Knowledge Management Support for Teachers

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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 in public schools. We suggest that some reform initiatives can support the development of new attitudes toward teacher professional knowledge. We describe a framework for knowledge management support for teachers in which engaging in more concrete knowledge sharing can bootstrap the attainment of more abstract levels of knowledge sharing. We present an envisionment of a knowledge management support system emphasizing long-term participatory design, the integration of synchronous and asynchronous interactions, place as a metaphor for organizing knowledge resources and activities, and multiple views of knowledge.

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, and some is tacitly held 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, that it is accessible when needed.

This 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 luxuries that occur outside normal routine. People value and protect what they know and what they can do as a 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 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. 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. For the year 2002, International Data Corporation estimated that knowledge management software and services will be a six billion dollar industry.

In this paper we consider how the concepts, tools, and techniques of organizational knowledge management can be applied in public schools. Teachers and 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 consider the nature of professional knowledge in education. The greatest obstacle to effectively managing teacher professional knowledge is the attitude — even among teachers — that teaching is basically common sense. Contemporary school reform initiatives are challenging such attitudes. But school reform is multifaceted, incorporating aspects of teacher training and professionalism, school management, curriculum content and pedagogy, and the use of technology. Typical understandings of reform focus on outcomes and accountability for teachers and students, rather than on organizational values and dynamics that cause the outcomes. We suggest that some reform initiatives can support the development of new attitudes toward teacher professional knowledge.

We then 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. We describe a framework for knowledge management support for teachers in which engaging in more concrete knowledge sharing can bootstrap the attainment of more abstract levels of knowledge sharing.

Finally, we present an envisionment of a knowledge management support system. Our approach involves teachers and community members in long-term *participatory design* interactions to help ensure that the information technology we create addresses the concerns and practices of its users. Our system supports the *integration of synchronous and asynchronous interactions* to address the scheduling constraints of schools as a workplace. We employ *place* as a metaphor for organizing knowledge resources and activities to make the system more concrete and familiar, and to emphasize that local teachers and community members are in control. Our system provides *multiple views* of knowledge in order to 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 contemporary challenge of developing 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 more critical for schools to successfully address the challenges of knowledge management; society's future is at stake. Second, the schools have fewer resources to address the challenges of knowledge management; school systems cannot afford expensive consultants or business systems, and this is unlikely to change dramatically any time soon.

2. Teachers as Knowledge Workers

An organization builds knowledge through the activities and experiences of its employees. Some of this knowledge may become codified in the form of organizational mission statements, rules and procedures. But much of the knowledge exists in a more informal form, often represented in a tacit form as employee "know-how." Researchers have used the term *knowledge worker* to emphasize that individual employees typically bring a wealth of specific experiences and personal heuristics in selecting, planning, and carrying out their assigned tasks (Kidd, 1994). Teachers are prime examples of knowledge workers, in that they have considerable personal discretion and responsibility in analyzing, developing, and implementing their curricular goals.

A requirement for any knowledge management system is that the knowledge workers who are developing and using an organization's knowledge—as well as the organization itself—must recognize what constitutes knowledge and that the knowledge has value. Many aspects of the teaching context work against this, although ongoing reform efforts are beginning to change the knowledge work perceptions of teachers and their organizations.

2.1 Perceptions of Professional Knowledge in Teaching

One irony in analyzing teachers' professional knowledge is that we all feel we know a lot about it already. Virtually everyone has been the recipient of public education; we all have strong beliefs about which of our teachers were effective or not, and what the ineffective teachers might have done to improve their methods. Indeed we continually apply our beliefs about education to our own teaching efforts directed at family members, friends, or colleagues at work. The problem is that this devalues the concepts and processes of education, moving them into the background fabric of our lives.

An unfortunate consequence of this devaluation is the perception by both teachers and the public that effective teaching is not difficult. Parents may not like it when their childrens' teachers lack academic background in science or other topics, but they generally accept it. Popular programs like "Teach for America" that place college graduates with no pedagogical training into the classroom offer further evidence—anyone who wants to should be able to teach. Teachers themselves often refer to what they do as an "art" or a "craft," rather than a "science," and affirm the value of "the practical" over theoretical or scientifically gathered evidence. Teachers also routinely downplay formal teacher preparation itself, and assert instead the value of learning "on the job."

Such attitudes and perceptions are also evident in the reasons novice teachers give for being attracted to the field and in their images of what "professional" practice involves. Reasons commonly given by aspiring teachers often include "being with children" (for those focused on elementary level teaching) or "communicating my subject with excitement" (for those at the secondary level) (see Feiman-Nemser & Floden, 1986; Zeichner & Gore, 1990). Typically absent are images of teaching as a knowledge-driven domain of expertise, where practice can emerge from an empirical approach toward more effective forms of activity, where assessment becomes an essential part of daily work, where inter-professional consultation and sharing of expertise are taken for granted.

Studies of teachers' professional knowledge have done little to counteract these dismissive views. Knowledge of teaching differs considerably from knowledge in other professions. It tends to be rather imprecise and tentative, bound tightly to personal experience, and not always connected to well-defined measures of learning outcome (Lortie 1975; Spring 1991). Teachers work in relative isolation from one another, developing and refining techniques that work well for them in their personal classroom culture (Tyack & Cuban 1995; Rosenholtz 1991; Goodlad 1984). Efforts to share methods or techniques are often frustrated by difficulties to reproduce learning results with seemingly similar students and teachers.

The absence of a compelling and clear language for describing teaching practice also limits how teachers can capture and accumulate their professional knowledge. The traditional vehicle for

describing educational practice is the lesson plan, but such plans are typically used prospectively, as a plan for how the teacher hopes instruction will go. Rarely are lesson plans used to recap successes and failures, to analyze why something did or did not work, or to collect and build up the contributions of multiple practitioners. Teacher preparation rarely provides bases for sharing experience in a comparative, analytic, and cumulative way that would enable insights to emerge. Rather, aspiring teachers experience an "apprenticeship of observation" in which a variety of traditional images of practice are enacted, leading them to conclude that teaching must always be idiosyncratic and personal (Lortie, 1975; Garrison 1995; Pendlebury 1995).

The generally dismissive view of teaching knowledge, the highly personal nature of individual teachers' concepts and techniques, and the lack of shared vocabulary and representations militate against the articulation and accumulation of professional knowledge by teachers. Nonetheless, two strands of educational reform are beginning to effect changes in how teachers and others view and manage their knowledge. One of these is a top-down movement emphasizing the development of shared goals and measures. The second is a more bottom-up effort aimed at enriching local interactions and exchange.

2.2 Educational Reform: Top-down

In the past decade, educational standards have emerged as a highly visible and politically-charged direction for educational reform. This reform movement emphasizes the *goals* of public education—what students should know at specified points in their school careers. The movement is expressed in many forms, at the national (National Research Council, 1996) and state levels (Virginia Board of Education,1995). One direct side effect has been the development of objective tests that determine whether students have met the standards. For example, some states now require that a student pass a standards-based achievement test in order to continue on to the next grade level, a significant departure from decisions traditionally made as a subjective judgement by teachers and their administration.

Another side effect has been increased attention to the accountability of teachers and administrators in ensuring that students meet grade-level standards. An immediate and simple

accountability measure is the proportion of students who pass the standardized tests, and school systems are now expected to send home their own "report cards" documenting how their performance on the most recent set of tests. At the same time, educators and the public realize that scores on standard tests are just one measure of learning achievement, and there is much discussion about alternative measures of teaching success, as well as procedures for providing feedback to teachers so that they can move toward more successful practices (Delandshere 2000; Leithwood 2000).

A second top-down (but often contradictory) reform movement addresses the *content* of teaching activities. Constructivist views of education have led to widespread beliefs that classroom work and testing should focus more on real-world problem solving, collaborative work, or other "authentic" forms of experience and assessment. New classroom approaches and pedagogy are being developed to explore and support such educational content. Information technology has been an important enabler of these new approaches, in that it can connect students to a variety of real-world data, as well as provide a range of interactive and engaging instructional experiences (Roschelle 1995; Brunner 1994). A key challenge for educational research is to resolve the contradiction between open-ended and problem-oriented educational activities and the objective testing typically mandated to assess learning standards.

The development of shared goals and standards and of richer approaches to instruction has produced many new challenges and requirements for the teaching profession. However much of the effect thus far has been to heighten awareness and concern; thus far there are few accepted answers about what the standards should be, how they should be tested, and how educational content should be delivered.

2.3 Educational Reform: Bottom-up

Another thread of educational reform is occurring through the activities of local school systems. To some extent this can be seen as a reaction to the reform movements operating in a top-down fashion: as new high-level goals are articulated, the expectations of educators and their communities begin to change, well before normative refinements or transformations of current practice are able to take place. Schools cannot wait until the educational establishment has had

time to rethink teacher preparation and to develop a new population of teachers into their organizations. They must begin to explore new practices that make sense in the context of their communities.

One consequence is that teachers are being given greater decision-making power in management of their schools (Mohr 2001). Traditional concerns for class size and resources have been expanded to include issues of staffing, merit evaluations, and oversight of colleagues' professional responsibilities. These opportunities for greater self-management are complemented by increased emphasis on teacher preparation, including contributions by experienced teachers through programs such as Professional Development Schools, clinical appointments with SCDE (school, college, or department of education) faculties, participation on admissions committees for SCDE teacher education programs, and engagement in formal mentoring programs for new teachers. Teachers in training (both in-service and pre-service) are encountering the view that sophisticated instruction is more dependent on their discipline-specific understanding of common student problems and misunderstandings ("pedagogical content knowledge") than on simple mastery of the teaching discipline.

Another shift is reflected in the increased interaction between schools and the communities they serve. Many schools now see themselves a resource for life-long learning by community members, where individuals of varying age and background are offered educational objectives and activities. At the same time, schools are coming to rely on the community as a resource for curriculum enrichment (e.g., via mentoring) and for informal learning outside of the boundaries of traditional classrooms (Carroll & Neale, 1998; Gibson et al., 1999). The shift toward greater school-community interaction is very consonant with the top-down emphasis on authentic learning and problem-based educational activities.

These initiatives arising from teachers and their communities can be seen as emergent responses to aspects of top-down reform. Individual teachers and school systems are developing their own models and languages of novel teaching and assessment practices. Numerous districts and schools, for example, participate in projects variously described as "Lesson Study" or "Critical Friends" (Stigler & Hiebert, 1999). These approaches to instructional improvement rely

on teachers becoming able to constructively critique and learn from each others' teaching experience, and many teachers engaging in these activities claim to find them very helpful (empirical evidence to identify their actual impact is being collected at present). Essential in these efforts is time for discussion, reflection, and joint activity around improvement, resources that contemporary school districts often find difficult to provide on a consistent basis.

There is a need to collect, collate, and document these distributed initiatives as they take place. A promising place to begin is with groups of educators already working within a shared community context. If such individuals are encouraged to reflect on and articulate of their own evolving practice, they can begin to build a shared professional vocabulary, a vocabulary that can then be compared and integrated with knowledge developed in other contexts.

3. Strategies for Knowledge Management

Organizations are collections of individuals each of whom is trying to act sensibly and productively, trying to understand what they are 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. Achieving this involves balance and coordination between top-down articulation of policies and tools and bottom-up cultivation of practices and workplace culture.

3.1 Knowledge in Organizations

An organization's capacity to innovate through managing 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 and 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 the creative innovations and work-arounds of the people and work activity that they supervise (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 meanings must understand and communicate more about their work. They must see their work from multiple perspectives, and must instigate and invite critical reflection. It is frequently the case that 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 often do not receive enhanced status or compensation for doing so.

Some of the challenges for realizing the vision of organizational knowledge management are top-down — employee reward systems that encourage risk-taking and collaboration,

technologies for representing and sharing informal information, etc. However, many more of the challenges of organizational knowledge management are bottom-up: They require a new workplace culture that Lave and Wenger (1991; Wenger, 1998) have termed "communities of practice". A community of practice is a group that 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.

3.2 Knowledge Management in Teaching

School reform can be seen as systemic innovation in knowledge management (Hargreaves 1999). For schools to be more effective organizations, teachers need to understand and to help define administrative and curricular goals and standards. They need encouragement and support 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 often conceived of and managed as a top-down transformation, that is, in terms of the primary consequences of administrative interventions. It envisions how better access, handling, and utilization of knowledge could change teaching and learning, but it does not describe the adoption process for new knowledge practices, or the consequences and possible side-effects of such processes for teachers and students. Top-down school reform typically articulates objectives in terms of the individual performance of teachers and students. And the chief incentive for adopting innovations is often threat, for example, the implicit and explicit threats of state-mandated standards of learning.

This causes conflicts in the different ways that teachers and administrators have come to think about the use of information in schools. Teachers' natural interest using information about their students and the effects of their own practice often clashes with enforced requirements to use that information to pass summative judgment on an individual school, principal, or teacher. Thus, clearly defining what information is to be available and shared, by whom, and to what ends, may be critical parts of the process of encouraging broader knowledge management practices in schools. Clarity is the first part of this equation; the second is generating trust on

teachers' parts -- trust that information about their successes and failures will not be used against them, that administrative decisions will be carefully segregated from instructional ones, and that some level of privacy and protection will be afforded to those engaged in the sharing and self-study activities that are involved.

School reform, seen as knowledge management, certainly requires top-down support in terms of policies, technology infrastructure, and performance expectations. But top-down approaches are not enough (Tyack & Cuban, 1995). Sustainable reform innovations depend on fostering a culture of peer-driven in-service mutual learning, that is, it depends on the establishment of communities of practice for teachers. Teacher communities of practice work together as teachers, and in the course of cooperating professionally, they come to 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. As in other cases of knowledge management, the people in the organization are best-positioned to create effective and sustainable innovations.

Although debate about school reform often ignores bottom-up, or peer-driven, innovations, it is not difficult to see both the need and the potential efficacy of such approaches. In our "Learning in a Networked Community" (LiNC) project (Dunlap, Neale & Carroll, 2000; Carroll, Chin, Rosson & Neale, 2000; Isenhour, Carroll, Neale, Rosson & Dunlap, 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, for example, presenting detailed design proposals to the larger project group or coaching other teachers in classroom applications of communications technologies (Carroll et al., 2000).

There are many collateral benefits of bottom-up knowledge management to school organizations. The resources created by teacher communities of practice can be disseminated beyond the original community of practice. Libraries of classroom activities and materials can become part of the discourse of best-practices for other teacher communities, and they can serve as models for pre-service teachers. Codifying and making more public peer-based resource development and mutual learning can also help teachers to coordinate with other stakeholders in public education. On-going case studies of classroom activity vividly describe professional work and needs for supervisors, enabling better supervision, and they make the school more visible to the community beyond the school, enabling greater reciprocal understanding and support between the school and its community.

3.3 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, Rosson, Isenhour, Ganoe, Dunlap, Fogarty, Schafer & Van Metre, 2001), including the LiNC project mentioned earlier. We believe that the pervasive "global village" vision of information technology should be complemented and enriched with distinctive local and regional focus. After all there would be little point to a global village if every part of it were 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 starting point for leveraging 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, since it emphasizes the uniqueness and value of one's knowledge to a community of peers. Benefiting from local knowledge resources might also be especially rewarding, since it naturally entails personal interactions with the colleagues who created the resources. Such relationships are critical to the success of knowledge management in schools: All of 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 relatively concrete exchange of specific resources through active and extended contributions to communities of practice. These levels are loosely based on our experiences in the LiNC project with the development of teachers' knowledge sharing practices, but they also comprise an hypothesis about scaffolding "transitional systems" in the sense of Papert (1980; after Piaget & Inhelder, 1969). Our three levels imply a progression in degree of knowledge sharing. They characterize a possible adoption process, and provide an initial framework for a language of teacher professional practice.

At the first level, teachers can 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 end up merely producing 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 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 designs of classroom activities in the form of lesson plans, objectives, classroom strategies, and grading policies. In some sense this was a natural outcome of the LiNC project because of the 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 schemes for grading class projects as part of developing commensurate grading policies across collaborating 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 shared resources, plans, objectives, and similar elements of an activity design will be inherently more specific to the context of the authoring teacher's classroom. Development and articulation of plans and objectives are also likely to be more difficult tasks than contribution to a knowledge base of available resources. It is, however, also likely that a successful activity or practice captured in the form of a plan will be more easily

adaptable and reusable in other classroom contexts. Articulation and discussion of the plan can help capture tacit knowledge about the activity that would be lost in either a simple list of resources for the activity or a static plan posted to a database that lacked discussion and annotation capabilities. With appropriate supporting technology, relevant elements of the plan can simply be copied, modified, and added to the knowledge base.

The third level is sharing of prototypes. These are artifacts produced by students or summaries of student work for a given activity, and may be thought of as implementations of designs (plans and objectives) that could be shared in the second level. In the LiNC project, the teachers could access in-progress and completed student work both from their own classes and from the classes of teachers with whom they were collaborating. Numerous other examples of publication of student projects can be found on the web, usually representing isolated efforts by individual teachers. For example, another teacher in our local school system has created a detailed web site with data and photos collected as part of 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 sharing at the level of prototypes 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, and annotating posted artifacts. The effort required to make prototypes available for sharing may be largely mechanical, since students would do most of the work of actually creating the data. Ideally, technology aimed at supporting this type of sharing would simplify summarization and publishing tasks that teachers already include as part of classroom activities. Prototypes shared in this way are iterative and ongoing, allowing teachers to collaboratively critique, scaffold, and adapt new materials as teaching needs and opportunities evolve. This increases the likelihood that both tacit and explicit knowledge surrounding these exercises will be shared.

As instances of situated classroom know-how, prototypes are unique to a particular activity performed by a specific group of students, but templates of underlying artifacts are reusable, data can be incorporated into future activities, and teachers can make independent assessments of the design of the activity. 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.

Teachers developing and sharing locally enacted materials are much more likely to contact, question, and engage relevant teachers, and thus articulate, produce, and reuse the professional knowledge. This type of knowledge building is strengthened by shared region, shared particular local problems, common interests, and common concerns faced by teachers in similar situations and environments.

New activities should derive from an analysis of current practice, but some simple scenarios can illustrate the deeper types of knowledge sharing we envision. The framework is summarized in Table 1.

Type of Knowledge Sharing	**Examples**
Tangible resources	• Materials for a master teacher's chemistry lab made available to other science teachers updating or expanding their chemistry classes. • Inventory of lab equipment and specimens available in nearby schools, universities and cooperating corporate facilities • Lists of materials to supplement a textbooks that is weakly aligned with SOLs
Plans and objectives	• Notes about how a lesson or activity supports the SOLs on water chemistry and life processes or on kinetic theory and forces among particles • Tips for connecting data input interfaces to computers such as a pH sensors, digital microscopes, or motion sensors • Sharing of SOL test data and training plans with teaching staff about how to use the data and staff development activities to improve instruction
Prototypes	• Lab reports for an extended series of experiments accessible online, along with discussion of successful and problematic elements of the activity. • Summaries of annual stream monitoring activity made available, along with historical

	data, photos, and notes about related classroom projects. • Data, student-generated summaries, and overview of techniques for a cross-grade weather monitoring activity at one school made available to teachers and administrators at nearby schools, along with tools and templates for constructing similar, linked activities.

Table 1. Levels and examples of knowledge sharing practices.

The three levels of knowledge sharing among teachers, the three types of sharable objects, illustrate the three key properties of discretionary knowledge management. Teachers affiliate when doing so addresses shared concerns, but they do not have a culture of collaboration (Tyack & Cuban, 1995). Sharing concrete resources, lesson plans and activities, and situated classroom know-how is 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. There are no organizational protocols for goal management in public schools. Indeed, the dialogs of knowledge sharing among teachers are as diverse as the teachers, and largely invisible to school administrators.

Finally, the exchange of concrete resources, lesson plans and activities, and situated classroom know-how is carried out informally. There is no clearinghouse of technical common ground. Teachers have substantial, and often unique knowledge about where they might find a certain chemical or specimen, which colleague tried a given activity with surface tension or the psychophysics of taste, and who might know how to pose rewarding questions about the motion of slinkies or fix a model train.

The potential impact of teacher development should be considered in terms of more than just an accumulation of teaching resources. Staff development should leverage and strengthen teacher communities of practice. Knowledge management can contribute to strategies for adjusting roles of teachers in developing organizational knowledge on various levels, but it must be introduced, supported, and evaluated with respect to deeper levels of impact. Such strategies

can leverage the variety of 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 can better capture and map the complex developments of organizational learning in schools. Such characterization of teachers' knowledge management can benefit teachers' work by providing ways to understand what constitutes and facilitates better access to concrete resources, to plans and practices, to organizational objectives, and to contextualized knowledge and community interactions involving local teaching practices.

4. Toward a Place-Based Infrastructure for Sharing Knowledge

Locality can function as a powerful framework and metaphor for organizing teaching knowledge and instructional resources. Schools belong to local communities. They depend upon community support. Making the local community the space where professional knowledge is represented, communicated, and collected allows teachers and community members to exercise greater control over their resources and information. It advances school-community cooperation and coordination, and helps to ensure that local shared professional knowledge reflects community norms, practices, needs, and goals (Rosenholtz 1991). Research encourages the development of shared professional identity through the creation of proximal learning communities (Brown & Campione, 1994; Bruckman, 1998; Lave & Wenger, 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 passively kowtow to top-down accountability pressures. District administrators often struggle to balance local community needs, statewide, and national goals, especially those related to scientific literacy, standardized test, and other accountability measures (Marzano, Kendall, et al. 1999; Spalding 1995; DeBoer 2000). School districts can benefit from the ability to audit, manage, and disseminate the professional knowledge created within its organization (Hargreaves 1999); however, knowledge management in schools should

proceed with the understanding that key dimensions of practical teaching knowledge are tacit, local, and dynamic.

We are adapting a place-based collaborative system, known as MOOsburg, to facilitate the management and dissemination of local teaching knowledge for two adjacent school districts in Southwest Virginia, Montgomery County and Giles County Public Schools. Our goal is to utilize some of the more advanced but unexploited abilities of computer networking that are currently unavailable to teachers. We want to emphasize current practices and activities that engage teachers in deeper levels of exchange and discourse than are currently represented by typical web-based efforts. Our three-year project funded by NSF involves local teachers and administrators in a participatory design approach to developing and adapting MOOsburg for teacher knowledge management.

4.1 Modeling Local Knowledge Management Support in Schools

Science and math teachers face particularly difficult working conditions today. Their subject matter is highly valued, and therefore, highly visible to the public. It often involves complex and constantly changing content knowledge. Science teaching demands a considerable amount of hands-on activity, fieldwork, and laboratory preparation, and science and math teachers are under special pressure to incorporate the latest technologies in their instruction. Recruiting and retaining science and math teachers in public education is particularly challenging due to relatively short supply and high demand for their skills in more lucrative professions. Thus, in addition to the normal demands of public school teaching, science and math teachers often face overwhelming problems as managers of teaching and content knowledge.

Many teaching issues are pervasive throughout school systems but are specific to local regions. Local values, backgrounds, and resources determine expectations of students. This means that a curriculum is, in many ways, of local concern, and that raises an interesting dilemma for educators: How do schools provide the most generic math and science "literacy for all" while also addressing the knowledge, resources, and needs of local constituencies. For example, throughout various grade levels science curricula includes scientific process and inquiry skills, but Virginia encompasses a number of very diverse regions. Teachers in different systems encounter

particular environments, experiences, backgrounds, expectations, and values concerning science. In the Eastern shores of Virginia, cities like Norfolk face critical inner city problems and enjoy very unique ocean ecology. In the mountains of Southwest Virginia, the situation is obviously very different. Here the problems are often representative of rural regions, the environment is also rich and unique, and the culture is an unusual mixture of traditional Appalachian and modern university influences.

In any case, the local region serves as a powerful source for literature, history, culture, and science curriculum for local schools. Locality gives meaning in the enactment of national and statewide standards, and it enriches and develops the resident professional knowledge of teachers. For example, teaching about local history, natural science, and culture helps create a sense of belonging and identity with a local area, and it provides numerous field-based learning opportunities in rural communities (Tate 1996; Eifler 1998).

Science and math teachers throughout the local region are involved in projects that overlap in many ways, but, unfortunately, they often have little opportunity to encounter and leverage instructional resources used by one another. Middle school Life Science teachers, high school Chemistry and Biology teachers and even Math teachers are all interested in instruction involving the collection and analysis of field data. For example, 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, this monitoring needs to be done over a wide area and in a variety of settings in order to produce meaningful conclusions about the environment. As such, local science and math teachers can share a great deal of interests and common inquiry when their instruction focuses on the local area. Imagine the following scenario drawn from experiences of local teachers:

> Garin, a Biology teacher in Giles High School, has been taking his students to a local stream to monitor the invertebrate populations and local aquatic species found. They have gathered stream biology data according to scientific protocols for the entire school-year. They have compiled the population statistics into tables and charts

and have related this data to what is known about how certain animals differentially tolerate pollutants. The students have taken photos of the area. They have also compiled photos of the aquatic life and descriptions and taxonomy describing them.

Jody, a Chemistry teacher at Blacksburg High School in the 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 nearby locations of fields, neighborhoods, landfills, dumps, and the chemicals likely to have been deposited at these locations. They have also collected photos and descriptions of chemical samples and illustrated chemical diagrams of these substances and their reactions in ground water.

In yet another nearby section of the stream, Terry, a Life Science teacher at Christiansburg Middle School, 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 distant places where wastes are released into the environment. She knows little about the pollutants, chemistry and invertebrates, and she knows nothing about the studies being managed by her colleagues. She does, however, have a strong desire to help her students understand the stream and enliven the curriculum she teaches.

Table 2. Problem Scenario

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

and other duties. Network technologies provide functions that can 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 three teachers in the scenario to leverage each other's efforts are not trivial. Ideally, such tools would need to support publishing of project materials, provide searching and awareness mechanisms to allow the teachers to discover each other's activities, include communication tools to support 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 concrete materials, the most primitive form of knowledge sharing in our proposed framework. While new means of adding on-line content are continually being invented, the web still strongly favors information consumers over producers.

The three teachers in the scenario might, for example, post materials from their classes' projects on the Web. Discovery of each other's work would, however, likely rely on serendipity. They might simply stumble across a colleague's materials while browsing or enter a matching query string into a search engine. Under more ideal circumstances, the availability of these materials might be announced on a commonly accessed web index or broadcast on a mailing list. Assuming the awareness obstacles are overcome and the teachers do learn of each other's efforts, the web does little to support active collaboration. Given the probably differences in the servers on which the web pages were hosted and the software with which they were created, it is likely that any one of the teachers in the scenario would be able to do more than simply link to content created by the other two.

In practice, a number of the teachers with whom we have worked do publish their materials, electronically or otherwise. Motivations for these efforts include a desire to experiment

with 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, the result of requests or mandates by administrators.

Facilitating more advanced knowledge sharing, such as sharing of plans and goals requires the capability for teachers to more easily become authors and editors. In this type of sharing, value is added to information when teachers generate reflections on, strategies for, or speculations about use of concrete materials (whether physical or digital), and make these contributions 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 Collaboration Support for Knowledge Sharing

A system that addresses the basic functional requirements for communication and authoring would provide the necessary set of features to allow teachers to publish concrete materials, share plans and objectives, and form social networks. For these activities to actually occur, however, additional issues must be addressed.

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 "pushing" information. Users must

take some action to join the list or contribute, but thereafter, information is delivered to their inbox without any further 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, since users must take some action each time they want to enter the system. This requires that the system be easy to access and inherently engaging. This is particularly true during the early stages of deployment before a critical mass of active users and content are present. Since periods of inactivity are inevitable, options for exploration and authoring must be made sufficiently interesting that users do not abandon the system simply because it was not densely populated during a particular visit.

Experiences with web-based or Lotus Notes-based asynchronous forums confirm this problem. As these systems typically only support reading and contributing text, any lull in the conversation can be fatal -- potential users who have nothing to contribute immediately will simply stop logging in (Whittaker, 1996). Systems that are based primarily on synchronous communication such as text chat) face an even greater challenge, since they depend heavily upon the simultaneous presence of multiple users.

An on-line system for capturing and sharing knowledge should include rich, interactive tools for authoring, including tools that allow re-use of authored materials. Simple publishing tasks such as posting lists of URLs require only simple tools. Supporting publishing, annotation, and refinement of original material as envisioned in the second level of our framework (sharing of plans and goals) requires more advanced capabilities.

In cases where users have established methods for basic authoring tasks, the system must co-exist with these, for example, by allowing arbitrary documents to be linked to or uploaded. 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 do not exist in 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, as many of them have abandoned feature-laden word processors for certain tasks in favor of more minimal HTML editors in order to simplify publication on the web.

The system should help users locate expertise and facilitate face-to-face interaction. The most advanced type of knowledge sharing in our framework, the establishment of social networks, shifts the nature of the activities away from people interacting with data, towards people interacting with people in the context of shared data.

Ehrlich and Cash (1994) describe a study of a collaborative Lotus Notes database used by analysts in a technical support group. While the artifacts in the database (descriptions and discussions of technical support issues) provided an archive of shared information, shared *knowledge* was derived from face-to-face interactions. When the database proved inadequate for solving a particular problem, analysts would turn to "gopher-net", looking over cubicle walls to see which of their colleagues were available to discuss the issue. In a broader study of asynchronous discussions, Whittaker (1996) cites "media competition" -- competition from synchronous modes of interaction such as phone calls or face-to-face meetings -- as a likely culprit in the failure of small, project-specific online discussion forums

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

The teachers with whom we have worked are certainly interested in more contact with their colleagues, and the administrations of the local school systems have demonstrated eagerness to facilitate workshops and other face-to-face interactions. The most significant barriers to such 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. On-line tools can help address these problems by allowing teachers to discover their colleagues' activities and interact remotely when face-to-face meetings are not possible.

4.4 MOOsburg: An Infrastructure for Knowledge-Sharing

To address these requirements and issues we will be extending MOOsburg, a web-accessible collaborative environment developed as a place-based framework for community collaboration, including school-community collaboration (Carroll et al., 2001). Like a traditional MOO, it models a geographical region (in this case, the town of Blacksburg and surrounding areas), and allows users to interact with each other and with objects in this modeled geography. MOOsburg incorporates and builds on the Virtual School, a suite of collaborative tools that support conferencing, note taking, experimentation, data analysis, and report writing (Isenhour et al., 2000; Isenhour, Rosson, & Carroll 2001). Students and teachers in seven area classrooms (across four schools in Montgomery county and one in Giles County) have used the Virtual School in a number of distributed group projects and mentoring activities (Gibson et al., 1999) over the past several school years.

The basic structure of MOOsburg allows creation of spaces, navigable with a layered, zoomable map and populated with collections of objects that describe, demonstrate, or implement parts of lessons, projects, and activities. Each MOOsburg location has a graphical representation, either sketched with whiteboard tools or imported from a flat or panoramic image, with avatars showing co-located users. The interactive, graphical nature of MOOsburg provides a more engaging user experience than static web pages or transactional discussion forums. It is also more accessible than traditional text-based collaborative environments like MOOs and MUDs, which rely on arcane text commands for most interactions. Finally, the mapping of the virtual environment to an actual geography will, we believe, make MOOsburg inherently interesting, since teachers will have an established structure for incorporating elements of their classroom, school, and community into their on-line activities.

MOOsburg locations can be populated with collaborative objects such as whiteboards, notebooks, simulations, and planning tools. Beyond support for publishing and discussing materials, MOOsburg facilitates re-use of successful resources, plans, and projects by providing tools to help teachers evaluate the potential effectiveness (in their own classroom) of the ideas generated by their colleagues, as well as means for adapting the published materials for their own use. Integrated synchronous and asynchronous communication tools provide one mechanism for evaluating effectiveness and adaptability of a given resource. Teachers can, for example, discuss a set of slides on a particular topic while simultaneously viewing, annotating, or editing them.

Integrated synchronous and asynchronous authoring and communication tools not only support re-use of materials among collaborating teachers, but also support location of expertise and discovery of potential collaborators. Users can explore the environment, inspect their colleagues' work, and leave messages, chat synchronously, or arrange face-to-face meetings with the creators of interesting artifacts. To support these activities we are designing additional search and awareness features that exploit the place-based nature of MOOsburg. For example, we would like to provide the capability to see where others are currently working, where recent activity has occurred, where teachers in particular subject areas have been working, and what teachers in specific schools or areas are doing. With these enhancements we hope to provide at least a limited virtual surrogate for Ehlich and Cash's "gopher-net".

4.5 A Scenario of Knowledge-Sharing in MOOsburg

Our hope is to develop a collaborative system for the Internet that allows diverse teachers in common regions to take advantage of each other's professional work. While teachers often work in isolation and with great autonomy, even teachers of very different subject areas have common activities, needs, goals, and expertise. This is particularly true of math and science teachers. Multiple views of the common professional knowledge and activities can serve different stakeholder constituencies. Our main goal is to offer tools that present better opportunities to observe, reuse, and leverage teachers' individual efforts.

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 important an important step, because it can bootstrap the attainment of more abstract levels of knowledge sharing. But the teachers must believe that they have simple and reliable access to useful and usable resources. Rosenholtz (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 with diverse goals sharing professional resources in ways that can significantly enrich organizational learning.

Terry, a middle school Life Science teacher, is interested in helping her students understand the environmental health of the stream that passes near their school. She opens a web browser and logs on to MOOsburg and sees that there are several water-quality data objects placed on the stream on the map in MOOsburg. When she opens one of the objects, she notices that it contains links and annotations from other teachers using the MOOsburg tool for their fieldwork.

Terry then clicks on the link to the other sites that are doing this work and discovers that teachers have water-quality projects ongoing in their classrooms. Terry notices that other students have discussed their collection procedures, their results, relevant scientific principles and processes, and their conclusions regarding environmental impact.

While Terry is interested in general environmental issues suitable to middle schoolers, other teachers have focused on more advanced and esoteric topics. For example, she notes that the data tool links to an object created by a high school chemistry teacher, Jody, working on water chemistry in the streams, and it also links to an object created by a high school biology teacher, Garin, studying ecology of aquatic life in the streams. Terry finds these and projects very useful perspectives since they provide nice examples of the interdisciplinarity of science involved in the study of stream environments; however, some of the material is too advanced for middle school students. Since the objects provide links to the other teachers, she sends email to them to ask about their projects. In discussing the issues with the biology and chemistry teacher, they decide to let the science supervisor know about their conversations and projects.

As a result of the conversations, rather than having her students simply redo the projects used by these high school science students, Terry has her students compile some of the results and analyses of the other groups into an online presentation for the local community. This requires distilling and representing data and results from other projects, so Terry decides that her students need to contact the other students and their teachers to help understand what was done and what it meant. This was easy to do since the links were readily available, and the

students were not only able to email questions, but actually use the chat feature, shared data, shared notebook tools, and audio conference to communicate and share information with the older students.

The chemistry teacher found that this was an excellent opportunity for his students to reflect on their lab work since the students were not only excited about sharing their work with other students and the community but also since it required them to explain the work very clearly and simply to the younger students. This tutoring, which took place entirely using MOOsburg tools, reinforced their understanding of the project and also gave the chemistry students confidence in their own ability to learn and explain the science. The chemistry teacher, along with the students, designed short activities using the MOOsburg tools that helped his students organize their tutoring and present their stream chemistry work using pictures from the field work, abbreviated data charts, graphs, chemical diagrams, other online sources, SOL objectives, and short lessons and mini-labs that built on each other. Ultimately, many of the sources became reused in the presentation compiled by the middle school students that could be accessed by their parents, judges of the science fair, and the larger community.

Table 3. A scenario of teachers sharing professional knowledge in MOOsburg

5. Issues for Peer-driven Teacher Professional Knowledge Management

Transforming current images of teaching knowledge and professional practice will require significant shifts in approaches to pre-service preparation and in-service development, school district and state system administration, and public attitudes and policies. For example, requirements for a more challenging, professionally-oriented model of teacher preparation include deeper immersion in assessment techniques, greater exposure to multiple models of teaching practice, a more reflective and diagnostic approach to those models and the subject to be taught, the characteristics of the students, personal strengths and weaknesses as a teacher, etc. 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 effective top-down school reforms are formidable. But even if this were attained it would still only create favorable pre-conditions for transforming the culture of teaching. Top-down school reform strategies, implemented through pre-service and in-service development programs, administrative policies, and standard technological tools and infrastructures, should be deliberately complemented by and coordinated with peer-driven innovations in teacher professional practice. 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 a strategy for facilitating peer-driven teacher professional knowledge management through communities of practice. We focused specifically on helping teachers to establish collaborative interactions with peers they can meet with face-to-face, though not necessarily on a daily basis. Our strategy leverages the knowledge, experiences, and meanings teachers already have about the community in which the live. It develops the relationship of teachers and schools to their local communities through sharing locally-significant resources and facilitating the direct participation of community members in school activities.

In this strategy, information technology is employed as a collaboration infrastructure for teachers. It provides a place-based environment discussing, developing, sharing and assessing plans and other resources, an environment accessible to teachers at home or at school, synchronously or asynchronously (section 4). This is the type of support teachers will need if they are to be able to support top-down reforms. They need to be empowered if they are to be accountable. A key to our strategy is long-term, participatory design. Bottom-up reform necessarily depends on innovations by teachers. In our approach, teachers are responsible for all innovations in 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 that of 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.

We see seven focal areas for research and development in peer-driven teacher professional knowledge management. The first of these is characterizing existing knowledge-sharing practices 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.

The second focus for further research and development is better supporting knowledge capture. This involves the development and evaluation of tools, procedures, and policies that make knowledge capture more natural and convenient, and 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 plans and objectives, resources must be analyzed, described, and contextualized in order to be sharable. This is special effort, but one challenge might be to develop techniques that add value for the originator of the knowledge, as well as for the reuser. At the level of social networks, knowledge capture will necessary involve significant special effort, but this effort can be incorporated with broader collegial interactions, and perhaps experienced as socializing as much as work.

Effective knowledge management requires that relevant knowledge should be easy to get to, at just the right time. 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 possibly-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 plans and objectives there are difficult issues of integrating retrieved knowledge with intensional work contexts. And at the level of social networks, there are issues of taking into account the point of view incorporated into an expert colleague's advice and load-balancing across a community of experts.

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 lots of metadata to information in reuse libraries or giving teachers easy access to knowledge-sharing chats and discussion forums may in fact disincline them to participate at all.

Knowledge management is often a matter of finding 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. At the level of social networks, people can capitalize on personal experiences throughout their community of practice 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, 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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