Knowledge Management Support for Teachers

J.M. Carroll[1], C.W. Choo[2], D.R. Dunlap[1], P.L. Isenhour[1], S.T. Kerr[3], A. MacLean[4] & M.B. Rosson[1]

[1]Center for Human-Computer Interaction, 660 McBryde Hall, Virginia Tech, Blacksburg, VA 24061-0106 USA

[2]School of Information Studies, University of Toronto, 140 St. George Street, Toronto, Ontario M5S 3G6 Canada

[3]College of Education, 115 Mill Hall, University of Washington, Seattle, WA 98195 USA

[4]Xerox Research Centre Europe, 61 Regent Street, Cambridge, CB2 1AB United Kingdom

Carroll is corresponding author: Phone 540-231-8453; Fax 540-231-6075; Email carroll@vt.edu

Abstract

Business organizations worldwide are implementing techniques and technologies to better manage their knowledge. Their objective is to improve the quality of the contributions people make to their organizations by helping them to make sense of the context within which the organization exists; to take responsibility, cooperate, and share what they know and learn; and to effectively challenge, negotiate, and learn from others. We consider how the concepts, tools, and techniques of organizational knowledge management can be applied to teachers' professional practices and professional development. We describe a framework for knowledge management support for teachers where the sharing of concrete knowledge bootstraps the attainment of more abstract levels of knowledge sharing. We describe the development of a knowledge management support system emphasizing long-term participatory design relationships between technologists and teachers, regional cooperation among teachers in adjacent school divisions, the integration of communication and practice, synchronous and asynchronous interactions, and multiple metaphors for organizing knowledge resources and activities.

1. Introduction

Organizations learn and have knowledge. The knowledge is dispersed among the people in the organization. Some of it is codified in documents and policies; some is embodied in projects and results; some is held tacitly by individuals and small groups. The challenge of *knowledge management* in organizations is to ensure that the organization continually learns, and that new knowledge is effectively incorporated into practices, so that it is accessible when needed.

Knowledge management is not easy to achieve in any organization. People want to teach and learn, to understand and share, but they have been socialized—and their jobs have traditionally been designed—for productive action. Learning and sharing are often luxuries that occur outside normal routine. People value and protect what they know and what they can do; it is central to who they are. But increasingly, steady productivity is not enough. Markets and technological infrastructures, and the knowledge and skills they require, are changing more rapidly and more pervasively than ever before. Organizations must evolve to survive.

Business organizations worldwide are developing and implementing a variety of techniques and information technologies to enhance knowledge management. Their objective is to improve the quality of the contributions people make to their organizations by helping them make sense of the context within which the organization exists; to take responsibility, cooperate, and share what they know and learn; and to effectively challenge, negotiate, and learn from others. New books, conferences, workshops, and consultancies abound. Companies like Lotus/IBM, Microsoft, Novell, and Xerox have identified knowledge management as a strategic market segment for information technology products. International Data Corporation estimated that knowledge management software and services will be a six billion dollar industry for year 2002 (http://www.idc.com).

In this paper we consider how the concepts, tools, and techniques of organizational knowledge management can be applied to support public school teachers. Schools manage and develop society's knowledge through teaching and learning. But schools, like other organizations, do not always manage their *own* knowledge effectively.

We first review contemporary approaches to knowledge management in business organizations, focusing on the nature of organizational knowledge needs, and strategies for addressing these needs. We argue that these approaches are both feasible and desirable in the school context and discuss the needs and opportunities for knowledge management in teaching. Contemporary school reform initiatives are multifaceted, incorporating aspects of teacher training and professionalism, school management, curriculum content and pedagogy, and the use of technology. We argue that many initiatives aimed at school reform can be facilitated by better knowledge management. We offer a framework for supporting knowledge management by teachers, in which the sharing of concrete knowledge can bootstrap the attainment of more abstract levels of knowledge sharing.

Finally, we describe the development of a knowledge management support system for teachers. Our approach recruits teachers and community members to join us in a long-term *participatory design* process that helps to ensure that the information technology we create addresses the concerns and practices of its users. Our focus is on *regional cooperation* among teachers who work in similar contexts and who can meet face-to-face, though not always daily or weekly. Our system integrates shared *communication* with sharing *practices*; it is more than a discussion forum and more than a document management system. Our system also integrates *synchronous* and *asynchronous* interactions to address the scheduling constraints of schools as a workplace. We show how *multiple metaphors* can be used to organize knowledge to better serve the different needs of various school stakeholder constituencies (teachers, parents, administration, community members). With support from the US National Science Foundation, we are currently implementing this system.

All organizations face the requirement for better knowledge management practices—the specific challenges of organizational learning faced by school systems are instances of general challenges faced by all organizations. However, schools are quite distinctive on at least two grounds. First, it is essential that schools succeed in knowledge management; society's future is at stake. Second, schools typically have fewer resources than commercial establishments to address the challenges of knowledge management; school systems cannot afford expensive consultants or business software, and this is unlikely to change dramatically any time soon.

2. Knowledge Management in Organizations

Organizations are collections of individuals, each of whom is trying act sensibly and productively; each member is responsible for understanding what he or she is doing and how it contributes to the bigger picture. Organizations that merely decompose large problems into simpler sub-problems become rigid and mediocre, particularly in circumstances of rapid change. The term *knowledge management* refers to organizational policies, practices, and tools that allow individuals to better understand and to help define the bigger picture of which their work is a part, and to more easily benefit from and contribute to the work of others in the organization. Successful knowledge management requires a balance and coordination between the top-down articulation of policies and tools and the bottom-up cultivation and evolution of practices and culture in a workplace.

2.1 Organizational Knowledge

An organization's capacity to innovate through management of its explicit and implicit knowledge is essential to success. A key product of any organization is knowledge. Organizations must inventory their own structures, processes, and technology with respect to accessing, handling, and utilizing knowledge. They need to encourage the creation of knowledge; to capture and consolidate knowledge through effective metaphors, analogies and models; to integrate and disseminate knowledge to people throughout the organization; and to present explicit knowledge as experience for vivid learning (Nemirovsky & Solomon, 2000). They need to develop and adopt techniques for systematically converting the tacit know-how of individuals into explicit knowledge resources for the organization (Choo, 1996, 2000). And they need to foster an organizational culture that values knowledge, that values sharing knowledge, and that values innovation and risk-taking in the development of knowledge.

There are many obstacles to effective knowledge management, including lack of trust, different frames of reference, lack of time and opportunity, rewards going to those who own knowledge, lack of capacity in recipients to absorb new knowledge, the not-invented-here syndrome, and intolerance for mistakes (Davenport & Prusak, 1997). People in organizations often gather information for decision-making, but then do not use it (Elmore, 1990). People create personal explanations of organizational phenomena, satisfying their own need to make sense (Schön, 1983), but not contributing to shared meanings and values across the organization (Weick, 1995). Workers sometimes fall into mechanical patterns of rule-following, settling for satisfactory but non-optimal decisions and practices (satisficing). And managers often do not understand their employees' creative innovations and work-arounds (Button, 2002).

Effective knowledge management entrains new roles and responsibilities for both managers and workers. Managing an organization's knowledge assets is a continuing social process of clarifying goals in the context of uncertainty, negotiating commitment, encouraging mutual learning and continual skill development, maintaining trust among stakeholders within the organization and beyond it (including societal norms and public opinion), and creating rationale. Workers who assume responsibilities for creating and sharing meaning must understand and discuss their work. They must see their work from multiple perspectives, and must instigate and invite critical reflection. Frequently the main beneficiaries of enhanced knowledge management practices are *not* the individuals who develop and carry out these practices. Yet the managers and workers who accept knowledge management roles and responsibilities do not always receive enhanced status or compensation for doing so.

Some of the challenges for realizing the vision of knowledge management are associated with organizational policies and management—employee reward systems that encourage risk-taking and collaboration, technologies for representing and sharing informal information, and so on. However, even more of the challenges are situated in the workplace: knowledge management requires a new workplace culture that Lave and Wenger (1991; Wenger, 1998) have termed "communities of practice". A community of practice is a group that regularly shares work practices and problems, and that works together over a significant period of time. Knowledge sharing is a central but incidental activity in a community of practice, carried out continuously and by all members as a by-product of doing work together.

2.2 Strategies for Knowledge Management

Based on the experience of organizations that have implemented successful knowledge management initiatives, five sets of methods and tools have been found to work well: communities of practice, knowledge repositories, expertise directories, peer assistance, and best practice replication (see Choo, 2000; Choo, Wei, & Bontis, 2002; for more discussion).

Communities of practice are self-organizing, informal groups whose members regularly share knowledge and learn from each other (Brown & Duguid, 1991; Wenger, McDermott, & Snyder, 2001). Communities of practice are defined by three features. First, members face common work activities or share common interests. Second, they can see the collective benefit of sharing knowledge, with each member recognizing the need to have access to the expertise of other members. Third, members develop norms of trust, reciprocity, and cooperation that support knowledge sharing. Communities of practice are increasingly common in knowledge-sharing initiatives; well-known successes have been reported by organizations such as Buckman Labs, Clarica Life Insurance, the World Bank, and Xerox.

Knowledge repositories are databases of codified knowledge assets that are systematically organized to facilitate searching and retrieval (Cross & Baird, 2000; Ruggles, 1998) Knowledge repositories may contain lessons learned, best practices, proposals, presentations, templates, and so on. A knowledge repository is typically the end-product of an orderly, well-defined process that includes analyzing needs, collecting documents, editing and indexing, packaging and dissemination. Knowledge repositories are used in firms like Accenture, Ernst & Young (where subject matter experts prepare standardized knowledge "PowerPacks" in each of its practice areas), and Chrysler (where Tech Clubs produce "EBoKs" or Engineering Books of Knowledge for its car platforms).

Expertise directories are directories of employee knowledge and skills that allow users to find, contact, and consult with individuals who possess specific skills or experience (Davenport, De Long, & Beers,1998). Well designed expertise directories are supported by systems and procedures that keep employee profiles up-do-date, and allow individuals to review their profiles and control access. Expertise directories are in place at Hewlett-Packard, Microsoft, NASA, and many large pharmaceutical companies.

Peer assists are knowledge sharing activities that occur near the beginning of a challenging work project. At British Petroleum, a team confronting a difficult problem can invite another team that has been through a similar experience to meet for one to three days, and follow a facilitated, semi-structured process to walk through the problem (Collison & Parcell, 2001). The requesting team has the opportunity to tap the knowledge of the assisting team, while the assisting team adds breadth and depth to its own expertise.

Best practice replication refers to planned processes that collect, codify, and transfer innovative practices developed at one location in an organization to the rest of the organization for possible adoption. For example, Ford deploys a formal system that "pushes" selected best practices to plants based on the type of work conducted in each plant, and "follows through" by generating reports on how many practices each plant has submitted and implemented (Dixon, 2000). A growing number of firms in manufacturing and process industries are capturing and replicating best practices.

Recent surveys and benchmarking studies by The Conference Board (Hackett, 2000), the APQC (2000), and other organizations have identified three major impediments to successful knowledge management. One main obstacle is that organizations do not clearly articulate the need to manage knowledge or its contribution to organizational goals and purpose. A second obstacle is that the competing culture of knowledge hoarding may block knowledge sharing. A third obstacle is that encapsulated functional units in an organization erect barriers that prevent knowledge transfer. It is interesting to note that all these impediments are internal to the organization, and are not so much driven by external factors or technology concerns as they are by the culture, politics, and values of the organization.

From an information perspective, the capacity to create, share, and use knowledge is distributed over a larger canvas in which an organization uses information to make sense of its environment, create new knowledge, and make decisions (Choo & Bontis, 2002). Sense-making produces a framework of shared meanings that give purpose and value to the activities of the organization, and guides perception of the problems or opportunities facing an organization. Dealing with complex or novel problems often become occasions for creating new knowledge. An organization possesses three kinds of knowledge: *tacit* knowledge embedded in the experience and expertise of individuals; *explicit* knowledge codified as artifacts, methods and procedures; and *cultural* knowledge expressed as assumptions, beliefs, and values. Creating new knowledge depends on the flow and confluence of these three forms of knowledge. The results of knowledge creation are new innovations or new capabilities. New knowledge represents a potential for action; decision making converts this potential into a commitment to act. Organizational decision making, guided by rules and premises, selects a course of action that promises goal attainment in the face of risk and uncertainty.

Thus, the capacity to develop knowledge emerges from a network of information processes and participants who construct meanings about the organization's identity and actions; create, share, and apply new knowledge; and initiate action through evaluation and selection of alternatives. Rather than being centrally controlled and coordinated, the capacity to develop knowledge emerges from the complex patchwork of processes and participants who enact and negotiate their own meanings of what is going on; stumble upon and wrestle with new knowledge to make it work; and creatively improvise and adapt rules and routines to address hard problems.

3. Knowledge Management in Teaching

The needs and opportunities for knowledge management in teaching are analogous to those in business organizations. Every individual teacher develops material resources, classroom activities, pedagogical techniques, and practical insight into learning, development, and human relations. These are knowledge assets that are potentially sharable and reusable.

The obstacles to knowledge management in teaching are also analogous to those in business organizations: School systems may not adequately articulate their knowledge-sharing goals, implicitly encouraging cultures of knowledge and resource hoarding, and reinforcing the boundaries between classrooms and between the teaching and administrative personnel. Indeed, it is widely observed that teachers work in relative isolation from professional peers, developing and refining techniques that work best for them in their personal classroom culture (Goodlad, 1984; .Rosenholtz, 1991; Tyack & Cuban, 1995)

3.1 School Reform as Knowledge Management

School reform can be seen as systemic innovation in knowledge management (Hargreaves, 1999; Marshall & Rossett, 2000). For schools to be more effective organizations, teachers must understand and help to define administrative and curricular goals and standards. They need encouragement, support, and recognition for sharing classroom resources and professional knowledge. They must assume greater accountability to students, to other teachers, and to the community beyond the schools.

However, school reform is sometimes conceived of as a top-down transformation, that is, accomplished primarily through administrative interventions. School reform initiatives may envision how better access, handling, and utilization of knowledge could change teaching and learning, but they rarely describe the adoption process for new knowledge practices, or the consequences and side-effects that such adoption processes would have for teachers and students. Top-down school reform often articulates objectives in terms of the measurable performance of teachers and students (National Research Council, 1996). In this context, the chief incentive for adopting innovations may be a perceived threat, for example, the implicit and explicit threats of state-mandated standards of learning (e.g., Virginia Standard of Learning, 1998).

A top-down knowledge management initiative can cause a conflict in the ways that teachers versus administrators think about the value and use of school information (Schlager & Fusco, in press). Teachers' natural interest in information that describes their teaching practices and the resultant student learning often clashes with administrative requirements to use such information as summative outcomes for an individual school, principal, or teacher. These parallel requirements suggest that a critical prerequisite for effective knowledge management in schools will be to carefully define what information is to be collected and shared, by whom, and to what ends. Clarity will be the first part of this definition process; the second will be generation of trust—teachers must be able to trust that information about their personal successes and failures will not be used against them; that administrative decisions will be distinguished from instructional ones; and that some level of privacy and protection will be afforded to the sharing and self-study activities.

As in business organizations, sustainable knowledge management in schools will depend on the emergence of peer-driven in-service mutual learning—innovations in workplace culture. Teacher communities of practice work together as teachers; in the course of their professional collaborations, these communities will better understand their own knowledge-sharing practices, as well as their frustrations, needs, and desires. Innovations in knowledge-sharing practices, and teacher professional development more generally, become a part of the social experience of working together. Communities of teaching practice may develop peer-critiquing (Stigler & Hiebert, 1999), long-term classroom mentor collaborations with community experts (Gibson et al., 1999), and highly delegated decision-making in school management (Mohr, 2001).

Bottom-up knowledge management yields a variety of collateral benefits for school organizations. The resources created by teacher communities of practice can be disseminated beyond the original community of practice. Knowledge repositories of classroom activities and materials can contribute to discussions of best practices for other teacher communities, as well as serving as models for pre-service teachers. Expertise directories can make lead or master teachers more accessible to colleagues within their school systems, and perhaps beyond. Codifying peer-based resource development and mutual learning—and making it more public—can help teachers to coordinate with other stakeholders in public education. On-going case studies of classroom activity provide vivid descriptions of professional work and concerns, which will enable better supervision; case studies also make the school more visible to the community beyond the school, enabling greater reciprocal understanding and support between the school and its community.

3.2 A Framework for Knowledge-Sharing among Teachers

We are interested in using information technology to create and sustain knowledge management support for teacher communities of practice. Specifically, we are working to promote cooperation in a professional community of teachers who can meet face-to-face, but not on a daily basis—an extended proximal community of practice. In part, this interest derives from a broader research and development commitment to community networking (Carroll, et al., 2001).

In our "Learning in a Networked Community" (LiNC) project (Dunlap, Neale, & Carroll, 2000; Carroll, et al., 2000; Isenhour, et al., 2000), we worked with four science teachers from four schools in a rural system through more than five years. At the outset, we were surprised to discover that the only two physics teachers in the school system we studied did not regularly collaborate. We should not have been surprised. The main top-down support for teacher collaboration is occasional in-service programs. Our project developed a communications infrastructure incorporating video conferencing, text chat, email, and a shared notebook tool to support cross-classroom project-based science. The teachers we worked with were all quite interested in such approaches, but they experienced many conflicts with their well-established, single-classroom practices in developing and adopting new practices. We found that the teachers became far more successful when they worked together as a coherent subgroup articulating classroom requirements and visions to the larger project group, and when they assumed roles with greater responsibility, such as presenting detailed design proposals to the larger project group or coaching other teachers in classroom applications of communications technologies (Carroll, et al., 2000).

We believe that the pervasive "global village" vision of information technology should be complemented and enriched with a distinctive local and regional focus—there is little point to a global village if every part of it is the same as every other part. Schools illustrate this well. There is a strong tradition of local control and local participation in American schooling. It is especially typical for elementary and middle schools to emphasize the current events, history, geography, ecology, and geology of their particular region or state. Such local content is intrinsically motivating for students and for teachers, and allows many concrete learning activities beyond the classroom. These emphases make schools and the school experience distinctively local and regional, though they are well-balanced by national standards and testing programs.

The development and use of local content and curricula provide a foundation for teacher communities of practice. Mass-market resources pertaining to one's own locality are likely to be limited. Thus, the need to develop local resources is real. Contributing knowledge resources that stem from personal practices and experiences might be especially rewarding to teachers, because it emphasizes the uniqueness and value of one's knowledge within a community of peers. Benefiting from local knowledge resources might also be especially rewarding, because it may entrain personal interactions with the colleagues who created the resources. Such relationships are critical to the success of knowledge management in schools: The key obstacles to effective knowledge management derive from the "tragedy of the commons" in which people fail to appreciate the importance of their own contributions to the development and conservancy of shared resources.

As a concrete starting point for supporting and modeling the impact and sustainable coordination of teachers' knowledge management, we contrast three levels of knowledge sharing, ranging from the relatively concrete exchange of specific resources, through active and extended contributions to communities of practice (Table 1). These levels are loosely based on the development of teachers' knowledge sharing in the LiNC project; many of the examples are drawn from our ongoing work with teachers on knowledge management support (Carroll et al., 2003). Although the framework is simple and tentative at this point, it presents a hypothesis about "transitional systems" in the sense of Papert (1980; after Piaget & Inhelder, 1969). That is, our three levels imply a progression in degree of knowledge sharing; they suggest a possible adoption process, and they offer an initial vocabulary for discussing teaching practice.

Level of sharing	**Examples**
Tangible resources	• Information on how to access shared testing equipment at a local field site. • Library of books on teaching science using toys made available through district staff development efforts. • Very large pendulum apparatus donated by retiring Physics teacher.
Activity plans	• Learning styles inventory / assessment. • Guide for conducting and elaborating field study of a local pond's ecology. • Schedule, reading list, & sample questions for a regional academic competition club.
Prototypes-in-use	• Templates and examples for cyber discussion circles, including annotated transcripts from past activities. • Stream monitoring tools and activities including data tables, data gathering protocol, descriptions of the environment, photos, discussion forum, and project notes. • Repository for semester unit on ecologically-sound architecture including instruction, resources, and templates for creating online group presentations.

Table 1. Levels and examples of knowledge sharing practices.

At the first level, teachers might exchange *tangible resources*. The six teachers in the LiNC project, for example, shared pointers to interesting web sites, laboratory equipment, construction kits, and other physical artifacts. Other examples might include books, specimens, contact information for local experts, and software simulations. Many professional development projects for teachers produce lists of such resources that teachers can share in their work.

Technology to support sharing at this level could include tools for tracking inventories and handling reservation of physical artifacts, maintaining lists of virtual artifacts, and discussing problems with or tips for using the shared resources. Contributing to a shared base of knowledge about such resources may require relatively little effort, and the resources may be usable for a variety of classroom activities. However, even with appropriate technology, the effort required to evaluate the potential usefulness of a given piece of lab equipment or other artifact, and then to design a useful activity in the context of a particular classroom may be a daunting task.

At the next level, we observed that teachers share ideas about *activity plans* in the form of lesson outlines, objectives, classroom strategies, and grading policies. In some sense this was a natural outcome of the LiNC project because of our emphasis on planning and coordination of cross-classroom collaborative activities. The teachers developed and shared variations on existing lesson plans and teaching objectives, as well as developing entirely new activities; they also shared their grading schemes for class projects as part of developing commensurate grading policies across different classes. Other types of exchange at this level could include sharing and discussion of school or district goals and community input concerning programs and curricula.

Many web-based and offline teacher development projects collect lesson plans from teachers, but these tend to be static lists that fail to respond to the dynamic contexts and circumstances in diverse classrooms. To address this, technology support for sharing at this level would need to go beyond authoring and include tools for discussing, annotating, reusing, and refining plans, activity materials, and grading policies.

Compared to items in a list of concrete teaching materials, the plans and objectives of an activity design will be more specific to the teaching context in which they are developed. Documenting and articulating plans and objectives is also likely to be require more work than simply posting a classroom resource as part of a repository. However, it is possible that capturing an activity as a plan will facilitate its successful reuse by other teachers—a "plan" may capture tacit knowledge about the activity's goals and implementation that would be invisible if its constituent resources were simply posted to a database.

The third level of sharing is *prototypes-in-use*. These are artifacts produced by individual students, classes, or teachers; they are actual implementations—often active and ongoing—of an activity plan that might have been described and shared at the second level. For example, in the LiNC project, the teachers were able to view or download in-progress and completed work from their own classes and from their collaborators' classes. Numerous other examples of student projects can be found on the web, usually representing isolated efforts by individual teachers. Another teacher in our local school system created a detailed web site with data and photos from an extended stream monitoring activity. Construction and maintenance of this site required considerable effort and expertise, but differences in availability of (and proficiency with) the required tools limit the opportunity for reusing the data, structure, or design of this site for activities in other classrooms.

Technology to support the sharing of prototypes-in-use might include tools for authoring and accessing completed or in-progress student work (e.g., completed worksheets or quizzes, photos of projects, data sheets, or summaries of collected data), as well as tools for extracting templates from, discussing the merits of, or otherwise annotating posted artifacts. The effort required to make these prototypes available for sharing may be largely mechanical, because students would do most of the work to create the content. Ideally, technology aimed at supporting such sharing would simplify the summarization and publishing tasks that teachers already include as part of classroom activities. Prototypes published and shared in this way are iterative and ongoing; collaborating teachers can critique, scaffold, and adapt new materials as instructional needs and opportunities evolve. This increases the likelihood that both the tacit and explicit knowledge surrounding these learning activities will be shared.

As instances of "situated classroom know-how", prototypes are unique to a specific activity performed by a specific group of students. However, templates of the underlying artifacts may be more readily reusable—data can be incorporated into future activities, and teachers reusing the prototypes can make independent assessments of the original activity or its variants. Refinements that allow useful activities to be incorporated into new classroom contexts may therefore be easier to identify. The success of tools such as CoWeb (Guzdial et al., 2001) in supporting activities that evolve over time and across disciplines demonstrates this potential.

Currently, knowledge management among teachers is discretionary. Teachers affiliate to addresses immediate shared concerns, but they do not have a culture of collaboration (Tyack & Cuban, 1995). If properly supported, the sharing of tangible resources, classroom activities, and activity prototypes may be immediately rewarding. It does not require a culture of collaboration, but it can help to foster one. Bilateral mutual exchanges, or sharing within small peer groups, addresses the standing mission of teachers and schools while still allowing any given teacher to participate in his or her own way.

It is also important to recognize that the teacher knowledge sharing we envision can be carried out informally, in a highly bottom-up fashion. There is no clearinghouse of technical common ground. Teachers have substantial—often unique—knowledge about where they might find a certain chemical or specimen, which of their colleagues has tried a given activity with surface tension or the psychophysics of taste, or who might know how to pose motivating questions about the motion of slinkies or how to fix a non-working model train.

The potential impact of teacher development should be considered in terms of more than just an accumulation of teaching resources. Staff development can leverage and strengthen teacher communities of practice. Knowledge management innovations might promote strategies for adjusting the roles of teachers in developing organizational knowledge on various levels, but they must be introduced, supported, and evaluated with respect to deeper levels of impact. Knowledge management for teachers should build on the tools and approaches developed for business organizations while addressing the distinctive characteristics of school organizations. By characterizing different levels on which to advance teachers' knowledge, our framework helps to formulate how organizational learning might develop in the school context. The framework may benefit teachers' work by providing ways to understand what constitutes and facilitates better access to tangible resources, to activity plans, and to implemented activity prototypes that directly incorporate local teaching practices.

4. Creating an Online Infrastructure for a Local Community of Practice

Locality can function as a powerful context, framework, and metaphor for organizing teaching knowledge and instructional resources. Engaging in shared research goals helps teachers develop shared professional identities and create professional learning communities (Brown & Campione, 1994; Bruckman, 1998; Lave & Wenger, 1991). When the local community serves as the space where professional knowledge gets represented, communicated, and collected, teachers and community members exercise greater control of their resources and information. This advances school-community cooperation and coordination, and is reflected in the body of local shared professional knowledge, norms, practices, needs, and goals (Rosenholtz, 1991). A local sense of professional identity can help divert, absorb, and give meaning to top-down pressures to increase teacher accountability and student assessment measures.

When teachers can articulate their own shared professional identity and goals as a community, they are more likely to assimilate broader political goals by reflecting on how to improve their own practices, and they are less likely to submit in a passive manner to top-down accountability pressures. District administrators often struggle to balance local community needs with goals articulated at the state or national level; the balancing act is particularly challenging for goals related to scientific literacy, standardized testing, and other measures aimed at accountability (DeBoer, 2000; Marzano, Kendall, et al., 1999; Spalding, 1995). School districts would benefit from the ability to audit, manage, and disseminate the professional knowledge created within its organization (Hargreaves, 1999). However, it is essential that efforts toward knowledge management in schools should proceed with the understanding that key dimensions of teachers' professional knowledge are tacit, local, and dynamic.

4.1 Leveraging Locality in a Teaching Community

Many teaching issues that are pervasive throughout a school system are specific to a region. Local values, backgrounds, and resources determine expectations of students. This means that a curriculum is in many ways a local concern, which creates a dilemma for educators: How do schools provide the generic math and science "literacy for all" while also addressing the knowledge, resources, and needs of local constituencies? For example, science curricula attempt to specify scientific process and inquiry skills at various ages, but the state of Virginia encompasses great diversity in geography, culture, and population demographics. Teachers in different regions must address varying environments, experiences, backgrounds, expectations, and values concerning science. On the Eastern shores of Virginia, cities like Norfolk face critical inner city problems and enjoy a unique coastal ecology. In contrast, the Appalachian regions of Southwest Virginia struggle with rural poverty, highly distributed supplies, and a wide range of climactic and physical conditions.

Inevitably a geographical region serves as a powerful source for literature, history, culture, and science curriculum for local schools. Locality gives meaning and focus in the enactment of national and statewide standards, and it enriches and develops the resident professional knowledge of teachers. Teaching about local history, natural science, and culture helps to create a sense of belonging and identity within the region, and it provides numerous field-based learning opportunities in constituent communities (Eifler, 1998; Tate, 1996).

Teachers throughout a local region may be involved in projects that overlap in many ways, but they may not have the opportunity to discover or sharek the instructional resources acquired and employed by one another. Middle school life science teachers, high school chemistry and biology teachers, even math teachers, are all interested in instruction that could benefit from the collection and analysis of field data. Teachers in rural settings consider their local forest and stream environments a valuable source for hands-on instruction in a variety of applications of science. Environmental scientists interested in water-quality need to monitor water pH, aquatic species, invertebrate populations, pollutants, and a wide range of other scientific data. Moreover, such monitoring should be done over a wide area, and in a variety of settings, to support meaningful conclusions about the environment. Clearly local science and math teachers have an opportunity for considerable shared interest and inquiry when their instruction focuses on the local area. Imagine the following scenario drawn from ongoing work with teachers in our region:

Garin, a high school biology teacher, has been taking his students to a local stream to monitor the invertebrate populations and local aquatic species. They have followed scientific protocols to gather stream biology data for the entire schoolyear, compiled the population statistics into tables and charts, and related their data to what is known about how certain animals differentially tolerate pollutants. The students have taken photos of the area its aquatic life, and constructed descriptions and taxonomies to describe the stream environment. Jody, a high school chemistry teacher in a neighboring county, has been taking students to measure pH, nitrate, and phosphate levels in a nearby part of the same stream. They have studied the chemistry involved in fertilizers, pesticides, and detergents used by local farmers and citizens. They have plotted locations of fields, neighborhoods, landfills, dumps, and the chemicals likely to be deposited at these locations. They have also collected photos and descriptions of chemical samples, and have illustrated chemical diagrams of these substances and their reactions in ground water. In yet another section of the stream, Terry, a middle school life science teacher, has begun to interest her students in how the surrounding environment determines the health of the stream and river associated with the watershed and why people worry so much about the distant places where wastes are released into the environment. She knows only a little about the pollutants, chemistry and invertebrates; she knows nothing about the learning activities underway in her colleagues' classes. She does, however, have a strong desire to help her students understand the stream and enliven the curriculum she teaches.

Table 2. Scenario describing an opportunity for knowledge sharing among local teachers.

In addition to curricular-based opportunities for sharing like those conveyed in the scenario, teachers are constantly confronted with a wide range of opportunities for collaboration with colleagues and the community. Science teachers may enlist community members and resources for laboratory and fieldwork materials and expertise; they often want to make these learning projects visible because they may attract the interest of parents or the community. Teachers may also be involved in other organizational activities that require collaboration and could benefit from better tools for managing pertinent information and resources. Teachers often must coordinate with special-needs or gifted teachers to create IEPs (Individualized Education Programs) that support a variety of alternative and enhanced learning activities. They administer and respond to standardized testing; they mentor student and beginning teachers. They sponsor clubs and extra-curricular groups, contests, and events that may be connected to the larger community. They assess and evaluate student work, recommend remediation specialists, report grades, and keep parents informed and connected to the classroom. They participate in district-wide staff development, site-based management decisions, committees, and other duties.

Network technologies provide functions that can provide innovative educational opportunities and help organize and reduce time and distance for teachers' complex and busy work.

4.2 Current Technologies for Knowledge Sharing

The requirements for a comprehensive set of tools that would allow the teachers in the scenario to leverage each other's efforts are not trivial. Ideally, such tools would support the publishing of project materials; provide searching and awareness mechanisms enabling teachers to discover each other's activities; include communication tools for discussion of possible collaborations (or to arrange face-to-face meetings for this purpose); and provide means for adapting and integrating materials from one project into another.

The World Wide Web provides a pervasive infrastructure for supporting distributed activities. However, commonly used web-based systems provide only limited support for the kinds of rich interactions that would be required to support active, ongoing knowledge sharing among the teachers in the scenario. The Web is best at supporting sharing of tangible resources, the most primitive level of knowledge sharing in our framework. While new means for building and sharing on-line content are continually being invented, the web still strongly favors information *consumers* over information *producers*.

The three teachers in the scenario might, for example, post materials from their classes' projects on the Web. In this case, discovery of each other's work would most likely rely on serendipity. One teacher might simply stumble across a colleague's materials while browsing or searching the web. Under more ideal circumstances, such materials might be announced on a shared web index or broadcast to a mailing list. However, even if we assume that these awareness obstacles are overcome, and that the teachers learn of each other's efforts, the web does little to support active collaboration. Given the likely differences in the servers hosting the web pages, and in the tools used to create them, one should not expect that a teacher would be able to do more than simply link to content created by the others.

In practice, several teachers with whom we have worked do publish their materials, electronically or otherwise. Motivations for these efforts include a desire to experiment with or expose students to new technologies (e.g., web pages or virtual reality software), or to make their classes' activities visible to the local community or to more novice colleagues. In other cases the publishing efforts are more top-down in nature, coming as the result of requests or mandates by administrators.

Facilitating more advanced knowledge sharing, such as the sharing of plans and goals, depends on the capability for teachers to become authors and editors. In this type of sharing, the value comes when teachers generate reflections on, strategies for, or speculations about their use of concrete materials (whether physical or digital), and make this practice-based knowledge available to their colleagues. A variety of tools provide basic support for these tasks. Email discussion lists, particularly if they are archived and searchable, as well as asynchronous forums such as BSCW (Bentley et al., 1997) and Lotus Notes provide means by which experiences and suggestions can be shared. Edited indices of resources (Aurora, 2001) or resource recommender systems represent attempts to go a step farther and distill experiences into recommendations. TappedIn (Schlager et al., 1997) supports various resource authoring tasks (such as compiling and commenting on sets of on-line resources) and synchronous interaction via text chat. This combination of features could at least minimally support the three teachers in our problem scenario, allowing them to publish, annotate, share, and discuss their activities.

4.3 Requirements for Community-oriented Knowledge Sharing

A system that addresses the basic functional requirements for communication and authoring would provide the minimal set of features to allow teachers to publish concrete materials, share activity plans, and discover, apply, and discuss prototypes-in-use. However, such sharing will not occur unless the social and technical infrastructures are mutually reinforcing. The sharing must be motivated and motivating; teachers must see an immediate benefit for themselves and their personal goals as well as for the longer term health of their local community. We suggest that the following three general requirements will be critical to the success of teacher knowledge management support:

1) Collaborative tools designed to support knowledge sharing must be engaging and accessible in order for the user community to gain critical mass. Collaborative environments that appear static or lifeless when not densely populated are unlikely to be useful, even for simple kinds of knowledge sharing such as publishing of concrete materials.

Mailing lists continue to be among the most widely successful tools for developing on-line communities, at least in part because they are based on the "push" of information. Users must take some action to join the list or contribute, but thereafter information is delivered to their inbox without effort on their part. Designers of tools that hope to support communities based at least in part on synchronous interaction and virtual presence face a more significant challenge, because users must take an action to enter the system. As a result the system must be very easy to access and inherently engaging, particularly during the early stages of deployment before a critical mass of users and content are present. Because periods of inactivity are inevitable, options for exploration and authoring must be sufficiently interesting that users do not abandon the system simply because it was not densely populated during a particular visit.

Studies of discussion forums confirm the usage problems that stem from “non-push” systems. These systems support the basic reading and contributing of text, and a lull in the conversation can be fatal — potential users who have nothing to contribute immediately will simply stop logging in (Whittaker, 1996). Systems that rely primarily on synchronous communication (e.g., text chat) face an even greater challenge, because they depend heavily upon the simultaneous presence of multiple users.

2) An on-line system for capturing and sharing knowledge should include rich, interactive tools for authoring, including tools that allow reuse of authored materials. Simple publishing tasks such as posting lists of URLs require only simple tools. But enabling teachers to publish, access, annotate, and refine material authored by others requires more advanced capabilities.

In cases where users have established methods for basic authoring tasks, it is essential that the system can co-exist with these—for example, by allowing arbitrary existing documents to be included or uploaded during construction of a new activity. This level of authoring support, however, provides little apparent advantage over basic web publishing or document transmission via email. Users are more likely to publish materials within the system if the available authoring tools provide functionality or opportunities that go beyond their existing software suites.

Domain-specific tools that support data entry or project management for a particular kind of activity may be an effective way to engage an initial set of users, but development of such tools is expensive. Designing more generic tools that support re-use and adaptation of artifacts is a more sustainable approach. Teachers may be more inclined to use tools in the system for tasks that they could do by other means if the results of their efforts can be more easily discovered and adapted by colleagues who may not have access to the author's usual word processor or graphics program. Our observations of local teachers suggest that there is hope for this approach; a number of them have already abandoned function-rich word processors in favor of more minimal HTML editors in order to simplify publication and sharing via the web.

3) The system should help users locate expertise and facilitate face-to-face interaction. The most advanced type of knowledge sharing in our framework relies on teachers' social networks (Schlager & Fusco, in press). Discovery of a peer's activity prototype is more likely within existing social network, as is the prototype's initial evaluation and decision to adapt it to current teaching needs. Through the process of reuse, the underlying social network is strengthened and expanded, as multiple teachers provide their own assessment and recommendations for further use. The focus of the sharing shifts away from people interacting with data, and toward people interacting with people, in the context of shared data.

An emphasis on socially-facilitated reuse is consistent with the collaboration described by Ehrlich and Cash (1994) in their study of analysts using a shared database. While the artifacts in the database (in this case, technical support concerns) provided an archive of shared information, shared *knowledge* was often derived from face-to-face interactions. When the database proved inadequate for solving a particular problem, analysts would rely on a "gopher-net"—looking over cubicle walls to see which of their colleagues were available to discuss the issue. In a study of online discussions forums, Whittaker (1996) cites "media competition"—phone calls, face-to-face meetings, etc.—as a likely culprit in the failure of small, project-specific online discussions.

A significant result of Ehrlich and Cash's study is that the technical support analysts could not effectively work from home, because isolation from colleagues limited the analysts' ability to make use of published resources. Of course such isolation is inherent in the teaching profession.

The teachers with whom we are working are very interested in having more contact with their colleagues; local school administrators are also eager to facilitate workshops and other face-to-face interactions. The most significant barriers to these interactions are awareness and scheduling difficulties: teachers are often simply unaware of their colleagues' activities, and if they are aware, may not be able to arrange meetings to initiate and sustain collaborations. Online tools might be able address these problems by allowing teachers to discover their colleagues' activities and to interact remotely when face-to-face meetings are not possible.

4.4 TeacherBridge: An Infrastructure for Knowledge-Sharing

To evaluate our analysis of bottom-up teacher knowledge management, and to further explore the requirements for systems supporting knowledge-sharing in a local community of practice, we are developing a toolkit called BRIDGE (Basic Resources for Integrated Distributed Group Environments). Our first deployment of a live system based on this toolkit is TeacherBridge (http://teacherbridge.cs.vt.edu/; see Figure 1).

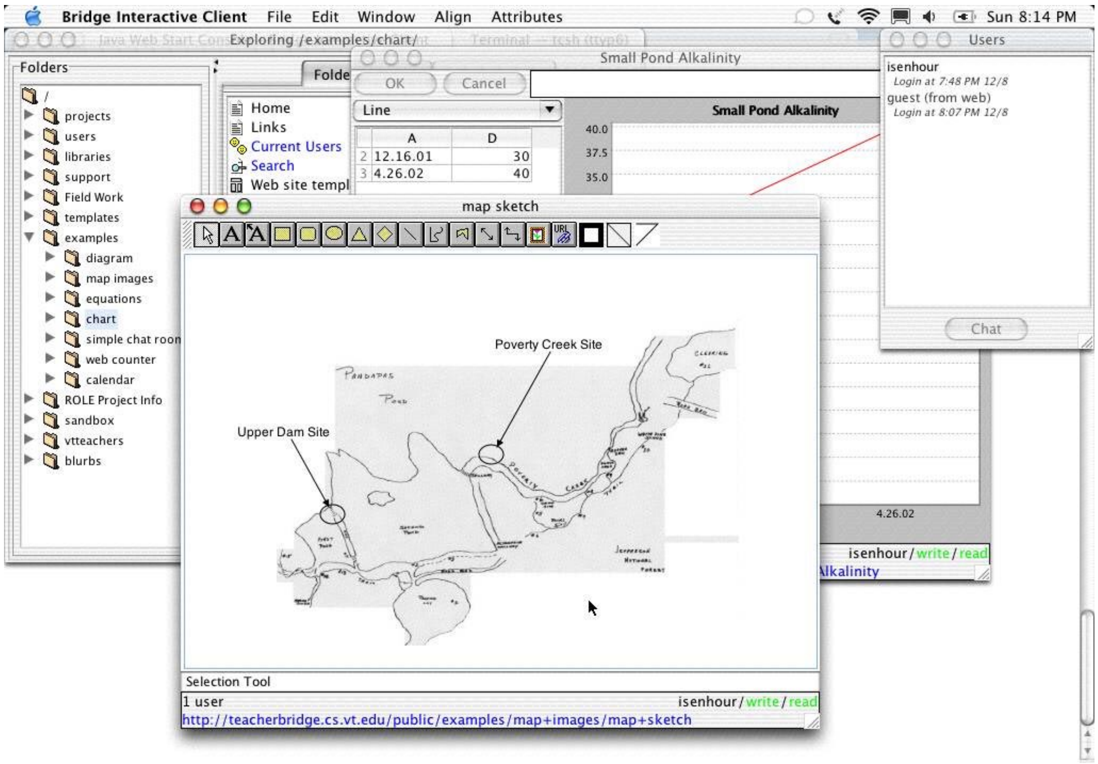

Figure 1. Some components of the Full Editor in TeacherBridge including chat, image tool, user list, and the explorer window where system objects can be accessed and edited by users provided that security permissions allow.

TeacherBridge was developed to support teachers in two adjacent school districts in Southwest Virginia—Montgomery County and Giles County Public Schools. The design of TeacherBridge reflects two major goals. First, we want the system to be comprised of tools that teachers use directly in their work. In other words, we want the online system to support local communities of practice by providing tools for teaching activities that grow and are modified over time. Second, in so doing we want the system to facilitate the management and dissemination of any local teaching knowledge relevant to other colleagues.

4.4.1. Authoring and Sharing in TeacherBridge

TeacherBridge supports the beginner, intermediate, and advanced user skills found in most populations of teaching professionals. For example, in addition to simple mechanisms for creating web-based materials, the system provides access to a range of advanced but unexploited features of computer networking (e.g., synchronous communication, image and map-based navigation; see Figure 1).

The design of the BRIDGE toolkit and the TeacherBridge system was based on earlier collaborative systems developed for use in educational applications—the "Virtual School" developed for collaborative science projects and mentoring (Gibson, et al., 1999). The Virtual School was based on a collaborative notebook, and included a suite of tools that supported conferencing, note-taking, experimentation, data analysis, and report writing (Isenhour et al., 2000; Isenhour, Rosson, & Carroll, 2001). Another system, MOOsburg, is a web-accessible collaborative environment developed as a place-based framework for community collaboration, including communication among students, teachers, and community members (Carroll et al., 2001). MOOsburg originated as a traditional text-based MOO, and like a traditional MOO it models a geographic region (in this case, the town of Blacksburg and surrounding areas), and allows users to interact with each other and with objects in the modeled geography.

The BRIDGE toolkit has also been influenced by CoWeb (Guzdial et al., 2001) and similar Wiki systems (Cunningham & Leuf, 2001). These systems support flexible end-user editing of web pages directly from a web browser, with "shorthand" tags that eliminate the need to learn HTML. These systems have been used for a variety of classroom activities and curriculum authoring tasks; they have also been extremely useful in documenting and discussing our design ideas as BRIDGE was developed.

On initial inspection, TeacherBridge looks like a conventional web site, with home pages for teachers, classes, and cross-classroom projects. Each piece of content on the site, however, is a view of a “live” collaborative object that can be edited at any time by a single user, or simultaneously by multiple users. Such editing is done with Java-based client software, launched via Java WebStart directly from the TeacherBridge site. Where appropriate, objects can also be edited directly within a web browser, with no additional software required.

Text objects are rendered as web pages and form a "glue" useful for interconnecting other content. While users are free to include HTML tags in the text, BRIDGE supports a Wiki-style shorthand to simplify basic formatting tasks, as well for linking and embedding other kinds of objects. Files containing externally generated content can be uploaded via drag-and-drop. A whiteboard tool supports basic drawing tasks, simple image manipulation, and specification of image- or map-based navigation. To support a more general notion of "image-based composition", the whiteboard also supports markup of image data generated by other tools in the system, such as a collaborative charting tool and equation builder. A discussion object supports asynchronous, threaded communication. A chat object supports unthreaded, synchronous communication. A calendar object allows creation of event calendars in a variety of formats.

Viewing or editing of all objects in the system can be protected by a password, and teachers can create accounts for their students if they wish. Version histories of all objects in the system are available, as is information about which users are currently accessing each object.

Beyond textual composition (the construction of web pages) and image-based composition (markup of graphical content), we are developing objects that support "interactive composition". Our goal is to give teachers tools that allow them to create interactive classroom activities. For example, we have experimented with tools that support creation of literature and special topic discussion space (see Figure 2).

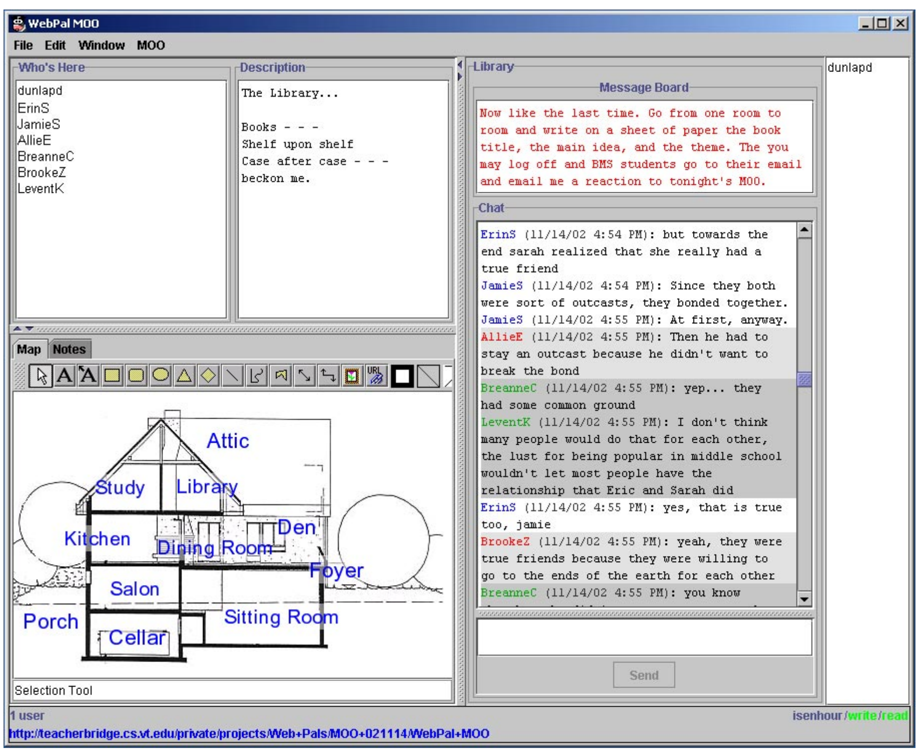

Figure 2: Collaborative discussion space including graphical navigation, shared text editor, chat, user list, editable room description, and central message board for teachers to direct student activity in dispersed rooms.

During this interactive activity, students log in, move between "rooms" devoted to specific literary works, chat with one another and with the teacher, and collaboratively author themes. In another example, students working on an environmental quality project do so within a "workspace" that allows them to share their documents with collaborators in a remote classroom, and to chat with their remote teammates (Figure 3).

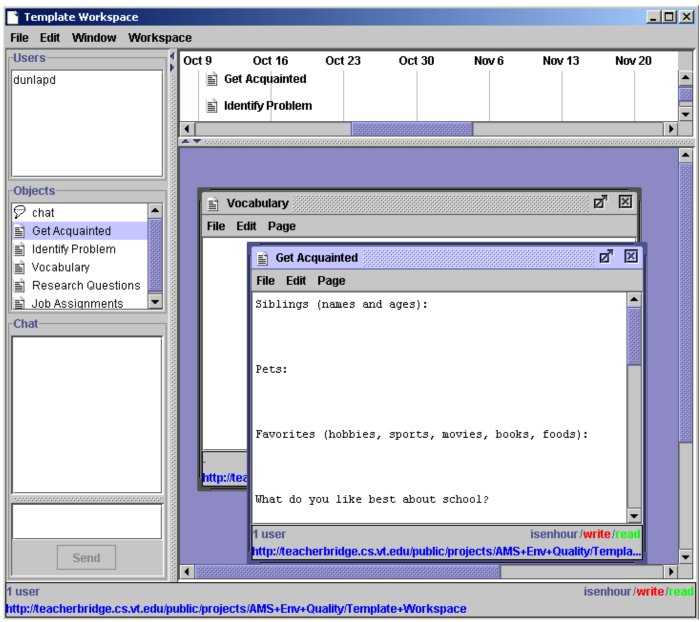

Figure 3: Collaborative Workspace includes user list, timeline of document revisions, shared documents and document list, and workspace chat.

Our intent has been to keep the basic appearance and behavior of a "normal" web site, both to reduce apprehension about getting involved in the project, and also to provide motivation for getting started. Most of the teachers working with us see value in making their materials and activities web-accessible, and we believe that providing an easy path from publishing a static web page, to simple activities like setting up a discussion forum, to more complex data-sharing or collaborative authoring activities, will keep users engaged.

We are exploring ways to provide a limited virtual surrogate for Ehlich and Cash's "gopher-net", giving TeacherBridge users an efficient way to find out what their colleagues and potential collaborators are doing, and then to reuse or contribute to colleagues' work. Users are free to explore the site, either from the web or using the Java client. The need for passwords that protect student work presents something of an impediment to this, though we are investigating solutions. Synchronous and asynchronous communication channels are available, and active design efforts are underway to generate new mechanisms for discovering expertise; discussing resources, plans, and activities; and evaluating the potential effectiveness of artifacts in the context of a particular classroom setting.

4.4.2 Multiple Metaphors for Knowledge-Sharing in TeacherBridge

Our goal for TeacherBridge is that diverse teachers in a region will discover and reuse one another's professional work. Teachers often work in isolation and with great autonomy, but even teachers at varying grade levels, or teaching different subject matter, may have overlapping activities, needs, goals, and expertise. Because teachers come to a knowledge-sharing system with their own instructional goals and experiences, it is important for the system to provide multiple views of the "same" knowledge and activities. An elementary science teacher and a high school biology teacher may be able to use the same set of stream-analysis tools, but they may need to see these resources from differing perspectives to evaluate its potential.

Teachers who experience directly the benefits of sharing basic knowledge and resources are more likely to learn and share insights among one another. Even the exchange of very concrete materials can be an important step, because it sets up a channel for sharing at more abstract levels. But the teachers must believe that they have simple and reliable access to useful and usable resources. Rosenholts (1991) found that teachers "in learning-enriched settings primarily cited colleagues in conjunction with their own problem-solving and creative capacities, actions requiring substantial efforts. But in learning-impoverished settings, teachers used primarily those material resources that were immediately accessible to them and that required only minimal effort" (p. 103). Our project seeks to develop learning-enriched communities that anticipate and value requests for assistance and knowledge. The following scenario illustrates a vision of teachers and students with diverse goals, but who are sharing professional resources in ways that enrich their own activities and the school organization in general.

Terry, a middle school life science teacher, wants to help her students understand environmental health issues related to streams in the region. She opens a web browser and goes to the TeacherBridge system and carries out a search for "stream water-quality" projects. A brief list is returned, and she recognizes "Johns Creek" from a favorite hike she takes with her family every year; she sees that the project author is Garin, a high school biology teacher from a neighboring county who she has met a few times at summer workshops.

Terry follows the link to Garin's project and finds a brief description of his aquatic life studies, as well as a link to his project "workspace". When she opens the workspace, she finds a map annotated with icons that appear to denote field-monitoring sites. As she moves her mouse over each icon, a short description of the site is displayed. When she clicks on an icon, she is taken to a page with data tables, analyses, and student-written summaries related to this site. As she scans the page, she can see that this is the combined work of Garin and several other science teachers who are sponsoring activities at Johns Creek. Returning to the map overview, she sees that similar icons lead to other pages, and is impressed with the amount of observation and data collected for this one site. However, she notices that there is no overall compilation or description of what has happened to date.

As Terry investigates further, she realizes that most of the data has been generated by students in high school science classes; the perspectives and methods are a bit too advanced for her students to use directly. However, she also discovers that one chemistry teacher, Jody, has formed a discussion group. She can see by exploring Jody's project timeline that these chemistry students meet online once a week to discuss their new data, relate it to other classroom studies, and raise issues uncovered through library or web-based research. The discussions each week seem to be organized by topics proposed by individual students, and a week-by-week review provides a good sense of how the interest of the group shifts as new data arrive. Terry begins to wonder whether her middle school students might be able to connect with this online group, to ask their own questions, and come to understand some of the issues in simpler terms. When Terry reviews Jody's TeacherBridge profile, she is encouraged to pursue this further, because she sees that Jody has a history of novel teaching activities, including mentoring by local experts and community residents.

Terry sends of an email suggesting the cross-age mentoring, and is delighted when Jody agrees that a mentoring exchange between her students and Terry's could be a valuable lesson to both. They decide to have both classes meet online several times in the next few weeks. Terry proposes that her students will have the assignment to compile the results and analyses of the various other classes into an online presentation for the local community. Jody agrees that her students will help by answering questions of methods and interpretation.

Terry sets up a new workspace to support her students' authoring project and their interactions with Jody's class. Over a period of several weeks, her middle school students construct web pages that incorporate graphs and explanations developed by the more advanced students. Terry shows them how to use the timeline to get a more process-oriented view of how the data were collected and the interpretations changed over time. Her students create their own discussions linked to the earlier discussions by the older students, but using simpler terms for the methods and analyses. A few of the high school students became very engaged by the process, recognizing that their work is now being used as part of a more public commentary on this field site. Thus, in addition to consulting with Terry's students, they construct several new TeacherBridge activities (e.g., a simple simulation that allows users to enter aquatic life parameters and graphs several stream quality outcomes) for inclusion in the presentation. When the web site is complete, Terry advertises it to her students' parents, as well as the community in general. Jody, Garin, and the other participating teachers see that their students are excited about sharing their lab results with other students (and though them, with the community at large); Jody observes that her students' learning and self-confidence is enriched by the requirement to explain their science activities to the younger students.

Table 3. A TeacherBridge design scenario of collaboration among diverse teachers and students.

The scenario shows how TeacherBridge is designed to provide differing views and access mechanisms for the same underlying resources, to better meet a range of teaching and learning needs. For example, the middle school teacher initially browses the online resources via an interactive map, a place-based index into the learning activities that emphasizes their local relevance and connection to the real world. At the same time, she is given a social view of the underlying work through colleagues' names and affiliations, and later on through her investigation of author profiles. In the online discussion, the embedded knowledge and experience is organized more thematically, with topics emerging as the discussion progresses, and the "level" of the discussion adjusting to accommodate the less sophisticated participants. Finally, the historical view of project activities (i.e., the timeline and the record of versions) is used directly to support the middle students' compilation; by taking this temporal perspective, Terry and her students can understand the *processes* of science investigation taking place at this local field site.

This design scenario also demonstrates how our work on the TeacherBridge system reflects many of the same insights present in contemporary work on knowledge management by businesses (Section 2.2). Terry and her colleagues are participating within a community of practice that is self-organizing but motivated by overlapping interests and teaching goals. The online project data and activities comprise a knowledge repository; however, it differs from those typically created in business settings in that it is more informal and emergent. Rather than codifying and formalizing the stored knowledge, TeacherBridge supports the use of multiple views to gain flexible access to different aspects of the knowledge. There are no explicit expertise directories; the expertise of different teachers is conveyed implicitly through their authoring and reuse activities. The interaction between Terry and Jody can be seen as a peer assist instance; indeed in this case, with the mentoring of middle school science students by high school counterparts occurring as a natural follow-on effect. Finally, the collection of related projects related to Johns Creek, along with annotations and discussions of their usefulness (e.g., the compilation produced by the middle school class) can be seen as an informal technique for collecting and sharing best practices, though the practices in TeacherBridge are highly situated by the local context of the teaching activity (i.e., science issues investigated at Johns Creek).

5. Issues for Peer-driven Teacher Professional Knowledge Management

Transforming current images of teaching knowledge and professional practice will require significant shifts in pre-service teacher training, in-service professional development, school district and state system administration, and public attitudes and policies. A more challenging, professionally-oriented model of teacher preparation assume deeper immersion in assessment techniques; greater exposure to multiple models of teaching practice; and a more reflective and diagnostic approach to those models and the subject to be taught, the characteristics of the students, and the personal strengths and weaknesses as a teacher. It will be difficult to create such a model in a competitive marketplace where many programs vie for students, and where cheaper and quicker programs are increasingly favored.

The challenges of designing and implementing top-down school reforms are formidable. But even if top-down initiatives are put in place, they only establish the preconditions for transforming the culture of teaching. Top-down reform strategies (e.g., pre-service teacher training programs) must be deliberately complemented by and coordinated with peer-driven innovations in teachers' professional practice (Schlager & Fusco, in press). Although teachers can and do benefit in many ways from working together (section 3), the culture of teaching is weak with respect to professional knowledge, assessment, and collaboration. Effective systemic reform requires bottom-up innovations in teacher professional development.

We have described an approach to peer-driven teacher professional knowledge management founded on communities of practice. Our specific focus is on helping teachers to establish collaborative interactions with peers they might meet with face-to-face, but not on a daily or even regular basis. Our strategy leverages the knowledge, experiences, and meanings teachers already have about the physical environments and communities in which they live. As conveyed by our envisionment scenario (Table 3), our goal is to enhance the relationship of teachers and schools to their local communities through the sharing of local resources, and the participation of community members in school activities.

In this strategy, network information technology is recruited as a collaboration infrastructure for teachers. A web-based infrastructure can provide a place-based environment for discussing, developing, sharing, and assessing plans and other resources; it can be accessible to teachers at home or at school, synchronously or asynchronously (section 4). This is the type of support teachers need to respond to and elaborate school reform initiatives. Teachers must be empowered if they are to be accountable. A key to our strategy is long-term, participatory design; changes in the culture of teaching depend absolutely on innovations in practice that are envisioned and implemented by teachers. In our approach, teachers are responsible for the creation and applications of teaching resources, practices, and knowledge. They can only carry out such responsibilities if they are truly in control. Thus, a central challenge in realizing systemic reform is helping teachers to define and adopt knowledge management practices, including the use of requisite information technology tools.

Our project is investigating one strategy among others. TappedIn is a related investigation that emphasizes the potential synergies of national-scale teacher professional communities, instead of local school-community interactions (Schlager & Schank, 1997). And obviously, there are many other possibilities. Further investigations would be timely and worthwhile.

Reflecting on the work we have done thus far, we see seven focal areas for research and development in teacher knowledge management. The first of these is characterizing *existing practices* for knowledge-sharing in schools. Any effort aimed at supporting or improving knowledge management must begin with understanding current practices and the goals of the organization with respect to knowledge management. Our proposals are based on our own classroom research experiences, but it would be desirable to have a more broad-based characterization of knowledge sharing in schools. This would provide a background for understanding descriptions of knowledge sharing within a given school or school system. The three levels of our framework provide a starting point for classifying current knowledge management artifacts and practices.

A second focus for further research and development is *knowledge capture*. This involves the development and evaluation of tools, procedures, and policies that capture knowledge in more natural and convenient ways, and that are better integrated into day-to-day work. Our framework provides some initial guidance for thinking about this challenge. At the level of concrete materials, tagging and setting aside materials because they might be useful to someone else must be nearly effortless. At the level of classroom activity plans, resources must be analyzed, described, and contextualized in order to be sharable. This requires special effort, but one challenge might be to develop techniques that add value for the originator of the knowledge, as well as for the person reusing the plans. With respect to the sharing of situated activity prototypes, knowledge capture may require even more effort, but such effort may naturally build from broader collegial interactions, perhaps being experienced as socializing about work, as much as doing the work itself.

Effective knowledge management requires that relevant knowledge should be easy to get to, at just the right time. Thus a third focus for further research is better *retrieval* of sharable knowledge. Ideally, materials created and shared by others should be retrieved with the same methods and tools used for developing and handling personal resources. Digital work environments with large and persistent shared workspaces suggest possibilities for achieving this, but this is far from a solved technology problem. Moreover, full access to relevant knowledge is not always feasible (e.g., when the amount of knowledge is large) or safe (e.g., when the knowledge is restricted). At the level of classroom activities, there are difficult issues of integrating retrieved knowledge with intensional work contexts. At the level of prototypes in use, there may be issues concerning the values and point of view incorporated into a colleague's usage example, as well as load-balancing across a community of professionals.

Knowledge is a relationship between a person and information resources. Thus, a fourth focus is helping people *make sense* of information so that it can become shared knowledge. People need to be able to see immediately where information came from — including personal information about the people who created the knowledge, and episodic information about its prior use. They need to see how complete and reliable the information is — including case study reports and testimonials, outcomes assessment of prior usage, and pointers to the people who created it and to those who have used it. Ideally, they need to see just how it bears on their own task at hand. This is subtle and entails tradeoffs; merely attaching metadata to information in reuse libraries, or giving teachers easy access to chats and discussion forums, may in fact disincline them to participate at all.

Knowledge management is often a matter of *rediscovering information* one has come across before. This fifth focus is supported by mechanisms like bookmarks in Web browsers, but only to a very limited extent. We need techniques that allow people to more easily reuse their personal knowledge management experiences. When knowledge sharing is integrated with the social networks making up a community of practice, people will be better able to capitalize on personal experiences gained by other colleagues, through facilities such as recommender systems and collaborative filtering of information (e.g. Glance et al., 1999).

A sixth challenge for research and development is supporting knowledge management *through time*. Change is fundamental to organizations. A community tends to evolve through common interests and concerns. At the organizational level, Turner (1999) describes ways in which organizational structures can impede or support the development of communities within an organization, and some techniques for helping develop a sense of community among individuals within the organization.

The seventh challenge is *evaluation* of knowledge management tools and procedures. Although many tools and techniques for knowledge management exist or are under development, little is known about how they are used, and more specifically what problems arise in their use. For example, distributed groups now often share documents or other data via email attachments or shared file systems. It is important to evaluate the effectiveness of such techniques—what information is shared in this way, or more importantly what cannot be shared, or is lost. Carrying out an adequate evaluation of knowledge management tools is complex. The evaluation must focus on a work group, or even an entire organization. The relevant evaluation data will need to be collected and integrated from many sources. Neale and Carroll (1999) describe a multi-faceted method of groupware evaluation, which involves the gathering and interweaving of distributed video records, field notes, and session logs, along with a variety of asynchronous communication such as email or document exchanges. It may be possible to extend comprehensive evaluation methods such as this for use in the knowledge management domain.

Adapting the concepts and techniques of knowledge management to support peer-driven teacher professional development is an important opportunity. It will leverage the considerable investments that have been made in top-down systemic reform by supporting the emergence of a culture of teaching based on knowledge, assessment, and collaboration.

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