AC 2008-359: WORK DESIGN FOR ENGINEERING EDUCATION IN A FLAT WORLD: A GLOBAL, VIRTUAL, COLLABORATIVE MODEL

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Introduction

Every society in the world is confronted with real world problems that need engineering input and solutions. Some of these problems are shared by the global community, while others are local problems. Two major members of the engineering community that respond to these engineering challenges in the world are industry and academia. Industry responds to these challenges by helping create and realize the "technological and engineering solutions." Academia helps solve these problems with scientific research, and by training future generations of engineers with both research (at the graduate level predominantly) and engineering skills (at the undergraduate level to work in industry).

This cycle of research and technology development for solving engineering problems in the world, and solving and sharing of successful solutions for engineering problems, is limited, however, by two important factors:

1. geography and distances;

2. limited engineering skills/expertise in local communities.

Given these limitations, this paper proposes a cyber-infrastructure framework among global engineering communities for engineering education, training, learning and problem-solving, and for sharing successful engineering solutions among world communities.

The framework in this paper is based on the following principles:

1. to generate the best engineering solutions for engineering problems in the world community, one local community may not have *all the skills and expertise* needed to solve the problem, but may still have *a core competency* needed to solve the problem;

2. to solve the problem, partners with *core competencies from the global engineering community (industry and academia)* join together in a virtual manner to solve the problem, and document the solution; and

3. based on a service learning paradigm, the infrastructure can use *engineering education and training of students* as the medium for generating solutions to engineering problems in the community.

Background and Literature Review

Our research framework in the paper is driven by prior research findings in creating virtual organizations. We briefly review prior research in virtual organizations in the following paragraphs.

A virtual organization is considered a collection of geographically distributed, functionally and/or culturally diverse entities linked electronically for communication, coordination and group activities [10]. The metaphor most commonly used to describe a virtual organization is that it is a company without walls [16]. Collaborative networks of people work together regardless of their location [6, 2, 21] or ownership of the network. This collaborative work may be managed in the form of need-based teams that form and dissolve based on market needs/opportunities [9, 11, 20, 27].

A virtual team can be viewed as a group of people interacting through interdependent tasks guided by a common purpose, working across space, time, and traditional organizational boundaries, connected through electronic communication links [27]. Because virtual organizations are geographically distributed, electronically linked, functionally and/or culturally diverse, and laterally connected (more than hierarchically connected), they afford dealing with highly dynamic processes and contractual relationships in reconfigurable organizational structures with permeable and edgeless boundaries [10].

Important aspects of virtual organizations studied in the literature include the emergent evolutionary and structural of virtual organizations, communication in various forms and its effect on virtual work organization, virtual task characteristics, transaction cost economics of organizing virtual work, and trust in virtual organizations.

Given the reconfigurable nature of virtual organizations, the emergent structural properties of virtual organizations have been modeled based on social network theory [35, 3, 4, 1]. Social network models postulate that informal group interactions, more than formal structured and mandated interactions, exhibit over a period of time, a pattern of communication and a network structure that can be used to explain organizational behavior and evolution [29, 1]. Organizations when viewed as information processing systems organize their information technologies for processing, exchanging and distribution information required for effective task performance. Hence, measures of performance of organizational systems relate to measures of performance for information processing functions. Ahuja and Carley [1] have extended the concept of social network modeling to measuring emergent structural properties of virtual forms of organizing work. The degree of centralization [36] refers to the degree to which interactions among members in the organization are mediated by a supervising member who plays a focal role in task accomplishment [14]. The reciprocity that exists among members of a virtual community is also an important factor that has been modeled using social network theory [25, 1]. Although members of a virtual organization may have a common long-term binding goal, since the membership in the organization itself remains fluid (self-organizing based on fulfilling a market need), members enter and exit the organization as the need for having the organization evolves. Hence, reciprocating any favors among members in such an organization will be based on short-term time spans, and members may or may not directly be able to reach other in a reciprocal manner [1]. The number of hierarchical levels in a virtual organization is also an emergent property of virtual networks [24]. Since virtual organizations afford lateral communication and interaction, several studies report that high-status members are unable to dominate other members compared to face-to-face or other forms of communication [5, 12, 34]. Flattening of communication hierarchies [41, 31] may result.

Although electronic communication affords the opportunity to form connections such as lateral connections and lateral blending of expertise that would otherwise be impossible to form or maintain [15, 30, 7], some critical communication issues can impede the effectiveness of electronic communication media in a virtual organization. There is likely to be a substantial increase in communication volume [22], but not necessarily an increase in communication efficiency, especially for tasks that involve problem solving. Researchers agree that for low complexity, routine tasks, face-to-face meetings may be more efficient than electronic communication [18, 19, 39, 8, 33]. Lack of provision for face-to-face meetings may also result in poor message understanding among members in the virtual organization because of the lack of any physical and linguistic co-presence for inferences about mutual knowledge [23]. Whether mutual understanding among members of a virtual community is possible is debatable [28]. Some studies conclude that participants in a virtual community use community membership as a cue to make inferences and judgments about another member in the community. Therefore, social context can be used to interpret messages and responses [13, 32, 41]. A key aspect in the framework proposed in this paper is to identify the social and community contexts that facilitate formation and maintenance of relationships.

The relationship of task characteristics to the method and media used in communication has been extensively studied in the literature. The face-to-face mode of communication may be more appropriate for initially building a shared interpretive context among stakeholders; computer-mediated communications can then be effective in continuing the communication within the established context [42]. The modality of communication may affect the task more than the task affecting modes of communication [28, 26]. Studies have concluded that groups are more effective in tasks requiring divergent thinking when using electronic communication media than when using face-to-face modes of communication. Tasks requiring convergent thinking, such as for reaching consensus or resolving conflicts may be more effective if done face-to-face [17, 40, 37, 38, 22]. Individual styles and preferences, experience, and social norms for interpersonal interaction, practices, and conditions surrounding media use also influences electronic communication patterns in organizations [32].

Problem Description

Figure 1 illustrates in a simplified way, a generic, traditional form of organization of the engineering education and research enterprise. In this representation of the traditional organizational form, each community (could be a local community within a country such as El Paso, Texas in USA or Beijing, China) generates *engineering problems*. The engineering problem-solvers include *industry* and *academia*. Note that to simplify the representation for discussion purposes, we have grouped all industry into one representation, and all academic entities into one; in reality, we would have several industries, and several academic entities within a community responding to the problem solving need.

Academia is considered to broadly be composed of faculty and students. The colored dotted lines in figure 1 represent networks and channels of interaction that can exist when responding to the *engineering problem needs* generated by the society-at-large. There is interaction between faculty and students in the form of training and learning to solve engineering problems (represented by the brown two-way interaction line). Faculty conduct scientific research with support from industry. Industry is then able to translate the science into useful technological and engineering solutions for the benefit of the community.

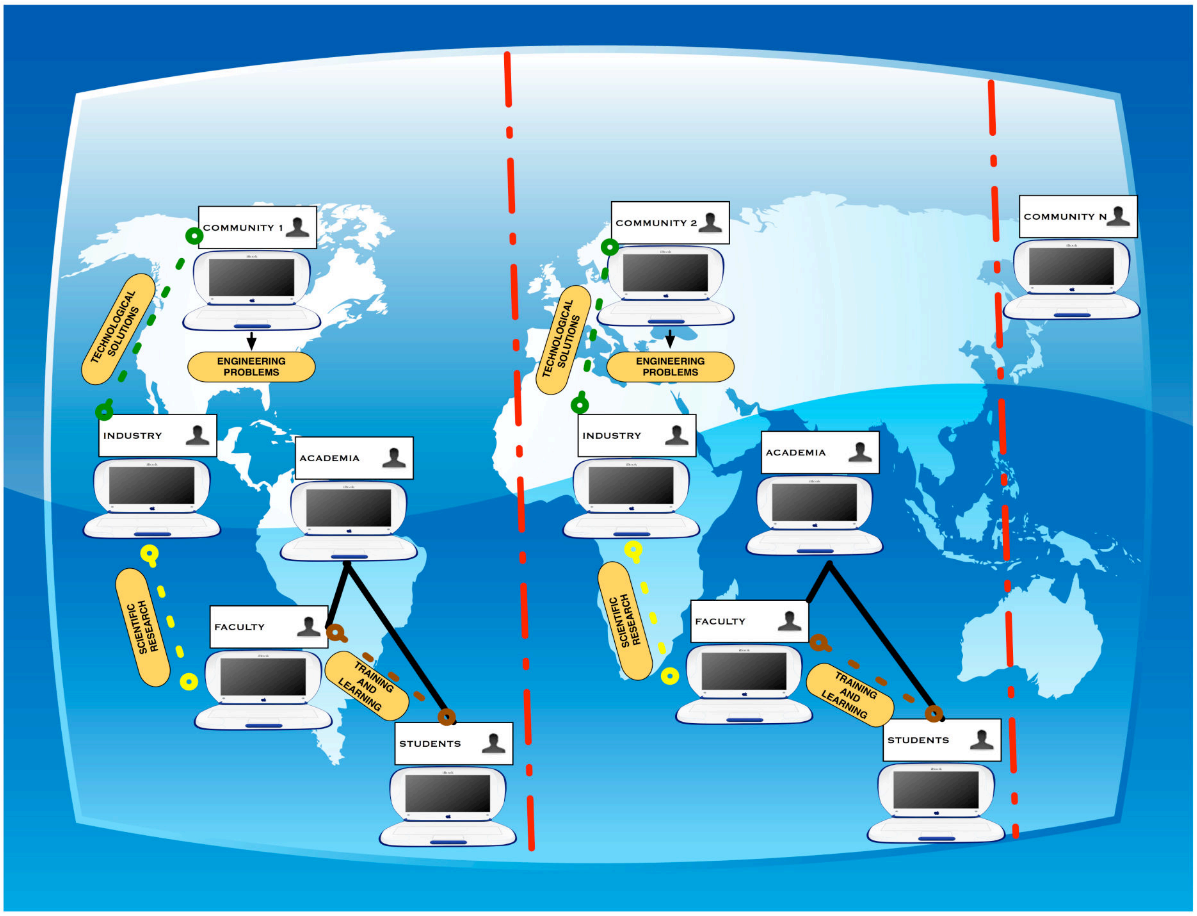

FIGURE 1. Traditional engineering education enterprise model

In the traditional model of engineering education enterprise, boundaries (represented by the red vertical lines in figure 1) exist between entire communities, the industrial enterprises in those communities, and the engineering academic enterprises between these communities. These boundaries primarily come from two major sources - geographical boundaries and expertise/skills boundaries.

Hence, generating and validating engineering solutions to an engineering problem generated by a local community in China or India may be limited and constrained by geography and distances, and the level of skill/expertise available to solve the problem in the local community. Additionally, any good engineering solutions generated lack wider dissemination to benefit other communities that may face similar problems.

In summary, not only is the potential to *outsource* engineering problems and to use the *best global engineering skills* for obtaining *best solutions* lost, but the potential to *share the solutions and validate solutions* in a larger engineering community is lost as well. Use of computer technology for modeling and solving problems in the traditional model may be somewhat limited by what is available in the communities – economic disparities, for example, in a community may prevent significant use of computer-based technological tools for engineering problem modeling and solutions.

Proposed Solution and Benefits

Figure 2 represents our proposed engineering education enterprise model. This structure for interaction and the content of interaction among the community members (society-at large) and the engineering problem-solving community (industry and academia) is significantly different from the traditional model in several respects.

In the proposed model, each community (could be geographically dispersed) still generates the engineering problems driven by societal factors. These problems are then cataloged in a world repository of problems (and solutions). Industries in different geographically dispersed communities, and academia in different geographically dispersed communities may then be able to respond to these problems.

Additionally, the proposed prototype structure will include mechanisms for peer-to-peer lateral interaction. Several categories of peer-to-peer interaction are envisioned.

Peer-to-peer interaction among different industries could occur for sharing *technological resources (based on core competencies)* to enable technology transfer from academia and for developing useful technological solutions. Lateral interaction among faculty from different geographically dispersed communities is envisioned for *development of engineering teaching and learning material* for enabling students to solve the engineering problems in the world repository.

Integration of faculty research and education is also accomplished through this model – faculty core competencies for solving real world engineering problems is achieved through research, while at the same time, generating teaching and training materials for student training purposes is driven by faculty core competencies developed through research. Additionally, even the most basic concepts in engineering are viewed in our model through a real-world problem-solving *lens.* In preparing teaching and training material, faculty must not only be involved in performing new research unique to the engineering problem, but also be able to translate basic engineering concepts in terms of the real problem for generating effective problem solutions.

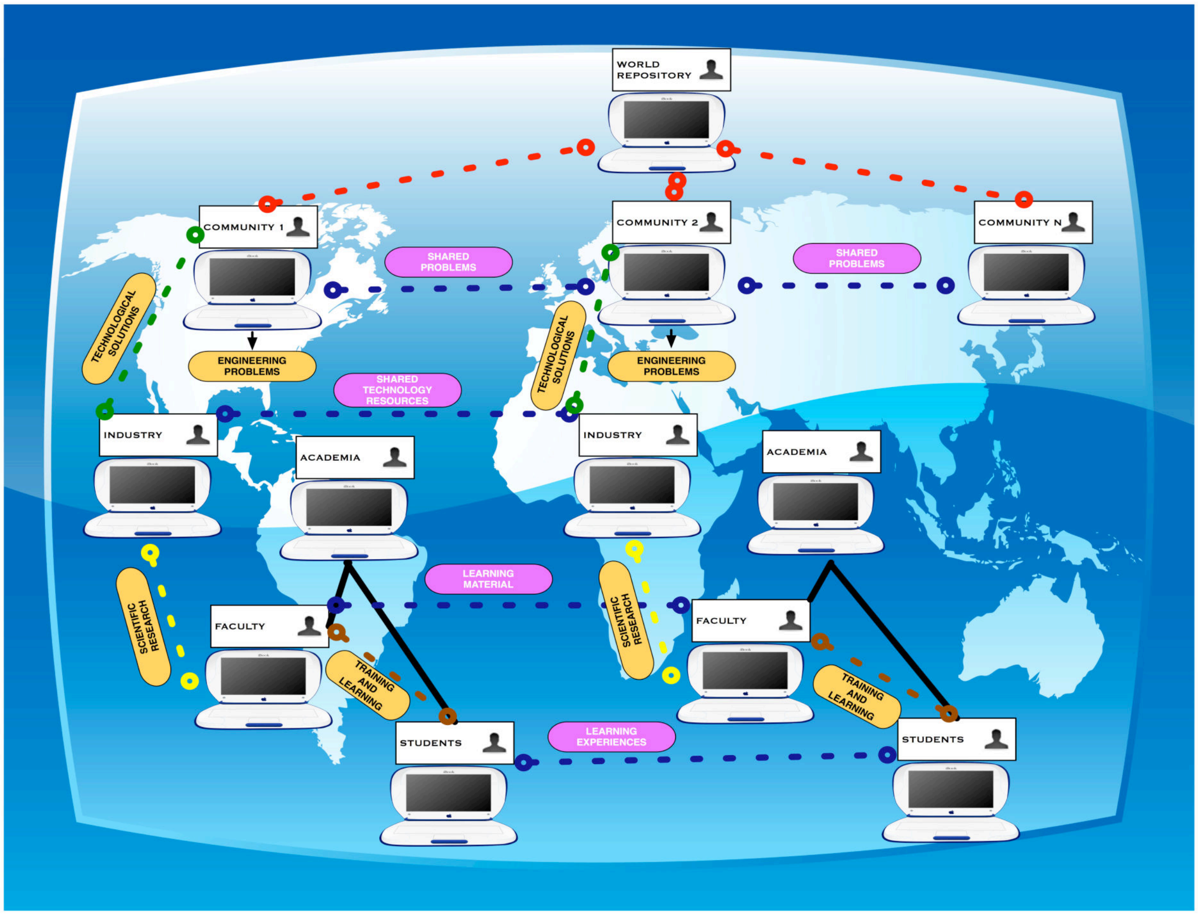

FIGURE 2. Proposed Interaction Structure and Content Basis

The last major category of peer-to-peer lateral interaction enabled by our model is among students. Enabling peer-to-peer interaction in the virtual college among engineering students in the global community will allow them to *share learning experiences and strategies* for engineering material, and for solving real world engineering problems.

The lateral, peer-to-peer interactive networks envisioned in our framework will enable geographically dispersed engineering problem solving groups to collaborate and share engineering expertise to solve problems generated by ***any community*** connected in the network. Any engineering problem solving group with the required core competency to solve the engineering problem can contribute to solving a piece of the puzzle.

Other interactive elements built into the virtual framework include industry-faculty two-way interaction, and faculty-student two-way interaction. These two-way interactions could occur at a local community level or at a regional, national or even an international level because of the network structure.

With the interaction structure built in the model, and with the central world repository providing access to engineering problems in any community, and engineering solutions generated by the virtual engineering problem solvers, the limitations of geography and expertise on the quality of the engineering solutions are overcome. Additionally, engineering students are trained to solve real world problems with teaching material jointly developed and refined by the global engineering faculty peer group.

Industry can develop technology-based solutions based on the best available *academic core competencies*. Industry partners can also hire engineering graduates with the knowledge that these students are able to solve real world problems using globally developed solution strategies and tools. Industries can be viewed by members of the society-at-large at helping bring technological tools and solutions that help solve societal problems. This can spur further industrial growth. Students stand to benefit immensely from this structure as well in several ways. They are exposed to real world problems, and will not view concept and theory as being useless for practice. Additionally, students benefit from the collective wisdom of state-of-the-art teaching material developed, shared and refined in a global faculty collaborative. Students also have the opportunity to share with and draw from their students peers across the globe. This will enable development of their professional and social contacts. Students also improve their job prospects by solving real world engineering problems with real world tools and materials.

Conceptual Framework

To realize the vision of the virtual college, a conceptual framework with hardware and software architecture are proposed. User scenarios, expected functionality, system requirements and shared organized content systems are fundamental to the proposed system architecture. Although the virtual college is envisioned initially in English, it is recognized that language barriers will have to be overcome through software design solutions to increase access of the virtual college portal.

As envisioned, the virtual college proposed in the paper will have various types of users, namely, community (e.g. a village or social group), faculty, students (working under faculty supervision), and industry. Different users will have roles that provide different hierarchical authority and access to functionality. The following scenarios provide a description of the functionality required by each participant and the corresponding authority.

Scenario 1: A Community Looking for a Solution

The leader of a village in a remote area has identified a need that would directly improve the quality of life in the community (e.g. crop harvesting tools, home-related technology, water treatment, etc.). The leader, with the help of an organization (e.g. engineers without borders, peace corps, local aid groups, etc.) is informed of the virtual college infrastructure. The community leader posts their need in the virtual college through a local internet café. The virtual college interface was relatively easy to use and understand making it easy for the leader, a person with very limited computer knowledge, to fill the information forms. Since the problem was posed in a colloquial manner, faculty make contact with the community leader to clarify the design specifications (i.e. a technical requirement list). It is necessary to make clear to the community that the purpose of the virtual college is to provide engineering solutions to engineering problems using dispersed worldwide expertise, and that nominal costs for intellectual property rights exchanges would be involved in realizing the solutions. Eventually, one or more solutions are offered to the community; these solutions were taken to the local government, aid agency, or development organization to realize it with great success.

Scenario 2: Faculty and Students Working on a Project

As part of their Senior Design project, a multidisciplinary group of students is looking for a challenging and meaningful project. These students belong to an academic institution (e.g. BYU, Shanghai Jiao Tong University, Monterrey Tec Mexico, etc.). The team's advisor suggests the virtual college as a source for real-life service learning projects. The advisor and the students access the virtual college system and search for projects based on its characteristics (e.g. technological area, complexity level, geographical location, who is currently working, etc.); they find a handful of candidate projects and select one. The students register in the virtual college system to work on this project, and during the semester they communicate with the virtual college system manager to obtain more information about the project and even manage to establish direct communication with the remote community. The virtual college system provides varied functionality for the students to search, share, and learn about related engineering topics; it may be possible for teams from different institutions to collaborate on the same project. Through industrial connections, the advisor manages to find technical support from local industry for the students to solve the problem. At the end of the semester, the team submits their design to the virtual college system. Eventually, the students learn that their design was successfully implemented; the team, advisor, and university are commended by the virtual college.

Scenario 3: Participation of Industry in a Project

A solar-cell manufacturing company is called by a faculty member from a partner academic institution to help in a service-learning project. A team of students requires expertise in the area of solar-cell power. An expert from the company helps the team to design a solution for a given problem; the solution is submitted and the community decides to implement it. The company would like exposure to its products and offers a discount to the community. Because of the specific skills learned through the project, the company offers job interviews to the students involved. The company looks forward to collaborating with similar student-based design projects. The virtual college system allows the company to search for projects throughout the world and identifies the teams involved in solar-cell power technology.

User Hierarchy and Expected Functionality

It is important to note that the virtual college encourages initiative from all participants: community, faculty, students, industry, general public, non-governmental organizations, aid agencies, etc. The proposed hierarchy is horizontal rather than vertical, with few layers to maximize communication among participants.

Community Member: Has access to databases of current projects and submitted solutions. Can submit project requests based on a local need. Can have communication with other community members and with faculty and students participating in a project.

Faculty: Has access to the databases of current projects and submitted solutions. Has some authority to open an account and create a student team. Can communicate with faculty from other institutions and with industry. Has limited management ability for specific projects.

Students: Have access to databases of current projects and submitted solutions. Can communicate with a community, faculty or industry partner. Can upload and download information depending on the project their faculty advisor has interest in solving.

Industry: Has access to databases of current projects and submitted solutions. Depending on the project involved, the industry partner can have added functionality to send/receive information and communicate.

Virtual College Technical Manager: Is able to upload information content, review other's proposed content and make improvement suggestions.

Virtual College Manager: At the highest level, management users have the authority to modify the system itself, manage user membership, and decide on the content.

Proposed Conceptual System Architecture

In this paper, a wiki like structure is incorporated for realization of the virtual college. A wiki such as wikipedia, is a medium which can be edited by anyone who can access to it, and also provides an easy method for creating and managing hyperlinks.

In general, database servers and web servers play an important role in a server system. In database servers, a wiki normally stores all the text and data (articles, user details, system messages, etc.) in a database, which it is capable of sharing with other web-based applications. A schematic diagram of the Wiki like system is presented in Figure 3. Different users and Graphical User Interfaces (GUI) are controlled by web servers while database servers are able to direct functional implementation and content data.

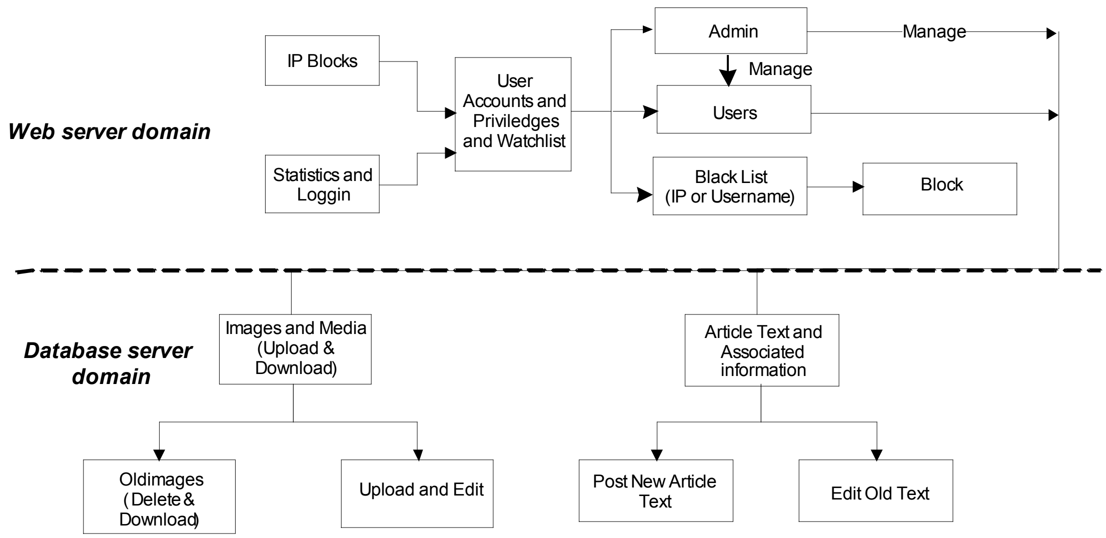

Figure 3. A Schematic Diagram of the Wiki-like System

Example of Implementation of the Wiki-like System

School XXXX has joined with a number of other schools to design, model, analyze and build a next generation formula race car. The participant schools include academic institutions in U.S., Canada and Mexico. In this project, students are required to design and deliver the parts for the race car and assemble the parts together and create a working prototype of the car.

Through a Wiki like framework, universities participating in the project can exchange data and information through wiki. They are also able to post questions, notes and post even design drafts on the wiki. The authorized users from other universities can browse and edit it easily as well as post new information. Authorized users can edit the original articles or texts; others can browse information through Internet Explorer. They may obtain new ideas by reading others' notes. A wiki also makes the collaboration effort more efficient. Users in different countries can continue work on one issue and share the progress through a wiki (i.e., update and edit what they are doing rapidly). With the friendly content management system, any data will have good protection. Wikis can divide users in different groups so that it makes the authorization clear. Sometimes even users in other projects can be granted permission to participate in the project to provide some support.

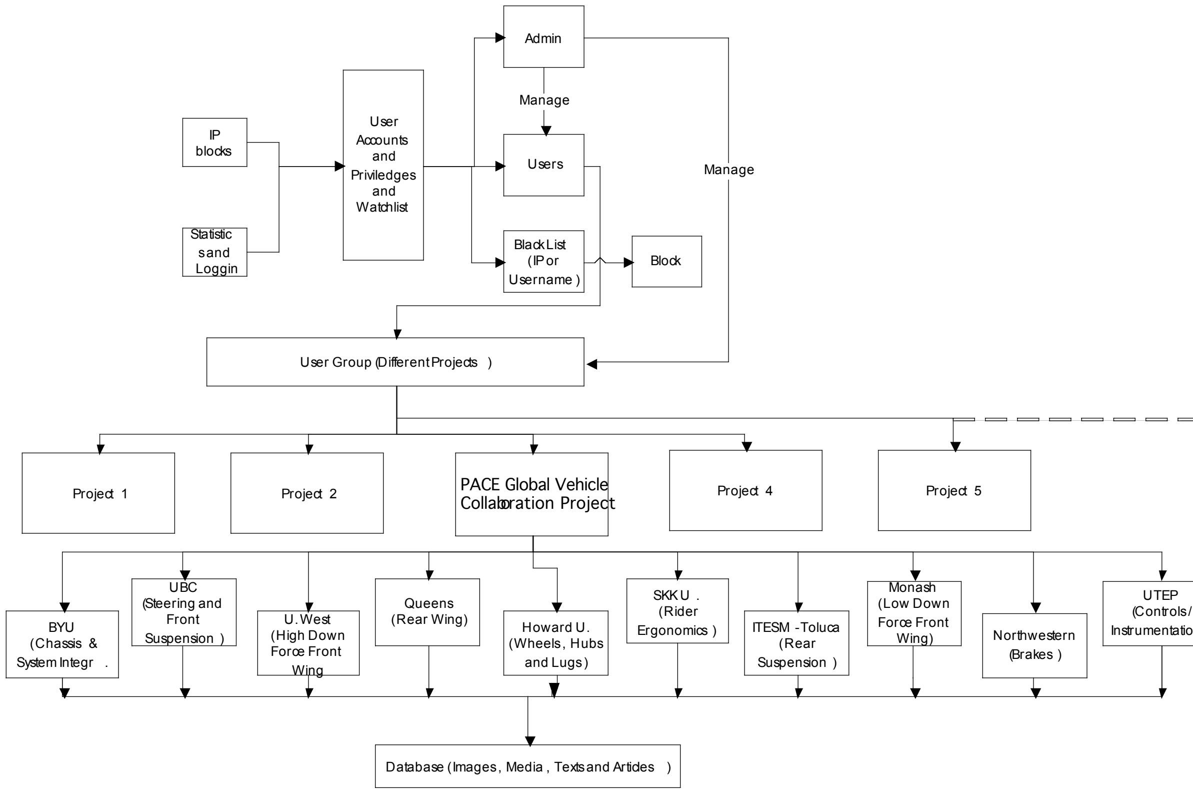

Figure 4. The Example of PACE Project through a Wiki-like System

Moreover, as each team posts their progress and design work in the wiki website, they can be stored and shared in the same main database. Therefore, each team is able to view the entire project transparently. After each team finishes their assignments, the administrator will compile the work into a final report that can be sorted into a specified directory of the server. Once the report has been appraised, feedback can be uploaded into the directory for reference. Since accumulating information is a characteristic in the Wiki like structure, domain knowledge expansion can be easily achieved if the database can be updated periodically. The wiki-like server system is able to provide effective communication, information sharing, knowledge expansion, browse/edit/post documentation, synchronization and integration of collaboration efforts and continuous quality improvement in a collaborative, heterogeneous environment. The example of this Global Vehicle Collaboration project through a Wiki-like structure is depicted in Figure 4.

Future Work

A number of research issues remain for the virtual college portal to function effectively. The emergent structure of the virtual college system can be modeled using network analytic methods for social network modeling. In modeling the emergent structure of the virtual engineering college, based on prior research in this area, three important research questions in organizational structural elements of the emergent virtual engineering college need to be addressed:

1. *The degree of hierarchy*. In the virtual college, we expect that the number and extent of reciprocal relationships will be much larger than the number and extent of non-reciprocal relationships.

2. *The degree of centralization*. Centralization refers to the extent to which the network is organized around a central focal point. With the virtual college, it is expected that lateral, peer-to-peer networks will see heavy interaction and activity, indicating dispersed global activity rather than activity with a few focal points in the local community.

3. *The hierarchical levels in the emergent virtual engineering college*. This refers to the number of levels or layers through which one must go through in order to obtain information or accomplish a task. Again, the model promotes a lateral peer-to-peer support structure, so it is expected that there will be fewer hierarchical levels for access to problem solutions, and information for solving problems, than a traditional engineering educational enterprise structure.

4. These properties of an international virtual engineering college can be studied using the context of specific task sets for the engineering college. Engineering problems can be supplied by the community at large. Task sets for the international virtual college of engineering can be categorized as research (by faculty), development of educational materials (by faculty), education and instruction (by faculty), problem-solving and solution generation (faculty, students and industry), and translation of solutions into technology prototypes and products (primarily by industry). These broad task categories will no doubt include several sub-tasks, some routine and some non-routine and complex, with varying degrees of task difficulty. The emergent structural properties of interaction of the virtual college will be significantly affected by inherent task properties such as the type of task, the type of information to be shared, and the type of communication devices and media used. For example, for a routine task requiring immediate action, an elaborate lateral, peer-to-peer decision or action process may actually reduce task performance measures such as time to task completion and expected errors. A more local, centralized solution may be more beneficial in a routine task. A more complex task such as a gear design for a new machine, on the other hand, may require extensive, multiple rounds of peer-to-peer interaction in addition to external input from outside the peer network for a final solution. These task characteristics can be modeled in relation to the roles played by people in the problem-solving process, and the evolving organizational structure. A mapping of tasks and task characteristics in relationship to organizational structures that emerge for accomplishing the tasks will be a key outcome of the proposed framework.

Conclusions

This paper presents a framework for creating a virtual work portal for solving engineering problems. Using social network modeling methods and analyses, the framework presented in the paper models a virtual, collaborative, global engineering education initiative. Researchers will understand what factors foster, and what factors hinder virtual interaction among engineering educators, students, industry and the local community in which engineering schools function. When local community problems are solved by the engineering community at a global level, students will be able to understand the global and societal impact of their engineering solutions. Research issues in the proposed framework will advance the *science of virtual learning* through virtual collaboration and virtual problem solving.

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