts with students elsewhere across the WWW. Teachers and students can download and adapt entire games or their constituent components from the Explorium. This software was originally developed by us to facilitate the distribution of educational applications written in Agentsheets. As part of the proposed project, we will extend the Remote Explorium to allow students in different classrooms and different schools to share their WebQuest games over the Internet. Currently, researchers at the University of Colorado can put Agentsheets applications on a WWW page for students elsewhere to download easily. To implement our vision of WebQuest as a collaborative learning project, we will have to extend the Remote Explorium to allow students to post their games to the Web, so that the sharing is bi-directional. We also envision people trading components of games, such as graphical depictions of characters, programmed agent behaviors, or collections of narrative questions and answers related to given themes. This allows students to design their own games while taking advantage of components created by other students. However, experience with Remote Explorium to date demonstrates that teachers and students need additional support to take advantage of the distributed resources. We have designed another program to provide just such support.

The Teacher's Curriculum Assistant (Stahl, Sumner, Owen, 1995) retrieves summary information about games in the Explorium and elsewhere on the Internet. It uses this information to help teachers or students locate the game and curriculum examples on the WWW that best match their pedagogical needs. In addition, it provides curriculum ideas and resources to guide the classroom use of the games.

The problems that teachers have using the Remote Explorium are typical of the plight of people trying to obtain educational resources from the Internet generally:

- There are no effective methods for locating relevant curriculum sites, such as WWW pages containing WebQuest games on specific themes.
- It is difficult to search for items of interest; search engines are too generic and indexes to education sites are too idiosyncratic and anecdotal.
- There is no choice of versions for different ability levels, or if there is it is not systematically organized.

Figure 3. The Teacher's Curriculum Assistant interface for locating, searching and selecting resources: the Profiler, Explorer and Versions. These tools help a teacher find educational resources on the Web that are relevant to classroom goals and plans.

- There are no software support tools for adapting resources to one's particular needs.
- There are no aids for organizing selected resources into coherent curriculum plans.
- There are no simple mechanisms for teachers and students to share their experiences by posting comments or new games back to the Internet.

Figure 4. The teacher-client interface for adapting, organizing, and sharing resources and curriculum: the Planner, Editor and Networker. These tools help a teacher incorporate educational resources into personalized lesson plans and share successes with these resources on the Internet.

We have prototyped a curriculum development design environment to respond to these problems. The Teacher's Curriculum Assistant maintains a database of information about on-line educational resources. It uses information in the database through six user-interface components: Profiler, Explorer, Versions, Editor, Planner and Networker. The Profiler defines the user's needs in order to query the database for relevant resources. The Explorer allows a user to browse among related resources and curriculum ideas. The Versions component explains the differences between different versions of the same resource so that the most appropriate one can be chosen. (See Figure 3.) The Editor is used for adapting resources, e.g., editing a text document. The Planner helps a teacher to arrange resources into a lesson plan and to make adjustments to the plan. Finally, the Networker simplifies Internet access, facilitating the posting of comments and new games as well as handling the downloading of selected resources and the updating of the database. (See Figure 4.)

The Teacher's Curriculum Assistant was designed based on our philosophy of adapting curriculum and resources to the particular pedagogical needs, learning styles and personal interests of the students and teachers in a classroom. The proposed project will allow us to explore the use of LSA in matching textual materials to the background knowledge of individual students, taking full advantage of the built-in support for multiple versions of resources.

5. Experimental Design

We are developing a suite of educational tools in continuous interaction with classroom experience with the tools. We are not designing a finished product, to give to a teacher and evaluate how it works. Rather, we start with prototypes that have some of the features we think we eventually want to have, obtain feedback about their performance, and gradually modify and elaborate our designs. As we have pointed out above, it is not so much the software tools that we are concerned with, but how they are to be employed effectively in the classroom.

The current version of WebQuest has been used in Boulder middle schools. We intend to expand this use locally, including into high schools. We have close working relationships with a number of teachers in different schools who have used our software in their classrooms and who are eager to try WebQuest. In addition, we have contacted several non-local groups and made plans for possible future cooperation. We would let those groups use our tool in the way they prefer, but obtain data on their project from them as well as collect our own data by sending a project member to visit and observe out-of-town sites at regular intervals.

The kind of data we plan to collect are both observational and experimental. Observational data will come from teachers, students, project members who observe classroom use, along with records automatically collected by the computer systems themselves. A project diary will be used to help us organize and preserve these observations and permit their use at later points in time. While much of the observational data will necessarily be informal and opportunistic, we also plan to develop organized observation protocols to ensure comprehensibility and facilitate comparison. The construction of such a protocol would be one of the research goals for the first project year.

We do not plan any large scale classroom evaluation experiments, which would be premature as well as exceeding the resources of the project. Instead, mini-experiments directed at specific questions that arise in the course of this project will be used. At this point, we can sketch only a few obvious first experiments, but these should make it clear how future experimental and evaluation research in this project could proceed:

- Is WebQuest effective as a tool for learning how to search the WWW? Groups of students with varying amounts of experience using the WWW with WebQuest are compared with equivalent students using the WWW with traditional "how to" instructions. Their success at specified search tasks as well as browsing behavior and browsing strategies will be evaluated. Follow-up questionnaires can be used to assess long-term effects.
- How well does LSA evaluate written student responses? We are hopeful that LSA can make fine enough distinctions to identify plagiarism a strong temptation when students can easily cut and paste from WWW pages into their essays. We will have to determine empirically whether scores of very high similarity between an essay and a resource text indicate the likelihood of literal copying. Throughout the project, specified samples of student responses will be scored both by LSA and human graders to evaluate the effectiveness of LSA to evaluate written student responses.
- How effective is LSA in helping students to formulate questions? The precise experiment cannot be outlined at this point, because it depends on just what we shall come up with in this regard and how the WebQuest components will evolve. But eventually formal experimental comparisons can be made not only between our support system versus no support, but also between a teacher-led group discussion and the LSA support system. Such studies would be important not so much because they might tell us that LSA is 50% or 70% as effective as a good teacher, but because it might pinpoint differences in the

way a teacher helps and the ways our system can be used. Data like this could be more reliable than informal and fortuitous observations and would help direct the evolution of our system.

- During the use of LSA tools, we can easily and automatically make them available or not to a particular student working on a particular topic or question. By randomizing these assignments and using LSA-based custom evaluation tools we will be able to do almost continuous objective measurement of the effect of the tools on problem solving and knowledge acquisition. Statistical analysis by classical randomized within- and between-subject differences (simultaneously in this design) will be straightforward.

- How can software environments best be used in the classroom? Constructivist approaches like game creation typically require longer time commitments and more individualized work than traditional school schedules can accommodate easily. Solutions to this problem will be investigated by working with teachers and trying different ways to integrate the use of the software into classroom processes. We will try small group projects, independent student efforts, after-school arrangements, etc. in order to allow motivated students to develop exceptional but time-consuming games. We will explore different ways of sharing work among groups, between classes, having classes build on previous year's accomplishments. WebQuest will be introduced into a range of schools, from more traditional to more experimental to see how different solutions can be found in different organizational contexts.

- How can coherence of knowledge be promoted? Without guidance, students authoring WebQuest games will tend to build an unstructured sequence of questions and answers. One of the goals of evaluation will be to examine this possibility and to determine what kinds of constraints can be built into the system so that students construct coherent bodies of knowledge. Although resolving arbitrary relationships between a game situation and questions posed may be an impetus to students' creativity, deeper learning will result if questions build on each other, and motivation may be better sustained if the questions are related in a meaningful way to events in the game. For example, the discovery of an underlying relationship in pieces of topic knowledge encountered might become a goal for progressing through the game. LSA may also be useful here in helping students construct an interrelated network of concepts and ideas from the information collected from multiple sources.

- How can software environments best support learning? In addition to providing challenges and sources of information, software can provide guidance. For instance, the LSA mechanisms can be used to guide students to the most appropriate versions of materials. When software mechanisms determine that a student response is inadequate, they can suggest further sources of information to be consulted. We have used computational critics in many of our other software environments to alert users to relevant information (Fischer, Nakakoji, Ostwald, Stahl, Sumner, 1993), and will try to combine critics with LSA tools in this project. We will observe how effective these techniques are within classroom practice.

- ❖ How can the Internet be used as a medium for the collaborative construction of knowledge? In the later years of the project we will investigate the effectiveness of tools like the Remote Explorium and the Teacher's Curriculum Assistant in turning the WWW into a bi-directional medium in which students contribute knowledge as well as consume it. It is premature to determine how specific functionality of this software will be evaluated.

- ❖ Where is the best boundary between what must be known and what can be found when needed? In general, we want to further our understanding of an important conceptual problem that must be dealt with if technology such as that proposed here is to be used effectively in education. The problem is the relation between external memory and internal memory. Without some internalized knowledge, external information sources cannot be used effectively. Over-dependence on external memory may discourage the construction of internal knowledge. Clearly, one cannot teach all the knowledge a person might at some point need. Is there something one must know in order to be able to understand what one looks up, and if so, what is that essential knowledge or skill that we need to teach? To what extent does this involve general knowledge? To what extent is it tied to specific domains? Our Web-based information retrieval capabilities will be excellent in a few years; we need to make sure that our understanding of the conceptual issues concerning the knowing / finding tradeoff keeps up with our technological capabilities.

The primary responsibility for evaluation methods will rest with Drs. Tom Landauer and Walter Kintsch, two experimental psychologists with a great deal of experience in research like this. They will also be the LSA experts of the project. The development of the WebQuest system and its integration with Remote Explorium and Teacher's Curriculum Assistant will be under the direction of Dr. Gerhard Fischer, a computer scientist experienced in software research, in cooperation with Dr. Gerry Stahl and Corrina Perrone. The task of integrating WebQuest into classroom activities will be directed by Dr. Eileen Kintsch in cooperation with David Clark, a Boulder teacher now using WebQuest who is an authority on student use of the Internet (Clark, 1995).

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Part IV: Other Proposals at the University of Colorado

Collaborative Research on Knowledge-Building Environments: Growing a National and International Research Community for Distance Learning Information Technology

Knowledge-Building Environments (KBEs) are software systems to support collaborative distributed learning. This is a complex research area that has made significant progress in the past decade but that will require substantial work by an international research community to achieve its potential in the next decade. Active research networks have been established in many countries, but there is no organized network of KBE researchers in the US to work collaboratively within this international community.

Coordinated multi-disciplinary work is needed at the levels of theory refinement, software design, and curriculum development. Many of the necessary enabling elements are becoming available now for progress in developing this new KBE information technology that will meet rapidly growing societal requirements: theories of learning that recognize the role of social context; technologies for building and combining software components; experiments in structuring effective distance collaborative learning; and networks of researchers in other countries. This project will build on these elements in the following areas:

- Learning Theory: synthesizing theoretical approaches into an analysis of social knowledge building, oriented toward the design of software to support collaborative distance learning;
- Information Technology: defining technical standards for the interoperability of KBE data,
- knowledge-base servers, Web interface components, and agent widgets from different
- research prototypes;
- IT Education: developing curriculum, course methods, and assessment measures for educating multi-disciplinary students in the theory, design, and educational use of KBEs;
- IT Workforce and International Collaboration: involving students and researchers in hands-on software design and the sharing of design ideas in

face-to-face workshops and in Web-based discussion, and growing a network of researchers and students in the US to work with researchers abroad.

The project will expand over five years from one grantee (Colorado) and three subawards (Berkeley, Cornell, Southern Illinois) to five collaborative grantees and five subawards, directly supporting from 9 to 21 students each year and involving many more in courses and conference workshops. The project will create an active research community, involving educators and technologists together, enhancing the utility, scope, and depth of IT support for knowledge-building activities. This will create a workforce capable of turning the potential of distance learning into a classroom and workplace reality, using the theories, technologies, and methodologies developed in this project through international collaboration.

Problem Statement

"Long-distance learning is skyrocketing" according to an Associated Press article (December 19, 1999). Already in 1997/98, 60% of colleges offered Internet classes, with 54,000 different courses enrolling 1,600,000 students. Yet, the technology and methodology for designing Internet courses is still very poorly understood. Most teachers simply put traditional course materials on the Web, ignoring the potential of computational support. At best, they use generic communication technologies (like First Class, NetMeeting, Lotus Notes/Domino) that were not designed to support learning, or they use systems that administer and deliver traditional materials (like WebCT or LearningSpace) but do not go beyond this (Cameron et al., 1999).

The educational research community of the past decade has established a consensus that traditional lecture-based and teacher-centered approaches do not by themselves produce the most effective learning. Students should be actively involved in constructing their own understanding within collaborative social contexts. Students in a course should function as a community of learners, community of practice, or knowledge-building community (Brown & Campione, 1994; Brown & Duguid, 1991; Lave, 1991; Scardamalia & Bereiter, 1996). Active student projects that provide authentic motivation can form the core of a problem-based learning (PBL) approach (Barrows, 1994). Computer-based tools should be designed to support the collaborative knowledge-building process. Although there is broad agreement that methodologies and tools are needed for computer support of collaborative learning (CSCL), these have yet to be developed.

Important initial steps have been taken to formulate theories, try out prototype systems, develop pedagogical methodologies, and experiment with innovative courses (Hoadley & Roschelle, 1999). These steps have provided enough experience to demonstrate how much is left to do and to indicate a path for further research. There is an assortment of theoretical approaches that seem vaguely complementary, but no synthesis that provides a coherent framework for designing courses and knowledge-building environments (KBEs). One software system – CSILE (Scardamalia & Bereiter, 1996), now Knowledge Forum – has been under development for over a decade and has been widely fielded and assessed. A number of other prototypes are being designed and investigated to explore alternative functionalities: CoWeb (Guzdial et al., 1999), WEBGUIDE (Stahl, 1999b), WISE (Cuthbert, 1999), CoVis (Pea, 1993), FLE (Muukkonen et al., 1999). These attempts to support collaboration repeatedly run into the same technical and social problems: low participation levels, shallow discussions, divergence of ideas, little building of deep knowledge structures (dePaula, 1998; Guzdial et al., 1999; Guzdial & Turns, forthcoming; Hewitt et al., 1998; Hewitt & Teplovs, 1999; Stahl, 1999a, 1999b, 1999c). The overcoming of these barriers to collaborative learning remains an open research issue.

Experience indicates that the design of the KBE "killer app" is too complex for any one research group. The theoretical, technical, and pedagogical issues are deeply intertwined and each still requires basic research. A high-functionality system is needed, unlike the self-contained functions of email, the Web, or e-commerce. An international research community is emerging to address this challenge, with energetic research networks and international virtual universities in a number of countries. Unfortunately, there is no coordinated effort within the United States which can relate to these networks abroad. We need to develop a multi-disciplinary community which can understand and advance the theory, technology, and pedagogy; can disseminate that understanding in carefully conceived courses; and can interact in the international community.

Project Goals

Learning Theory: To synthesize and adapt current theories of computer supported collaborative learning to define a conceptual framework for the design of knowledge-building environments.

Information Technology: To propose, negotiate, and promote interoperability standards for data and components of knowledge-building environments.

IT Education: To develop and test content and methodology for multi-disciplinary, problem-based courses on information technology for distance learning.

IT Workforce and International Collaboration: To build a US network of established researchers and new students in the field of computer supported collaborative learning that can collaborate with networks in other counties on information technology for distance learning.

Research Issues

Learning Theory: How can current theories be synthesized into a coherent view of knowledge-building processes and how can this guide the design of software?

Information Technology: How can standards be defined for interoperability of KBE data, knowledge-base servers, Web interface components, and agent widgets to promote exploration without restricting software design options?

IT Education: How can problem-based learning be adapted to distance learning? What software can support this? What constitutes an effective curriculum (problem case-base) for coverage and depth concerning information technology for distance learning?

IT Workforce and International Collaboration: How can a productive network of US researchers be established, grown, and sustained so they can collaborate with distance learning research networks in other countries?

Project Objectives

Learning Theory: To produce a series of white papers that are discussed by the project community and then published.

Information Technology: To establish a set of interoperability standards, examples, and tools.

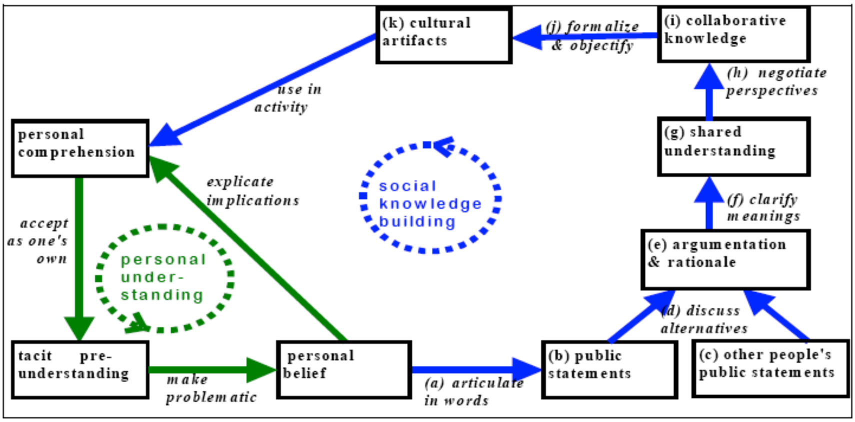
IT Education: To develop and test a sequence of courses on the technology and pedagogy of distance learning.

IT Workforce and International Collaboration: To organize periodic workshops for project members, students, and international collaborators and to provide Web-based media for project reports and discussions between workshops.

Theoretical Framework

This project focuses on a particular approach to CSCL – namely the Web-based support of collaborative knowledge building (KBE) – and a particular approach to instructional design – namely problem-based learning (PBL). While face-to-face PBL is an established method, the design of distributed PBL using KBEs is very much a current research topic (Cameron et al., 1999). To provide a framework for the design of KBEs to support distributed PBL, the project will synthesize and refine a set of currently accepted theoretical approaches from the perspective of guiding software design.

The diagram below (from Stahl, 2000) provides a starting point for this, combining aspects of activity theory, situated learning, hermeneutic philosophy, and distributed cognition theory.



The idea of this diagram is that the knowledge-building process can proceed through many different phases. A KBE can be designed to support a number of these phases with different functionality. A similar approach is being developed in Finland (Muukkonen et al., 1999).

Technology Approach

Many ideas of KBE functionality have been tried out and a number of promising new features and approaches have been proposed. The problem is how to combine various sets of features into a technically and pedagogically coherent system. In order to allow functions from different prototypes to be recombined to explore new system configurations, we need to achieve interoperability of data, servers, components, and widgets.

The PI has already begun to define an XML standard for interchange of threaded discussion data, which forms the core of many KBEs. Data from four different prototype systems used at Colorado have been exported to the XML standard, where they can be displayed in XSL and analyzed by simple text manipulation tools. Work has already begun on separating a perspectives server out from the PI's WEBGUIDE KBE (Stahl & Thomas, 1999), so that Web client interfaces developed using HTML, Perl, or Java can easily access a shared knowledge-base without worrying about the database or perspectives computation internals. Java beans technology provides a technical foundation for programming components and widgets that can be mixed and matched in alternative systems. So the technology for interoperability seems within reach.

The problem is to agree on standards within the KBE community. The goal is for someone to be able to combine, for instance, a knowledge-base server from Colorado's WEBGUIDE, a discussion interface from Toronto's CSILE, domain scaffolding from Berkeley's WISE, and a design module from Helsinki's FLE with some innovative notification agent widget. Then they can assemble a system to test the effectiveness of their new agent widget (McLean, 1999) without having to build a whole system from scratch. The data from their experiment can then be exported to XML and analyzed with existing tools to compare the results with those of other systems.

The definition of interoperability standards requires international collaboration. Although many researchers are informally converging toward a common set of technologies (SQL backends, Java servers, Web-based clients, threaded discussion), the KBE software field is still very immature. It will be important to devise standards that foster experimentation rather than restrictions that limit design options. That is a tricky research issue.

Curriculum Development

The starting point for curriculum development in this project is provided by the work of the Problem Based Learning Institute (Cameron et al., 1999) and the Canadian CollabU (Breuleux et al., 1999). The PBLI has tried to support distributed PBL with commercial communication tools, and has identified specific needs for customized KBE software. CollabU has begun to experiment with a course on learning technology taught at five different universities, with students divided into cross-campus projects. The PI has also conducted two multi-disciplinary seminars using KBE prototypes for class discussion: one on the theory of KBEs and one project-based course of KBE research with students at Colorado and Dortmund.

This project will begin by working with PBLI and CollabU, participating in their experiments and offering our own multi-campus courses. Our courses will focus on the wicked problems of KBE software design and will use various KBE prototypes.

During the grant period, we will develop both a curriculum and an instructional methodology for courses on information technology for learning. The methodology will define an approach to distributed learning design, incorporating and adapting techniques that have proven successful in face-to-face PBL. The use of appropriate technologies will be described. The methodology will emerge from our experimental courses. Course content will cover theory, pedagogy, and technology. It will be aimed at a multi-disciplinary undergraduate and graduate audience, as well as at classroom teachers, distance education instructors, and workplace trainers.

Community Building

The PIs of this proposal will be hosting the next CSCL conference (December 2001) and the next GROUP conference (October 2001) at the University of Colorado. Project participants will also be active in the European CSCL (December 2000) at Masstricht in the Netherlands, as well as meetings of ICLS (International Conference of the Learning Sciences), CILT, AERA, CHI, Cognitive Science, WebNet, CSCW, and other important international meetings of computer science and education researchers.

At CSCL '99, the PI (with Marlene Scardamalia and Timothy Koschmann) planned and conducted a successful workshop with over 60 participants from the US and abroad on "Collaborating on the Design and Assessment of Knowledge Building Environments in the 2000's". Many of the ideas and prospective participants of this project were involved in that workshop, which itself grew out of an earlier working group at CILT '99 (the NSF-supported Center for Innovative Learning Technologies). This proposal is a product of collaboration funded by a CILT seed grant intended to stimulate collaboration among KBE researchers.

International conferences provide a convenient venue for national and international collaborators to meet face-to-face as a supplement to Internet-mediated communications. This project will organize four meetings per year for project participants and collaborators to get together. Two of these will be day-long organized conference workshops where people will exchange and discuss their project work results. The other two will be informal SIGs where people can socialize and exchange ideas one-on-one. Some of the meetings will be in Europe; some will take place at research labs. The project will support some costs of student participants to attend these meetings and international conferences.

The building of a national and international collaboratory is an explicit aim of this project. In addition to involving people as project participants (collaborating PIs, subaward recipients, student researchers) and as students in project courses, the on-going work of the project will be publicized widely. Articles in conference proceedings and journals will be important, with shared focus and special tracks or special issues arising naturally from the project identity. In addition, a project newsletter will be circulated by email and Web, and discussion forums on project topics will be supported by the KBEs that emerge from the project.

National Collaboration

In years 2 through 5, from 2 to 4 other universities will be added to this project as collaborative institutions. Each will submit a collaborative research proposal with biographical information about their PI and a budget to support a graduate student and an undergraduate student to work on this project. Each collaborative budget will run about $120,000 per year. Collaborating institutions will be selected as part of the work of the project, with the following institutions tentatively interested at this time (more details in full proposal):

Institution	*PI*
Stanford	Christopher Hoadley
Berkeley	Jim Slotta
Georgia Tech	Mark Guzdial
Hawaii	Daniel Suthers

Project Year	*Number of Institutions*	*Total Project Budget*
1	1 (Colorado)	$510,000
2	3	$740,000
3	4	$869,000
4	5	$990,000
5	5	$990,000

International Collaboration

There are now active KBE research networks in the following countries who have expressed strong interest in collaborating with this project (more details in full proposal):

Canada OISE Toronto Marlene Scardamalia & Robert McLean

Finland Helsinki & Turku Kai Hakkarainen and Erno Lehtinen

Norway Oslo & Bergen Anders Morch

Germany GMD & Dortmund Wolfgang Prinz and Thomas Herrmann

Canada TeleLearning NCE Alain Breuleux and Tom Calvert

Mexico Monterrey Virtual U Jose Rafael Lopez Islas

United Kingdom Open University Simon Buckingham Shum

Anticipated Impact

This project will establish a new research focus on KBE design and a national network of established researchers and new students that will significantly contribute to an existing international collaboration exploring this field of information technology. It will produce enabling theories, technologies, and pedagogies to support the efforts of this new workforce to move KBEs from research prototypes to robust IT systems that can fulfill growing societal requirements. Effective KBEs will provide a new paradigm of collaborative knowledge management, exploiting the online availability of information with more powerful means than are currently available.

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Models for Organizing Collaboration: Ways of Supporting Distributed Learning

Proposal to Lotus Research

Primary Research Objective

The goal of this research is to identify a set of models of collaboration that can serve to guide both (a) the design of collaboration software by Lotus and (b) the application of this software to specific learning situations by user organizations. The identified models will be compiled and presented in a format that has been demonstrated to be usable and useful in supporting distributed learning.

The following sequence of questions will be investigated:

- How do people learn what they need to know as part of their collaborative work ?
- What are the major phases of collaborative knowledge building according to current theories?
- What are effective instructional methods for promoting distributed learning according to current best practices?
- What forms of computer support can support these knowledge-building phases and instructional methods?
- How can user organizations be guided in organizing the functionality of Lotus software and other resources to promote collaboration?

These questions will be pursued from the perspective of informing on-going planning, design and research on collaboration and distributed learning software at Lotus. It will build upon the existing expertise and research of the project partners and will be prioritized to meet stringent project time constraints.

Partners

Researcher:

Gerry Stahl, University of Colorado

Jose Rafael Lopez Islas, Monterrey Tech Inst

Kamran M. Khan, Marist College

Lotus Representatives:

Randy Cox, Director of Engineering

Nada Abu-Ghaida, Product Designer

The researchers each bring to this project a background in relevant academic research and working relationships with practitioners of distributed learning. The Lotus representatives come from strategic positions within the Lotus software development process and also bring working relationships with practitioners who will help to evaluate the results of this project. (See attached resumes.)

Gerry Stahl is a Research Professor at the Center for LifeLong Learning and Design of the University of Colorado, with a joint appointment in Cognitive Science and Computer Science. His specialty is the theory and design of collaborative knowledge-building environments.

Jose Rafael Lopez Islas is the Director of Research and Educational Technology at the Monterrey Institute of Technology's Virtual University. The Virtual University enrolls students throughout Latin America and the Monterrey Tech System is the largest user of Lotus' LearningSpace. Professor Lopez' research focuses on the social construction of knowledge.

Kamran Khan is the Vice President for Information Technology and Chief Information Officer of Marist College. His specialty is Distributed Learning, Knowledge Management and E-Commerce in education and corporate partnerships.

Randy Cox is Director of Engineering for Lotus at Redwood City, where he leads work on the next version of LearningSpace. He proposed this project on models of collaboration in order to provide a theoretical framework for planning future Lotus software.

Nada Abu-Ghaida is a Product Designer at the Cambridge offices of Lotus, where she designs interfaces for future Lotus learning technologies. She agrees with the importance of this project and emphasizes the need to help user groups to organize software functionality and other resources to support distributed learning

Proposed Scope of Work

This project addresses the problem of how to organize software functionality and content to support distributed learning. Instructors of distributed training and classes have few guidelines for how best to support distributed collaborative learning using new computer-based technologies. For instance, how does one organize course materials and activities including readings, simulations, collaborative projects, group discussions, negotiation processes and portfolio artifacts into an effective educational experience that achieves targeted instructional objectives? Even designers of this technology have no place to turn for an overview of current theoretical frameworks and best practices that can inform their designing of future functionality. If Lotus is to maintain its leadership position, it must go beyond generic discussion software and course administration with innovative functionality to support multiple phases of collaboration and of the social (i.e., group and organizational) construction of knowledge. In addition, it must provide guidance to its user community on how to organize computational and digital resources for effective distributed learning.

Stage I

The objective of this project is to develop and test a methodology or a coherent set of principles and practices for organizing software functionality to support distributed learning. This will be based on a review of models of knowledge-building activities. Stage I of the project will be the systematic review of models of collaboration from the perspective of informing computer support of distributed learning. These models will draw on several of the most influential theories (e.g., situated learning, activity theory, constructivism) and instructional design approaches (e.g., case-based and problem-based learning). The project will either develop a model that combines ideas from these different theories or will compile a set of several models of collaborative learning that are applicable to computer-supported distributed learning.

The project participants are all experts in the topic of the project at both theoretical and practical levels. Thus, they are already familiar with many of the important theoretical approaches and are experienced in the issues of distributed classroom and training settings. The project will bring together this existing knowledge, fill in important missing areas of knowledge, and organize the knowledge in a coherent and useful way.

Perhaps the most important work product is the research survey. We will attempt to accomplish this prior to summer (March - May).

In early summer, we will have a project meeting/workshop where we evaluate our findings. If we feel that we have substantially completed the research phase, we will proceed to the development and testing of a guidebook based on our research. If we feel it is important to continue the research work, we will revise our project schedule in order to ensure that the research phase is adequately accomplished. The goal is not to exhaustively catalog every possible theory, but to make sure that we have gleaned the most important implications of the major theories and methodologies. The research phase will culminate in a digital catalog of the models we have found and developed. This will include theoretical models of collaboration and individual elements in the collaborative process, relevant theories of cognition and of instructional design, existing best practices, and current commercial support tools.

Stage II

Following the research on models for organizing collaboration and our first project workshop, we will develop a guidebook for designers of distributed learning based on these models. This will be a practical guide with principles and step-by-step procedures for organizing software tools and instructional content into effective and coherent presentations. We will try to develop this methodology and draft the guidebook over the summer (June - August). Marist College is a Lotus shop and has staff and students trained in LearningSpace and other Lotus products; Khan and colleagues will take a lead role in implementing the guidebook.

Stage III

From July - November, we will assess the usability and effectiveness of the methodology and guidebook in business, research and educational settings. This will not involve the development of any new technology. Ideas for new software functionality will be assessed through mock-ups, scenario walk-throughs and in-depth surveys. The guidebook will be reviewed by potential users and will be revised in response to their feedback. The academic researchers will use typical situations in their own institutions and activities to test the guidebook in academic distributed collaborative learning settings. They will also use their industry contacts to involve industry representatives in reviewing the guidebook from the perspective of industrial distributed collaborative learning settings. For instance, Stahl will work with corporate trainers at Athenaeum International, with managers of distributed research groups at Seagate and with employee development trainers at StorageTech, to assess the guidebook's applicability to a wide range of industrial distributed learning tasks. Lopez will test the guidebook in graduate courses taught through the Virtual University, with students located in different countries of Latin America and all over Mexico. The Lotus representatives in the project will work with people from their alpha and beta test sites and from their user community to conduct similar assessments of the guidebook.

Deliverables and Timeline

Contract and project start and end dates: March 1, 2000 - December 31, 2000.

Stage I

March - May: Catalog of models of collaboration and distributed learning instruction. The catalog will be deployed in Lotus Notes/Domino. First workshop of project participants.

Stage II

June - August: First draft of guidebook on how to support distributed learning. The guidebook will be deployed in Lotus Notes/Domino.

Stage III

July - November: Review of guidebook by user organizations. Publication of revised guidebook in Lotus Notes/Domino. Second workshop of project participants and possible third workshop with user organizations and/or Lotus representatives.

December: Final report and wrap-up.

POW! (Perspectives On the Web)

Proposal to Colorado Advanced Software Institute (CASI)

The asynchronous management and negotiation of knowledge in shared collaboration spaces should be supported by software that keeps track of personal, group and comparison perspectives. The POW! Project will produce a Java server to facilitate quick development of Web-based client software incorporating perspectives to support collaboration in educational and corporate settings. The POW! Project will release the Java server on the Web with an appropriate license. It will have a clear API, XML data exchange and sample code for educational clients in Java, HTML and Perl. The Project will also develop requirements for corporate applications in management and training.

Problem, Background and Opportunity

We are speeding toward a society in which people are networked together to share information and to learn and work collaboratively. The hardware infrastructure is developing rapidly, with Colorado in the communications forefront. Technologies for simple exchange of information _ like email and audio/video/textual conferencing _ are being widely adopted. However, software support for the collaborative construction of deeper knowledge remains an open research issue.

Teamwork, flexibility and collaboration are becoming the mode of operation for modern companies, whose employees may be geographically dispersed. Companies must make complex decisions that synthesize the expertise of many employees; they must become _learning organizations_ that share effective, evolving _organizational memories._ Imagine a corporate reengineering workshop in which people from throughout an organization gather (physically and/or virtually) to set a new strategic direction: how could software support this process by facilitating the construction, sharing and synthesis of different perspectives on the problem? The design of such software goes far beyond what is available today and involves consideration of both technical and social issues.

If we can develop sophisticated conferencing software for Colorado companies to meet their own organizational learning and decision-making needs and to provide training for other corporations, then we will complement Colorado_s strengths in the hardware and communications sectors and move into a leadership position in educational and groupware research.

Objectives

The PI has developed a research prototype named WEBGUIDE designed to support deep knowledge construction by collaborative groups over the Web. Testing in classroom situations has suggested several tasks needed to make this software practical for transfer to industry:

- to increase WEBGUIDE's speed and flexible further development or application.
- to explore its use in corporate settings of management and training.
- to make it available to other researchers to collaborate on further development and assessment.
- to allow for free development of alternative interfaces for different applications.

To accomplish these tasks, the POW! Project has the following objectives:

- to separate WEBGUIDE into: (i) a perspectives server that carries out the intensive computation of perspectives and sends requested data in XML format to (ii) light-weight clients.
- to study application of WEBGUIDE in corporate decision-making and corporate training situations.
- to release the POW! perspectives server as Open Source Software (OSS) under a license acceptable to the University and the Collaborating Company in order to encourage use of the server by other researchers.
- to develop and document sample light-weight clients for educational applications using Java, HTML and Perl technologies to demonstrate how Colorado corporations can quickly develop proprietary clients for corporate applications using the POW! perspectives server.

Accordingly, the POW! Project has the following milestones and deliverables:

- by 1st quarter of grant: to create a POW! perspectives server in Java with a clear API and with XML data exchange to Java, HTML and Perl clients. Optimize, modularize and document the server code and API.

- by 2nd quarter of grant: to negotiate an OSS license with the University and the Collaborating Company and to release the POW! server under this license on a website with appropriate documentation to support collaborative development of the software.
- by 3rd quarter of grant: to develop and document on the website sample clients for the POW! server illustrating client development using alternative technologies.
- by 4th quarter of grant: to study applications of the software within the collaborating company and at its corporate training sessions, resulting in requirements for client applications in these settings.

Potential for Broad-based Technology Transfer

Over the past decade the PI has developed a perspectives mechanism to support collaborative knowledge building. He has applied this technology to a number of applications and this work has been widely accepted in the peer-review research community. The WEBGUIDE prototype to be used in the POW! Project implements the perspectives mechanism on the Web and has been assessed in educational contexts.

The Collaborating Company, Athenaeum International, is part of a national network of corporate trainers, MG Taylor, that has extensive experience conducting workshops and design sessions for Fortune 500 companies and other major clients. They use a successful training methodology and are interested in incorporating computer support into their approach.

The POW! Project will synthesize the expertise of both participants through joint planning of software for corporate applications. This will include attendance of the PI and graduate student at various corporate meetings and events; involvement of both sides in collaborative requirements planning for software; and joint assessment of the software in corporate settings.

The POW! Project will significantly further the development of the perspectives-based software for both educational and corporate applications. The server and the sample educational clients will be available under license for companies throughout Colorado and for university researchers to use. All corporate client software developed within the POW! Project will be available under the standard CASI conditions and licensing options.

Approach

The POW! Project builds upon successful research by the PI in the past to develop effective support for collaboration in corporate settings. The key innovative technology, a flexible perspectives mechanism was originally developed in 1991-1993 under CASI support and was subsequently used in NASA applications by Johnson Engineering. More recently, it has been implemented on the Web and tested in educational settings. In the POW! Project, it will be re-implemented in an architecture that will facilitate its deployment in corporate settings.

Past Work by PI:

As a graduate student working with Professor Raymond McCall, the PI developed a _perspectives mechanism_ within the PHIDIAS hypermedia system (Stahl, 1991; Stahl, 1992; Stahl et al., 1992) . This work was supported by CASI grants in 1991, 1992, 1993 _ earning CASI_s exemplary Research Award in 1993. The perspectives mechanism was a central part of the PI_s Ph.D. dissertation (Stahl, 1993a; Stahl, 1993b; Stahl et al., 1993a; Stahl et al., 1993b) . Since then, the PI adapted the perspectives mechanism to several different application areas, including Hermes 2.0_ and a system for ISO 9000 documentation which the PI developed within his own company (Stahl, 1995; Stahl, 1996; Stahl et al., 1995a; Stahl et al., 1995b) . Most recently, the PI developed WEBGUIDE, a Web-based hypermedia educational environment to support collaborative classroom learning, and tested it in both middle school and graduate level classrooms (Stahl, 1999a; Stahl, 1999b; Stahl, 1999c; Stahl & Herrmann, 1999; Stahl et al., 1999) . The PI developed a theoretical framework for perspectives and collaboration in his doctoral dissertation and in recent publications (Stahl, 1993a; Stahl, 1999d; Stahl, 2000) .

The PI is currently a Research Professor in Computer Science and Cognitive Science and a faculty member of the Center for LifeLong Learning and Design at CU. He has published widely on knowledge-building software environments, organized a well-attended international workshop on this topic and taught a series of advanced seminars on it. He has developed software since the mid-1960_s and has worked with the Graduate Student on WEBGUIDE for more than two years.

Supporting Collaboration

Collaboration is an important but difficult and poorly understood activity. The potential is that the ideas, expertise and critical abilities of a number of people can be synthesized to produce knowledge that no one participant could have produced and to share this knowledge among all participants. Software can support this process by providing an external memory or workspace in which each participant can develop personal ideas, can view the ideas of others, can incorporate others_ perspectives into their personal perspective and can negotiate agreements and clarify points of difference within the group as a whole. A computer-based environment can maintain persistent views of ideas that have been expressed, so that one can review the history of discussions and compare related ideas. A Web-based system can facilitate collaboration among people who are not present at the same time or place, allowing discussions and reflections to take place more gradually and completely over time as well as across arbitrary distances.

The Perspectives Mechanism

The technology currently implemented in WEBGUIDE and envisioned for the POW! Perspectives server supports the construction of knowledge in personal, group and comparison perspectives. The server allows users to define a network of interconnected perspectives which inherit content from each other _ so that my personal perspective automatically contains ideas that my team has already agreed on in its group perspective and a comparison perspective automatically contains ideas from my personal perspective and from those of selected colleagues. New perspectives can be added by users on the fly.

The perspectives server keeps track of all the relations among perspectives and ideas of different people. It prepares content views transparently so that client interfaces can navigate the perspectives and ideas intuitively. Users can articulate, reflect upon, modify, compare and negotiate ideas in the shared, evolving collaboration space without worrying about the underlying structure of the perspectives.

While much collaboration software could benefit from a perspectives mechanism, no other system has as versatile a perspectives mechanism as WEBGUIDE. Some systems have simple mechanisms, perhaps allowing several personal perspectives and one group perspective _ fixed in structure and lacking inheritance of content. Most collaboration systems have no such facility. Other researchers are interested in incorporating WEBGUIDE_s perspective mechanism once it is available as an open source server.

Approach to Domain Knowledge:

The PI and Graduate Student will attend corporate meetings of the training network to which the Collaborating Company belongs and will participate (as facilitators and observers) in corporate meetings and training sessions conducted by the Collaborating Company. These sessions will be preceded and followed by debriefing sessions with the Business Representative. Project staff will meet regularly with the Collaborating Company to collaboratively develop requirements for corporate applications of the software.

Approach to Software Architecture:

The PI has already acquired a Linux webserver with dual Pentium processors, fast database access and a high-speed Internet connection for use in the POW! Project. A Java application _ the POW! perspectives server _ will run on this webserver and will access a mySQL database. A light-weight client will run in the browser of a user running on any platform (Mac, PC, Unix, Linux). The client and server will communicate using CGI calls and XML data formats, allowing secure communication through firewalls. The calls will be optimized to enhance cross-Internet performance and maximize client display speed.

Approach to Intellectual Property:

The separation of applications into an Open Source Software (OSS) server and proprietary client will allow the Collaborating Company and other Colorado businesses to develop software for their own applications quickly and flexibly, while making use of the computationally complex perspectives mechanism seamlessly. This takes advantage of the benefits of both the traditional economic model and the new open source approach: development of the general mechanism can be shared while specific applications can provide economic competitive advantage. The details of the POW! license will be negotiated with the University and the Collaborating Company and will be designed to foster these complementary advantages.

Approach to Application Clients:

Internet technology is evolving rapidly. Compatibility with hardware and software in use at different sites is a major problem. The POW! perspectives server will run on a webserver, such as ours at CU, and does not need to be compatible with a variety of user systems. Some application client developers may want to take advantage of the latest versions of Java while others may prefer to maintain compatibility with older versions of HTML. The architecture developed by this Project will allow developers to create client interfaces using HTML forms, Perl scripts, Java applets and other technologies (such as XSL stylesheets). The Project will develop, document and post three sample clients demonstrating how to program client software using these different technologies and still taking advantage of the perspectives mechanism.

Resources

The University and the Collaborating Company already have adequate office space, computers, commercial software and networking to support this project. The University will only need funds for computer support. The PI will contribute technical expertise and the Collaborating Company will contribute expertise in supporting corporate meetings and trainings.

Evaluation Plan

The POW! Project will be evaluated by the production of the following deliverables:

- a POW! perspectives server in Java with a clear API and XML data exchange.
- negotiation of a license and the release of the POW! server under this license on a website with appropriate documentation to support collaborative development.
- sample clients for the POW! server illustrating the use of Java, HTML and Perl technologies.
- a requirements document for corporate client applications.

Follow-on Funding Plan

The POW! Project will provide a foundation for future work along two dimensions:

- The PI will raise over $100,000 in federal funds to continue work by him and the graduate student in educational applications using the POW! server.

- The Collaborating Company will raise funds internally and/or through investors to continue the development and marketing of software clients for corporate applications in collaborative distributed decision-making and training.

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The Research CyberStudio: Supporting Researchers as LifeLong Learners

The Research CYBERSTUDIO Project addresses the problem of training and supporting learners at the most advanced end of the educational system to be skilled interdisciplinary researchers. It targets graduate students who have completed extensive classroom study within a discipline but who could benefit from practical research experience within a supportive context. The project's theoretical perspective of lifelong learning postulates that people in knowledge-intensive endeavors need to be continuously developing skills and constructing knowledge, and that this can be facilitated by information delivery technologies within supportive collaborative contexts. Accordingly, the proposed project approaches its goals from a technological and organizational approach: creating structured communities of learners (research studios), and providing adaptable computer-based support (the CYBERSTUDIO) for these communities. The technical approach builds on innovative software prototypes by the PI and collaborators; the organizational approach leverages substantial local opportunities. While the project is designed to assist novice researchers, it will develop computer software useful to interdisciplinary research communities generally.

THE PROBLEM OF TRAINING AND SUPPORTING RESEARCHERS

Research is an important aspect of contemporary universities like the University of Colorado (CU). Increasingly, much of this research is taking on an interdisciplinary character, spawning special groups like the Institute of Cognitive Science (ICS) and the Center for LifeLong Learning and Design (L3D) at CU.

Despite a broad national effort to reform education from kindergarten through college and a significant attempt to develop computer support for education, little has been done to address the educational and computer needs of the most advanced students. The transition from an educated domain specialist to a skilled researcher is a lengthy and haphazard process, largely because the student is given little systematic support (Denning 1992). It is assumed that once students have completed their graduate course work they are capable of pursuing dissertation and post-doc research with minimal pedagogical support. However, experience within ICS and L3D shows that fledgling researchers need to continue developing their skills in reading, writing, and mathematics just like students at any level. As they become involved in investigating problems that spill outside the discipline of their academic training, they need to learn to read broader professional literature, to prepare journal articles or conference presentations, and to master new methodologies (statistical evaluation, experimental design, computer modeling, discourse analysis, etc.). Whereas most professionals have specialized productivity software at their command, interdisciplinary researchers lack such tools.

The Research CYBERSTUDIO (RCS) Project adapts current constructivist educational theories to the problem of training researchers. In particular, the following pedagogical principles underlie the Project's approach:

1. Knowledge is constructed within communities of learners (Scardamalia & Bereiter 1994).
2. The approach of a design studio provides an effective setting for learning (Schön 1987, 1983).
3. Learning takes place through a person's increased participation in a community of practice (Lave & Wenger 1991).
4. Individual understanding can be fostered by appropriate computer-based systems (Papert 1993, 1980).

Based on these principles, the Project conceptualizes the problem of training novice researchers in the following terms:

1. The learner is viewed as a newcomer within a research community, as an apprentice who needs thoughtful mentoring.
2. Collaborative research activities are organized into a "research studio" structure in which individual and group projects are conducted and critiqued.
3. Learners are assisted in gradually participating more and more in their research community to acquire the tacit skills of their profession.
4. Special software acts as a "CYBERSTUDIO" in which community members communicate and contribute, work and learn.

The uniqueness of the RCS Project lies in the creation of computer support to promote lifelong learning and to manage organizational knowledge within a research community. The CYBERSTUDIO software will therefore be described first. Then its usage by the community will be discussed.

THE CyberStudio SOFTWARE

A central hypothesis of this project is that computer support can play an important role in developing interdisciplinary research skills as well as in accomplishing the research itself. The challenge of the project is to create new software adequate to the attainment of this potential.

The lack of computer support to deliver information on an as-needed basis is endemic to interdisciplinary research in general, not merely to novice researchers. The theories of situated learning and knowledge construction suggest that there is a significant untapped potential of computer support for building communities of learners and for capturing group memories to inform newcomers. Such knowledge sharing software could be particularly helpful in the interdisciplinary context, where community members speak different technical languages.

Project participants will design, prototype, explore, and evaluate CYBERSTUDIO's software to support learning, communication, and work within interdisciplinary research groups. This software will be designed to meet the information and collaboration needs of researchers, especially novices. The success of the community-of-learners approach requires a high level of communication and organization; CYBERSTUDIO will provide a medium in which this can take place. The software will also identify and deliver relevant ideas from the extensive and growing writings of the group and related published literature, allowing people to share ideas across time and space (Stahl et al. 1995a, 1995b).

Here is an illustration of how the Internet-based CYBERSTUDIO software can be used: Suppose that a graduate student drafts a thesis proposal for software to categorize the content of Internet sites by reading level. The proposal text is analyzed within CYBERSTUDIO. The software delivers a list of web links pointing to the most directly related excerpts from cognitive science papers, key terms in an interactive, multidisciplinary glossary, specific entries in threaded discussions within the research groups, email messages on the topic, and contact information for people in various disciplines who have done relevant work. The student can then review and respond to any of this information. For instance, the student might compile a set of notes with hypertext links to several of the retrieved sources, make annotations to the sources (for future users to read), send messages to referenced people. Then the student can revise the proposal draft and resubmit it to CYBERSTUDIO to obtain a refined list of relevant information. All of this is done within the CYBERSTUDIO system.

While the CYBERSTUDIO repository of information is primarily directed internally to the research group, it also includes external links to web sites globally and it allows outsiders to view many materials in the network. Thus, it provides a medium of communication and documentation within a local research community while participating in the broader discourse of the World Wide Web.

The CYBERSTUDIO software system envisioned to support working and learning by interdisciplinary researchers unifies three technologies that the PI and collaborators at L3D and ICS have been exploring for many years:

1. Domain-oriented design environments (DODEs).
2. Dynamic web sites (DynaSites).
3. Latent semantic analysis (LSA).

These technologies will be integrated into CYBERSTUDIO network of research information services. CYBERSTUDIO captures knowledge as it is constructed within a research group and delivers items from this organizational memory when they are relevant to the new research of individuals, particularly newcomers.

1) Domain-oriented design environments. A DODE is a software application within which a professional conducts work. As the work progresses, the software responds by delivering domain-specific or community-historic information stored in its knowledge base that is relevant to informing the current state of the work (Fischer et al. 1993a, 1993b). By integrating working and information delivery, DODEs support lifelong learning or learning-on-demand.

2) Dynamic web sites. DynaSites are web sites that provide an interactive interface to a database of information shared by a group (Stahl 1997a). Based on intranet technology, they transform the World Wide Web from a generic broadcast medium to a group memory that allows collaborators to share their knowledge asynchronously. For instance, people in a research community can use their web browsers to find past discussions of ideas, glossaries of terms, and papers published by other members; as they generate new ideas, concepts, and essays using these resources, the new knowledge is added to the group memory interactively.

3) Latent semantic analysis. LSA is an automated technique for analyzing the semantic relations within a large corpus of text (Landauer & Dumais 1997). LSA can compare documents and rate the similarity of their technical content. When used properly, it can be effective for such tasks as evaluating the knowledge content of essays. Thus, it can be used by software to judge which of several student essays is most similar to a target essay. Experiments have shown that LSA is approximately as reliable as people in grading SAT essays and in selecting readings that are most appropriate for a given reader based on an essay by that reader (Wolfe et al. 1997).

The CYBERSTUDIO software developed by this project will incorporate information sources relevant to the research of the interdisciplinary groups involved (e.g., L3D and ICS). This includes both archival materials (published papers, technical reports, dissertations, seminar presentations) and process artifacts (on-going threaded discussions, email exchanges, meeting schedules or minutes, evolving glossaries of technical terms, annotated bibliographies, member information, etc.).

The project involves the development of techniques for capturing, structuring, evolving, retrieving, and presenting the information in CYBERSTUDIO. These techniques will include LSA applications (including the semi-automated production of a glossary of interdisciplinary technical terms in a corpus linked to key document excerpts), group perspectives (Stahl 1997a, 1995a, 1993a, 1993b), and a visual end-user language for querying and navigating the information base (Stahl 1993b, 1992a, 1991). Development of these techniques will be staged during the RCS Project period, with the glossary developed in Year I, perspectives in Year II, and the end-user language in Year III.

THE ORGANIZATIONAL APPROACH

The research studio is an approach to training through self-directed hands-on experience. Architecture students, for instance, spend a lot of their class time in studio classes, where they work on individual or group projects and receive critiques from peers and experienced designers. The project's research studios build on this model. Novice researchers will pursue their own dissertation research or participate in funded research within a community of learners, including both more and less experienced researchers. In addition to interacting informally and making formal presentations, people will share and co-construct ideas in settings such as reading groups, project meetings, and on-line discussion threads. Much of the communication associated with research studio activities will take place within the CYBERSTUDIO system and will be captured by it. Then, future newcomers can review the materials to learn relevant aspects of the group's intellectual history.

The project will investigate effective ways of structuring interdisciplinary research groups. This includes issues of physical office arrangements, meeting procedures, study groups, communication channels, and decision making. Like most professional workers, graduate students have too much to do; they must resolve conflicts of course work vs. research, individual projects vs. group efforts, meeting vs. working, learning vs. producing. Some of these conflicts can be ameliorated via institutional solutions such as adjusting requirements and reward structures. The framework of a research studio will be explored as a way of integrating research practice into the academic reward system, so involvement in group activities does not detract from personal achievement.

Apprenticeship or mentoring is important to the studio model of situated learning. A more experienced person provides systematic guidance or facilitation of student self-directed learning, and the student learns by working alongside old-timers. The mentoring relationship–just like the research studio–must be institutionally recognized in order to be effective. The project will investigate how this can be accomplished. It will start by formalizing apprenticeship relationships in the sense that they will be explicitly recognized within the group. Both the mentor and the apprentice will receive recognition for their work together. An on-going dialog concerning benefits and problems of apprenticeship will evaluate this approach.

Because the RCS project is itself an interdisciplinary research effort involving reflective practitioners, the participants in the investigation will have the task of evaluating their own learning. They will incorporate evaluation methodologies from multiple disciplines (educational evaluation, psychological controlled studies, software engineering debugging, user testing, etc.). Assessment will itself be a topic of research–how to evaluate support for lifelong learning and interdisciplinary research in naturalistic settings.

THE LOCAL CONTEXT

This project addresses the problem of training and supporting researchers from within an exceedingly rich context of growing interdisciplinary research at the University of Colorado (CU). It will take advantage of considerable independent resources from federal, foundation, and university sources and focus them on the needs of interdisciplinary researchers.

Project level. The PI is currently directly involved in two interdisciplinary research projects: an effort to develop computer-based organizational memories and one to develop educational software. The first is sponsored by the Center for LifeLong Learning and Design (L3D) and the second jointly by L3D and the Institute of Cognitive Science (ICS). The organizational memory project integrates ideas from learning theory, anthropology, and organizational theory as well as various aspects of computer science and particular application domains. The educational software project involves issues of psychology and linguistics as well as computer science and education. During Year I, the RCS Project will encompass the teams of graduate students, post-docs, and visiting researchers working on these two projects.

Center level. ICS is an interdisciplinary institute by the nature of cognitive science; it expects to become an accredited interdisciplinary degree program in the next year. Within ICS, there is an active research group exploring latent semantic analysis (LSA). LSA is a statistical text analysis method with promising applications to practical problems in educational software as well as theoretical implications within cognitive science. The LSA research group includes cognitive psychologists, computational linguists, and computer scientists. L3D is a center under both ICS and CU's Department of Computer Science, with strong involvements in education and environmental design. It encompasses projects developing conceptual frameworks and prototype software for applications in a variety of domains. L3D and ICS members teach undergraduate and graduate courses in computer science, design, and cognitive science. Students in the research groups and courses within L3D and ICS will provide the focus for Year II of the RCS Project.

University level. The CU administration is promoting the notion of a "total learning environment." As part of this commitment, L3D is establishing a broader interdisciplinary initiative across many departments of CU–the Center for Interdisciplinary Research on LifeLong Learning (CIRLL)–likely to be funded as an NSF center next year. CIRLL will directly support seven graduate research assistants and four post-docs, as well as coordinating the work of many more novice and experienced researchers across campus. In addition, L3D has a growing network of industrial partners; students intern at the companies and company employees spend time at L3D's research labs. In Year III, the RCS Project will expand to include novice interdisciplinary researchers in CIRLL and among the industrial interns.

Broader impact. It is anticipated that the lessons learned in the RCS project–pedagogical approaches, organizational supports, and computer software designs–will be disseminated beyond CU through research contacts at key centers like the Cognitive Studies of Interdisciplinary Communication program in the National Institute for Science Education at the University of Wisconsin, as well as through academic publications. Within CU the potential for dissemination is unlimited, with CU's focus on "total learning," its efforts to promote Internet support for teaching, its interest in distance learning, and its standing as a major research center.

CONCLUSION

The Research CYBERSTUDIO Project will explore organizational, pedagogical, and technological approaches to train advanced graduate students to be skilled interdisciplinary researchers. It will develop CYBERSTUDIO software to support the work of research groups. Gradually expanding its scope, the project will take advantage of a lively and growing community of interdisciplinary research at the University of Colorado. The approaches and software developed will be thoroughly evaluated, clearly documented, and broadly disseminated.

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