Virtual Community Knowledge Evolution

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Abstract

This paper puts forth a vision and a possible architecture for a community knowledge evolution system. We propose augmenting a multimedia document repository (digital library) with innovative knowledge evolution support, including computer-mediated communications, community process support, decision support, advanced hypermedia features, and conceptual knowledge structures. These tools and the techniques developed around them would enable members of a virtual community to learn from, contribute to, and collectively build upon the community's knowledge and improve many member tasks. The resulting Collaborative Knowledge Evolution Support System (CKESS) would provide an enhanced digital library infrastructure serving as an ever-evolving repository of the community's knowledge, which members would actively use in everyday tasks and regularly update.

Keywords

Virtual Communities, Knowledge Evolution, Digital Libraries, Concept Maps, Conceptual Knowledge Structures, Computer-Mediated Communication, Hypertext, Hypermedia, Workflow, Ad Hoc Workflow, Decision Analysis, Process Modeling, Repository, Professional Societies, Virtual Educational Communities

I. Introduction

Digital libraries commonly provide access to both text and multimedia reference materials as a collection of published documents and digital representations of other artifacts (art, music, etc.). This paper sets forth a vision of a digital repository enhanced with innovative knowledge evolution support, including computer-mediated communications, community workflow and process support, decision support, hypermedia features, and conceptual knowledge structures. These tools and the techniques we propose around them would enable members of a virtual community to learn from, contribute to, and collectively build upon the community's knowledge and improve many member tasks. Community knowledge includes its documents, discussions, decisions, conceptual models, workflows and processes. Community members should be able to contribute to, discuss and learn from the community's knowledge, and from each other (Ram et al., 1999). Our proposed Collaborative Knowledge Evolution Support System (CKESS) would result in an enhanced digital library infrastructure serving as an ever-evolving repository of the community's knowledge, which members would actively use in everyday tasks and regularly update.

We broadly define a virtual community to include anyone actively interested in, or associated with, a group formed around a particular domain of interest. Dispersed or local, the community would require electronic support to implement a continuous metaimprovement strategy in its services. Thus we parallel Mowshowitz' view of virtual organizations—flexible organizations which actively seek flexible approaches to their own improvement (Mowshowitz, 1995).

In this paper we consider two types of virtual communities: professional societies and virtual educational communities. A professional society can be seen as a special kind of virtual community, in which members participate to better understand its domain and improve the way they perform tasks in its domain.

CKESS should actively facilitate the growth of a virtual community into a "Networked Improvement Community" (NIC). Engelbart defines NICs as organizations which continuously improve the way they improve their products and services (Engelbart, 1990, 1992). Continuous metaimprovement occurs recursively at two levels. For example, in a professional society: (1) Members should find new ways to improve both the way they understand the domain and the way they perform their tasks. (2) The professional society should continuously reevaluate the way it improves its community support. Metaimprovement arises from critically examining the processes underlying knowledge evolution and task support. CKESS will achieve continuous metaimprovement by forming augmented "metaimprovement discussions" aimed at improving or "evolving" these processes. Metaimprovement, thus, is realized through improving process innovation. We believe that this concept can bring about the widespread flexibility or "virtuality" Mowshowitz envisioned.

We begin in §2 with an overview of current research. In §3 we present several scenarios illustrating our ideas. §4 describes the various tasks that members of virtual educational communities and professional societies perform. To be effective, CKESS should support most of these. §5 proposes an integrative architecture for CKESS. §6 lists several deployment issues. §7 presents a list of propositions and measurements for evaluation. §8 presents a short conclusion.

2. State of the Art

Several report repositories already exist for various communities. Efforts such as the CoRR Computing Research Repository and NCSTRL have been successful in having community members add and use materials. For others, such as the ACM Digital Library, subscribers may not add materials except through a formal review process. Our objective is to turn such repositories into full environments for knowledge evolution.

Many researchers have observed that knowledge management primarily is about people and cultural change rather than technical development (Abell, 1999). Research on online communities concerns itself explicitly with supporting people networking together to achieve a goal. Through this networking, knowledge is created and exchanged. Technology now plays an important role by supporting activities, recording knowledge and developing organizational memory (Ackerman & Halverson, 1998, 2000; Stein & Zwass 1995).

Key technical contributions to digital library efforts come from areas such as information retrieval/database management (Baldonado et al., 1998; Chang & Garcia-Molina, 1998; Crespo & Garcia-Molina, 1998; Ribeiro-Neto & Barbosa, 1998; Shin et al., 1998), hypertext/hypermedia support (Haas & Grams, 1998; Rutledge et al., 1997; Shin et al., 1997; Nevill-Manning et al., 1997), artificial intelligence (Chung et al., 1998) and information visualization (Furnas & Rauch, 1998; Kumar et al, 1998; North et al. 1996; Phelps & Wilensky, 1997). While some digital libraries support collaborative use (Crabtree et al., 1996; Schnase et al., 1994; Sonnenwald et al, 1999), most technological support concerns building collections rather than enhancing ways to use them. Studies exist concerning how a library *should* be used (Levy, 1998a, b) and how particular implementations are being used (Bishop, 1998; Furuta et al., 1996; Marchionini et al., 1997; Marshall, 1997, 1998; Schiff 1997), but to-date, the library's role has been largely passive, rather than active in directing the users' activities (see, however, some of the work on agency (Sanchez et al., 1997, 1998)).

Much research is being done on synchronous environments such as MediaMOO. While one should include a basic synchronous chat room to our system, we believe it more important to incorporate asynchronous group support tools and CMC. In this latter area, several issues have received scarce research attention: process support for virtual communities, the impact of digital libraries on virtual communities, and the idea of Networked Improvement Communities.

A number of research projects investigate provision of workflow and process support over the Internet via standard Web-based tools and protocols (Grather & Prinz 1997; Miller et al., 1997; Scacchi & Noll, 1997). The intent is to support the activities of geographically dispersed "virtual corporations" and their customers (WfMC 1998). So far little work has been done to extend this concept to virtual communities. In this project, we will use the capabilities of ad hoc workflow tools (Jablonski & Bussler, 1996) to help coordinate the activities of the CKESS community.

Since comprehensive deployment of digital libraries is only a recent phenomenon, few research efforts have studied the effects of their introduction on virtual communities. Studies to-date have focused on the characteristics of physical communities (Marshall, 1998; Schiff et al., 1997), or on evaluating specific digital library functions (Bishop, 1998; Komlodi & Marchionini, 1998). The closest research looks at the impacts of computer networking on scientific research communities (Hiltz, 1984; Star & Ruhlender, 1996).

Lastly, no research has been conducted to-date on the concept of Networked Improvement Communities. While much research and current business lore focuses on process improvement (Davenport, 1993; Davenport & Beers, 1996), we have found no work besides Engelbart's that studies systematic, continuous metaimprovement. The closest concepts are Total Quality Management (Hackman & Wageman, 1995) and the SEI Software Capability Maturity Model (Humphrey, 1988). The former lacks the emphasis of a continuous (and recursive) metaimprovement of an organization's improvement processes, while the latter is focused on traditional organizations, and thus far has not been applied to virtual communities of the kind CKESS supports.

3. Scenarios

These hypothetical scenarios illustrate CKESS support for improvement in an educational community and professional society (scenarios 1-2) and metaimprovement (scenario 3).

Scenario 1: Virtual Project Teams

Professor Smith taught civil engineering in the distance learning program at her university. Project teams in her bridge design course rarely could meet face-to-face as they lived in different parts of the area and had different work schedules. For her semester project she assigned teams of five students to thoroughly investigate a different kind of bridge. Each team was to prepare a Web site presenting its findings, as well as contrast specifics of these findings with the reports of each other group. Virginia Hamlin led one of the project teams, which could never meet in person. Virginia designed a preliminary conceptual knowledge structure (concept map or CKS) sketching out the different aspects of a suspension bridge: its history, its structure, its physical characteristics, examples, designs, articles, research studies, etc. She then drew up a preliminary ad hoc workflow process describing what each team member should do. The teammates followed her process adding links to the various documents they found annotated with their own descriptions. Most of these were in their university's digital library. The team members were constantly looking at each other's work, adding comments, interlinking related data and documents, and occasionally revising the CKS, which served as a visual overview of how all the different aspects of the project fit together.

Two-thirds of the way through the semester, Professor Smith gave all the teams read-only access to everyone else's project, so they could start interlinking related aspects of each. The project leaders began by studying each others' CKSs with the goal of constructing a common CKS. This "official overview" CKS would provide an overview of bridge design and link down to common aspects within each project group's CKS. They participated in a separate discussion area within the CKESS system, in which a heated debate took place. Several alternate CKSs were proposed and discussed. After a week, Professor Smith directed the project leaders to vote on one, that everyone then referred to as the official overview of the class as a whole. Groups created links between their own sites and the official site, and added links directly among sites. Each link had a semantic type such as "predecessor," "alternate design," "contrasting view," "stress-test data," "scientific evidence," "underlying theory," "illustration," etc.

Scenario 2: Developing a New Curriculum

Note: This scenario would apply for a curriculum committee within a single department or within a university school, as well as for a curriculum committee within a professional society.

The American Engineering Association's Curriculum Committee decided that a new series of courses should be developed to train engineers in electronic commerce infrastructures. The committee comprised professionals and academics from across the country and therefore had to work asynchronously. Committee members began by proposing alternate conceptual knowledge structures (CKSs) illustrating the concepts they believed the curriculum should cover and how these concepts interrelated and built upon each other. They used CKESS's discussion environment to discuss aspects of each proposed structure, linking specific discussion comments to parts of specific CKSs. After several votes they finally agreed upon a single CKS for the new curriculum. Then the committee developed a series of courses and the general topics for each. They linked in existing course syllabi and textbooks found in the community's digital library. They also linked in editorials and articles in the popular press and professional literature justifying certain aspects of particular courses and the curriculum as a whole. Academics on the committee found articles justifying other aspects in the educational research literature.

The committee then opened the curriculum up for discussion by the entire Association's membership. The CKS provided an overview of the curriculum's concepts. From the CKS, several hyperlinked guided tours emanated, providing alternate paths through selected lower-level documents within the proposal: one for professionals in the field, a second for professors, and a third for undergraduate students, who were also invited to review the proposal. Each guided tour linked together and annotated different sets of lower-level documents specifically for that group of stakeholders. Several on-line discussions ensued, and many annotations were made by the membership and responded to by the committee.

The committee also made most of their original on-line discussion public so people could see the rationale and process behind their proposal. Many comments were also made on specific discussion items. Based on this feedback, the committee made its final recommendation, which many universities went on to implement.

Scenario 3: Metaimprovement

The following scenario demonstrates metaimprovement because it implements a new process that evolved from a discussion on how to improve the way elections are run. The act of instituting such discussions was a new form of improvement for the organization, and these discussions then resulted in a variety of other improvements for the organization. Thus, the discussion capability is a metaimprovement resulting in a continuous stream of new improvements.

As a result of a “metaimprovement discussion” initiated by officers of the International Education Association, the executive board decided to revamp the nominating process for officer elections. The committee will begin soliciting nominations from the general membership through special computer-mediated discussions, allowing the community to express a level of preliminarily support for candidates using computer-mediated voting tools. Any candidate with a minimal threshold of preliminary support will appear on the ballot.

In addition, previously, the Association has had two vice presidents - one for the Americas and one for the rest of the world. Based on a lengthy discussion over the past two years, which arose from representing two vice presidents on the election conceptual knowledge structure, the Association has instituted a third vice president. The second will now represent Europe. The third will represent the rest of the world. The election process (and conceptual knowledge structure) have been rewritten accordingly and replaced the old versions in CKESS. A lively computer-mediated discussion has formed around them, which for the most part is very positive.

4. Virtual Community Documents and Tasks

A virtual community’s digital library repository should give access to all of its community's documents: books, journal articles, conference papers, audio tapes, videos, still pictures, course syllabi, etc.

But to support many of the everyday tasks of community members as well as to form an community memory and knowledge base, the digital repository should be expanded and support computer-mediated communications, process, workflow and decision analysis capabilities, and conceptual knowledge structures.

Table 1 illustrates the range of tasks that are performed by individuals and the community as a whole within a professional society.

Similarly, Table 2 illustrates the range of activities and tasks performed within virtual educational communities. Many tasks may be done by an individual, and all may be done by a formal or informal group. Each task can be done face-to-face or, given the proper group communication tools, by group members working at a distance. Each task can be done synchronously or, given the proper group communication tools, a virtual group should be able to perform them in a coordinated fashion asynchronously, i.e., working together, but at different times. Given the proper digital library technology, the materials used could reside at a distance from the person or people using them.

Table 1: Individual and Community Tasks for a Professional Society

Individual Tasks:	Community Tasks:
Learning about the community’s domain	Making a budget
Learning about the community’s members	Conducting elections
Teaching a course in the community’s domain	Creating the newsletter
Finding materials and appropriate references for writing a research paper on domain topics	Submitting materials to the newsletter
Determining the state-of-the-art for topics by researchers or software developers	Proposing a task force or special project
Mentoring community members in writing papers that meet the community’s norms	Running a conference or workshop
Looking for interesting research issues in this domain	Recruiting new society members

Table 2: Educational Community Tasks

Searching a digital library
Studying and learning about a subject
Designing and teaching a course
Developing and integrating course materials
Designing or doing homework projects
Holding class and recitation sessions
Authoring a research paper, article or textbook
Developing a curriculum
Advising and mentoring
Discussing, commenting and evaluating ideas/materials
Researching and forming concepts about a subject
Learning about and becoming a member of a community

5. Developing the Infrastructure

This section describes our approach to implementing the CKESS architecture. One should start with a single, limited virtual community, build a prototype for that community, and then expand efforts to other communities. The precursor to the following development stages, of course, is a detailed requirements analysis to ensure that one understands the target virtual community well.

We envision a pragmatic CKESS architecture to comprise a series of support tools that are independent of any particular digital library infrastructure. Integration will be ensured through a set of standard API (application programming interface) messages for the proposed CKESS modules. In the remainder of this section, we will show how tools from a number of different disciplines can contribute to the goals of the CKESS project.

Computer-Mediated Communications and Collaborative Knowledge Structuring

Various computer-mediated communication structures and tools allow "virtual communities" to work together online, not only communicating about specific activities, but also building a form of collaborative knowledge base. Hiltz and Turoff (1985; Turoff 1991) describe a number of fundamental structures and procedures "beyond e-mail and listservs" that help groups organize and retrieve information while collaborating via computer networks for months or years. Such structures within NJIT's ongoing Virtual Classroom™ project include segmentation into separate "conferences" organized by topic, with a branch or threading structure, which keeps all replies in a linked structure. Several field trials with scientific research communities show the ways these tools enabled groups of researchers and practitioners to enhance their productivity (Hiltz, 1984; Turoff et. al., 1993).

The current generation of tools and structures break down, however, when large groups (e.g., class sizes over 50) try to use them for extended and intensive information gathering and analysis. Thus, CKESS needs a set of richer and more powerful tools designed specifically to support professional communities of many hundreds to thousands of participants. Using a knowledge base and associated structured communications, we propose that community members collaboratively develop nonlinear Conceptual Knowledge Structures (CKS). These collaboratively evolving conceptual maps of relationships and entities will become the discourse structures for large-scale group communication among community members and other people wishing to learn more about the community.

CKS manipulation would integrate computer-mediated communications, concept maps, semantic hypertext, and structural modeling to support the following activities:

- Community members can propose and reach agreement on semantic structures (Turoff, et. al., 1999) that categorize various portions of the knowledge domain (including communications, documents and processes).
- Members use those same templates as morphologies for the collection, organization, and retrieval of discussions and other elements within the digital library.
- Individuals considered to be "organizers of knowledge", initiate, evolve and modify a knowledge structure according to new collaborative understandings of the domain. Organizers also can set up votes on relationships change materials and relationships.
- Groups use voting and scaling tools to reach a mutual understanding and consensus on the semantic links and nodes that become incorporated in the templates.

These tools would not merely foster consensus, but expose current issues or contrary hypothesis about relationships in the community's domain. Relationships among elements in a domain would be multi-valued in that participants should be able to vote upon both belief in their existence, as well as the relative strength or significance to others involving the same elements.

Thus, CKSs extend concept maps through this controlled structuring by organizers and integrated consensus tools. CKESS should incorporate the guidance and interfaces necessary for any community member to "organize" a CKS.

We strongly believe that CKSs incorporating an integrated collection of tools, presented in a well designed interface, would allow a community of knowledgeable individuals to individually contribute and collaboratively assess and evolve the knowledge that represents their common field of endeavor. Development also should be conducted in a strong evaluative environment where one can use current user experiences and practices to aid in the evolution of the tools and the interface.

Workflow and Process Support

The software process (Sommerville & Rodden, 1995) and workflow research (Miller et al., 1997; Scacchi & Noll, 1997) communities are moving toward a shared realization that process modeling and execution encompasses a spectrum of process types, from simple repetitive processes addressed by conventional workflow management systems, to knowledge and communication intensive activities such as design, software development, and business decision making, and from "emergent" or ad-hoc workflows to mission critical, structured, pre-defined processes (Sheth et al., 1996).

The tasks shown in tables 1 and 2 in §4 represent a similar spectrum, from relatively simple workflows such as adding documents to the knowledge base to more complex processes such as managing the review process for a conference. In both of these examples, standard reusable processes to guide users, route communications, monitor progress, send reminders, and provide an audit trail, will be developed. A community will also engage in less structured, more spontaneous and human intensive activities such as arranging meetings, collaborating to produce a progress report, and teaching a course in the community's domain. To support such activities, community members must be able to design their own processes using a graphical interface, automatically instantiate the processes, and then obtain machine assistance in executing the processes. Alternatively, the constructed process models could be used to provide active guidance for members seeking to perform tasks offline. Finally, relaxing constraints on user interactions even more, a workflow tool could be used to assist users without any predetermined rules or imposed structure. In this case, the logging capabilities of the system could be used to record usage patterns for later analysis, for example, using data mining techniques.

Several Web-based ad hoc workflow engines have been developed in research labs and commercially that could be used to support virtual communities (Zhao et al, 2000). Standards for workflow process invocation and control over the Internet have also been developed (WfMC 1999).

We propose enhancing CKESS with process models describing how the tasks are performed, and providing active guidance through execution (enactment) of these models. Using techniques such as those discussed in (Scacchi & Noll, 1997), CKESS community members would describe (model) processes for tasks such as those listed in tables 1 and 2 in a high-level process modeling language such as "PML" (Scacchi & Noll, 1997). Process modeling languages allow users to specify the type and order of tasks that comprise the process, and the resources (documents, tools and "products") that are required and produced by the process. Members could augment the models with narrative annotations, scripts, and links to related documents. This would enable the community to collect, document, and evolve best practices useful for improvement and training. An innovative feature of CKESS' process support would be the integration of process enactment and process improvement. Because CKESS should allow submission of new processes and improvements to existing processes, community members become both process performers and process engineers engaged in improving their own processes.

Decision Analysis Support

The list of community tasks tabulated in §4 involves decisions at various points during the execution of these tasks. Daily experience has taught us that most such decisions are non-trivial. The individual decision maker is usually confused by multiple and potentially conflicting decision criteria that prevent him or her from choosing a best decision alternative. Groups often fail to reach an agreed decision because the individual members' choices or rank orders of the decision alternatives vary considerably.

Individual and group decision problems, and models addressing these, have been studied in a variety of research contexts such as decision theory, preference modeling, human judgment and organizational behavior. The problem of effective decision making has been long recognized in business organizations, and various advanced information and decision support systems have been developed to address that issue. Today, we are witnessing the first decision aiding experiments for virtual community members on the web. Recommendation systems for shoppers at amazon.com or cdnow.com and a variety of other web shops illustrate the interest in and commercial value of such systems. The enhanced digital library environment envisioned here allows for the opportunity to develop decision analysis support for an actively collaborating and large community, extending the basic support available today.

Therefore, we propose enhancing CKESS with multi-criteria decision analysis (MCDA) models. MCDA models allow for the explicit recognition of multiple conflicting criteria, or at a group level, multiple conflicting group members. MCDA models have been widely applied at the individual and organizational level, and are well documented in theoretical and organizational literature (e.g., Dyer et al. 1992, Simpson 1996).

Implementation of decision analysis support models would require two major steps. First, one would develop MCDA models as flexible tools or "components" that can be plugged into a group's workflow when a decision point is reached or when the need for more substantial decision support arises to any individual in the group. Second, one would connect these models to the discourse structures described above, so that the communication preceding a certain decision is captured and the decisions taken are annotated. This connection between discussion and decision establishes an auditable 'trail' of the decision process of the individual or the group. This in turn would greatly improve the understanding and the transparency of the decision process of a group and any of its members.

Integration

Integrating all these components could follow a hypermedia modeling perspective. In the Dynamic Hypermedia Engine (Bieber 1998; Galnares 2000), for example, people can link nodes, make comments about nodes, place nodes on guided tours, display nodes within system overviews, etc. Essentially a node is an "element of interest". In many traditional hypermedia systems, only documents would be considered nodes. For many user tasks, however, links, comments, guided tours and overviews, etc., themselves all could be considered elements of interest, and therefore people might want to recursively link them, comment upon them, add them to a guided tour or include them in an overview. To implement this, we either model any component as a subclass of a node or map it to a node.

We would model integration within CKESS in a similar way. All objects within any CKESS subsystem would be a subclass of a node or map to a node. This includes:

- Repository: all multimedia documents, their components, attributes, access permissions, etc.
- Conceptual Knowledge Structures: Conceptual knowledge structures as a whole and component elements; participants and participant roles, etc.
- Computer-Mediated Communications: Discussion threads and items, participants, groups and participant roles, communication structures such as votes, etc.
- Process and Workflow: workflows, processes and their elements, resources, inputs and outputs, etc.
- Decision Analysis: options, preferences, weights, etc.

Hypermedia links then would allow each of these components to involve the others. For example, users would be able to start a computer-mediated discussion around any CKESS element or *node*, e.g., portion of a document, a process, a process step, a hypermedia annotation or guided tour, or even part of another discussion. A conceptual knowledge structure could contain any CKESS element. Similarly one could comment upon and include any CKESS element in a guided tour, etc.

Clearly, certain elements appear across subsystems, such as participants. For any element not modeled in the initial digital library repository, one would need to add a module to support it in a coordinated manner. Also to achieve integration, one needs to ensure that every CKESS object (as well as any compound object containing it) (a) has a unique identifier across subsystems; (b) a recognized semantic type or set of semantic types; and (c) if the object is virtual or generated upon demand, then a general algorithm or set of commands for the Dynamic Hypermedia Engine to regenerate instances of its semantic type or object class.

6. Deployment

At the same time one is developing CKESS, one should be planning, conducting and continually revising several deployment plans with the target community. This involves several issues:

1. Announcing and advocating CKESS: How best does a community announce and advertise CKESS' goals, features and services to that community, especially those with which they are unfamiliar, such as process support, decision analysis and conceptual knowledge structures? How will one get a critical mass of community members to "buy into" the repository, add materials to it, and use it to access information through it whenever this would be useful to them?
2. Managing and maintaining CKESS: How best should a community manage the knowledge repository? This will involve finding a group of people in the target community willing to install and be responsible for it. They will need to perform the deployment announcements and advertising described above. They will need to set up a help service. Some communities may require moderators or facilitators if the requirements analysis determines this (Berge, 1992; Collins & Berge, 1997). Guidelines also must be developed for maintaining the entire system.

7. Evaluation

In this section we present a preliminary set of propositions for this research and an indication of methods for evaluating the extent to which these outcomes are attained within a virtual educational community. The goal of this research is to understand and design an enhanced digital library functionality that supports the particular needs of online "learning communities" (which both our sample communities are) and which integrates with other common software tools, such as conferencing systems (also called discussion forums, or bulletin boards) for asynchronous interaction.

Table 3 lists an initial set of propositions and measures directed towards one or the other of our sample virtual communities.

Table 3: Initial Propositions and Measures

P1: An enhanced digital library support will increase the use of such resources in online courses. *Measures: Incorporation of Digital Library using assignments into syllabi of online courses; number of visitors to CKESS from participating courses.*
P2: An enhanced digital library will improve satisfaction with

online courses by students and faculty. *Measures: online surveys; faculty interviews.*
P3: A critical mass of community members will add documents, links and annotations, conversations, conceptual knowledge structures, and processes to an enhanced digital library in a sustained manner. *Measures: number and type of sources for objects added each month*
P4: The community's knowledge representations (i.e., conceptual knowledge structures) and dialog will lead to constantly evolving knowledge accessed by the community. *Measures: number of concept maps and stored communications*
P5: A critical mass of community members will use an enhanced digital library consistently. Measures: tracking repeat visits per month
P6: A critical mass of community members will find the combination of hypermedia, computer-mediated communication, conceptual knowledge structures, and decision and process support in an enhanced digital library useful. *Measures: online survey, diaries*
P7: Members will perform community and individual processes more effectively when supported by ad hoc workflow automation tools. *Measures: user acceptance of workflow automation for routine processes, number of ad hoc processes generated, workflow engine log files, online survey, diaries*
P8: A virtual community can maintain its organizational memory effectively through an enhanced digital library that combines hypermedia, computer-mediated communication, conceptual knowledge structures, and decision and process support. *Measures: member/officer interviews, member survey*
P9: An enhanced digital library can support continuous metaimprovement of the virtual community. Measures: member/officer interviews, member survey
P10: An enhanced digital library will promote collaborative work among community members. *Measures: member survey, count of individual and collaboratively authored papers by community members over the period of the project, analysis of discussion participation, email interviews with authors*
P11: An enhanced digital library will create new roles and forms of active participation in the community. *Measures: analysis of roles and artifacts created, numbers of sharable artifacts created*
P12: An enhanced digital library will improve the mastery of course materials by students. *Measures: comparative grade distributions, failure rates.*

By "critical mass," we mean a substantial and relatively consistent user base. No consistent measure of critical mass exists in the literature. People generally agree that it reflects the number of participants or activity necessary for a community to function (or thrive). One should come up with target percentages of participation as part of the requirements analysis.

It is necessary to measure both improvement and metaimprovement. Measuring improvement is one step beyond measuring usability of the system. Usability evaluates whether people find the system easy to use. Improvement evaluates whether people find that using CKESS results in better understanding of the domain, better work and/or a better research community. Measuring metaimprovement is one step beyond measuring improvement. Do people (or the community as a whole) find that CKESS' ability to improve their understanding and tasks itself continuously improves? Stated recursively, will the target community over time, through CKESS, help people improve the way they improve their understanding, and improve the way they improve the way they perform tasks?

To explore how different groups of community members can judge improvement and metaimprovement data could be collected from community leaders/officers (measured through periodic semi-structured interviews), general community members (measured through surveys), and if possible, people outside the community.

Ideally one would apply both formative and summative evaluation techniques, including both qualitative and quantitative methods. Formative evaluation would be used to iteratively assess and improve the functionality and usability of CKESS prototype. Summative evaluation would help assess usage, impacts, and satisfaction, in general, and the extent to which one achieves each of the goals, in particular.

8. Conclusion

This paper sets forth a vision and a possible architecture for a community knowledge evolution system. Most digital library efforts to date have concentrated on reengineering library features and procedures for electronic repositories. Our proposed research greatly will extend the scope of digital library support for collaborative knowledge evolution and continuous metaimprovement within virtual communities.

While we focus here on educational communities and professional societies, our proposed knowledge support certainly could enhance other virtual communities including medical and professional communities, and also organizations such as business and non-profit organizations. All these communities and organizations have multimedia documents, processes and discussions, and all potentially could take advantage of an enhanced digital library to achieve knowledge evolution and perhaps the status of becoming a networked improvement community.

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