“*Collaboration Services for the Math Forum Digital Library*” Project Description

1. Statement of Need 1
   1.1. The Need for Collaboration Support 1
   1.2. Target Audience: The Math Forum Digital Library Community 2
   1.3. Vision Scenario 3
   1.4. Impact 4
2. Project Goals 4
   2.1. Goals 4
   2.2. Objectives 4
3. Project Design 5
   3.1 Theoretical Framework 5
   3.2. Pedagogical Framework 6
   3.3. Project Team 7
   3.4. Prior Work 7
   3.5. Infrastructure Technology 10
4. Plan of Work 11
   4.1. Timeline 11
   4.2. Management Plan 12
   4.3. National and International Collaborators 13
   4.4. Project Evaluation 13
5. Anticipated Results & Impact 14
   5.1. Dissemination & Outcomes 14
   5.2. Sustainability & Contribution 15
   5.3. Integration of Research & Education 15
   5.4. Integrating Diversity 15
   5.5. Intellectual Merit 15
   5.6. Broader Impacts 15

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 up-state 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.