

# Experiencing CORAL: Design and Implementation of Distant Cooperative Learning

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**Abstract**— This paper describes application of information technologies to education, outlines the educational foundations and design strategies of the applications, and addresses related research issues. In this paper, we introduce the CORAL (COoperative Remotely Accessible Learning) system, currently under development at National Chiao Tung University in Taiwan, as an example of how information technologies are being used in science and engineering education.

## I. INTRODUCTION

WITH THE recent rapid advances in information technologies, educational researchers at every level and in every discipline have developed new methods, tools, and environments for instruction. As the Internet, bulletin board systems (BBS's), e-mail, and multimedia have already become parts of most college students' lives nowadays, applying these new information technologies to engineering and science instruction is a great challenge for teachers and researchers.

Although the effectiveness and impact of new information technologies on education are not yet well comprehended and documented, the promises and visions they hold for improving education are exciting. For example, computer-mediated networks provide distance education with a new medium for bringing teachers, students, and learning materials in different locations together. Students at home and in work places can have access to learning materials at any time. Individual students can communicate with their teachers and peers without the relative constraints of having to meet at specific places and times. Students can work on learning materials at their own pace and discuss them with other people when they have questions. In other words, they can learn individually but not alone; they are physically separated but study together through computer networks.

When information technologies are used to construct an interactive learning system, the technical components and pedagogical components should be considered indispensable. Information technology engineers and educators should work closely on constructing these new types of learning systems. Information technologies provide the system framework and

functional blocks upon which learning courseware can be developed. Information technologies help record and analyze students' interaction styles, learning strategies, and learning performance [1]. On the other hand, new instructional design strategies are required to utilize the full capabilities of information technologies. New courses are also needed to determine the extent to which information technologies apply to engineering and science education. In addition, empirically derived information on system functionality, student modeling, user-interface design, and learning outcomes is needed to guide the quantitative and qualitative development of educational applications of information technologies. Without this kind of empirical data, applications will be developed *in vacuo* and will have little or no chance to incorporate the full body of accumulated knowledge.

In this paper, we describe the CORAL system, an innovative application of information technologies to engineering and science education. The CORAL system is a network-based computer-assisted learning (CAL) system that supports cooperative distance learning. In concept and construction, CORAL is intended to integrate four major components:

- 1) an *interactive learning environment* that uses computer networks, multimedia, and the like;
- 2) *educational foundations* upon which to base design, development, and evaluation of the interactive learning environment and the courseware;
- 3) *domain knowledge* that will be built into the courses;
- 4) *research efforts* into applications of information technologies.

## II. INTERACTIVE LEARNING ENVIRONMENT

In this section we first give an overview of the CORAL system and then introduce the information technologies employed in the CORAL system, including computer-mediated networks, hypertext techniques, multimedia presentation, graph-theory-based measurements, and neuro-fuzzy analysis models.

### A. Overview: The CORAL System

The focus of the CORAL system, as indicated by its name, is *distant cooperative learning* based on computer-mediated networks. Students can access courseware via networks at any time and any place; moreover, they can have learning partners with which to discuss problems they encounter and work together toward solutions. Motivation to learn is expected

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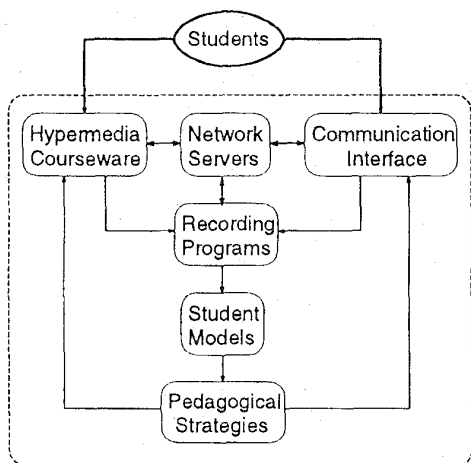


Fig. 1. CORAL: An overview.

to increase significantly in such an environment. And too, teachers can enjoy an excellent instruction management environment, monitoring individual student progress and obstacles to progress and provide assistance when needed. Furthermore, from an educational research standpoint, the information collected on multimedia networks can be used to build an objective and dynamic learning model without interrupting students' learning processes.

The primary goal of this study of the CORAL system was to identify the relationships among student attitudes, aptitudes, performance factors, and learning patterns. The results of this study will be used to construct a database for pedagogical strategies. We have been developing hypermedia courseware on the Internet that can be used for self-paced learning by employing a Netscape-like browser. We accumulate information via learning-behavior recording programs, questionnaires, interviews, and other methods to more thoroughly understand students' learning patterns when using these products. These patterns are then analyzed by using statistical and artificial-intelligence-based methods to develop student models. Section IV provides a more detailed discussion on student modeling. The pedagogical strategies developed will be used to adjust the courseware and discussion interfaces. Fig. 1 illustrates the modules in the CORAL system. Below, we introduce the information technologies employed in it.

### B. Computer-Mediated Networks

We can explore the educational use of computer networks from various angles. From the student point of view, the first role of networks is *course-on-demand servers*. When requested, a courseware database server provides the course units demanded by the students without delay. To deliver multimedia materials in a real-time fashion we need state-of-the-art compression and transmission techniques.

Secondly, from the system designer's viewpoint, computer-mediated networks can be considered *platforms to play back*

*the courseware*. Efficient resource allocation is a primary factor here. Courseware copies should be migrated dynamically via the networks and cached on client machines to achieve optimal presentation. Further, interfaces customized for individual student learning characteristics should also be taken into account when we develop our so-called intelligent learning environment.

Next, in terms of cooperative learning, the networks can be considered *communication tools* that enable students to exchange information among themselves. We incorporated a teleconference-like communication interface in the CORAL system. The interface includes audiovideo windows to show partners and a shared electronic whiteboard over which ideas can be conveyed. In addition to this on-line real-time discussion interface, we provided a shared notebook at each node in the hypertext courseware. This is a BBS-like post window for students to leave questions and comments and to get feedback from others in an off-line manner. Sample screens are shown in Figs. 2 and 3. In summary, the effectiveness and efficiency of multimedia communication were improved in the CORAL system so that the environment encourages students to communicate with each other.

For teachers the networks are *ideal management tools*, enabling them to monitor the individual learning and communication processes of the students. We developed a self-test node for each courseware unit to collect information about students' comprehension. Students can also send messages to the teachers. Existing research indicates that some students are more willing to express themselves in a network environment than in a conventional classroom situation [2].

Finally, computer networks are a *data collection and analysis tool* to conduct educational research. For instance, a recording program was designed into the CORAL system to collect students' behavior in terms of navigation paths through hypermedia courseware. The data accumulated here to accurately describe a hypermedia navigation path include factors such as the visiting sequence of hypertext nodes, the lingering time at each node, and the usage frequency of multimedia resources. Navigation patterns are discussed in more detail later in this section and in Section IV. The collected information, together with other student characteristics, were used to construct learner models. New pedagogical strategies can be developed based on the learner models so that the system can adjust itself to the characteristics of new users. This is a critical step toward realizing a customized learning environment.

### C. Hypertext Techniques

Hypertext techniques are used in the CORAL system to design multimedia courseware accessible through the networks. Hypertext consists of sets of text units connected by links. Information can be accessed with a maximal degree of navigational freedom [3]. In the past, documents could only be read in linear fashion. By contrast, today there are many ways to unfold information for learners.

A hypertext system works like a database that stores knowledge and allows users to retrieve the knowledge by navigating

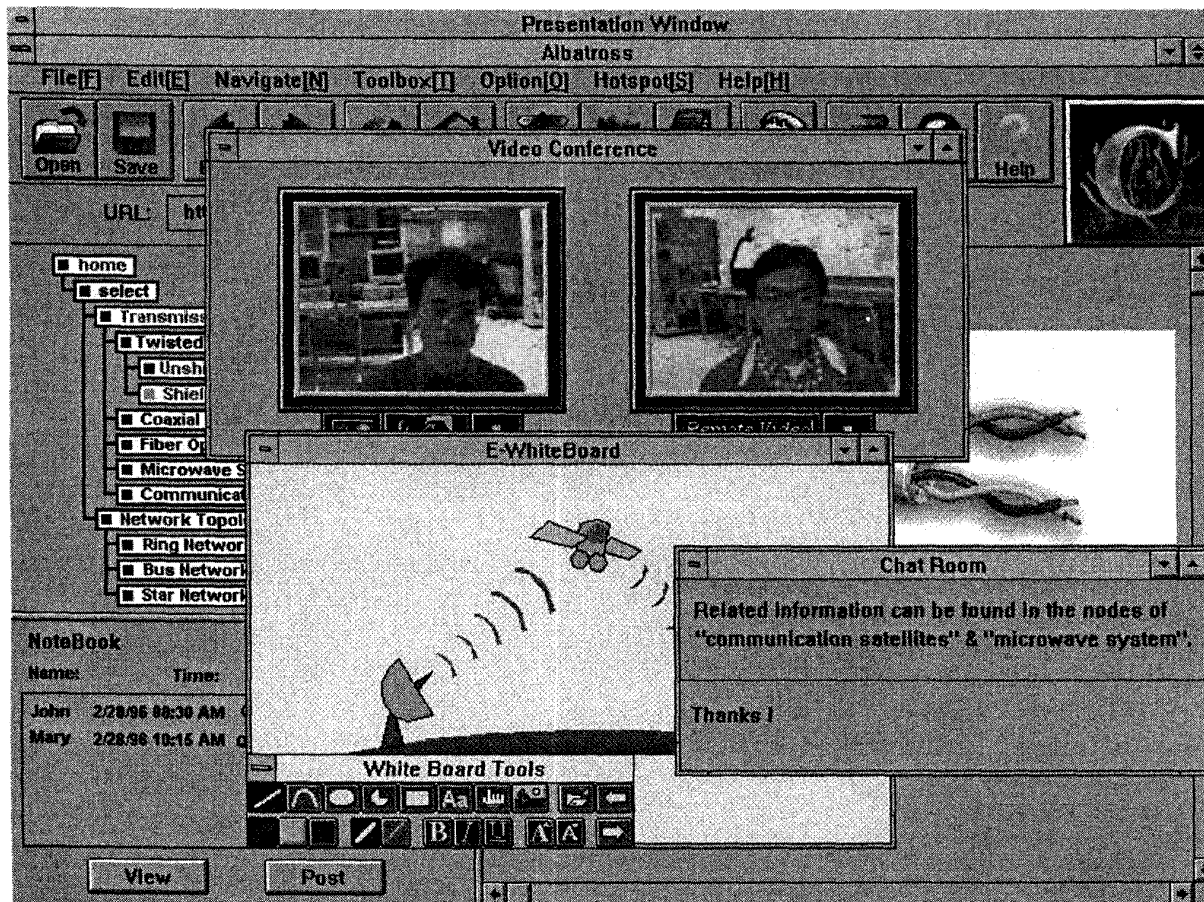


Fig. 2. Sample screen of the CORAL system. It includes a window for multimedia presentation, the talk interface, and a whiteboard.

through *hyperspace*. Usually a hypertext system provides many navigation methods. In addition to the conventional sequential search method, it supports associative links between related topics so that users can conveniently jump to whatever they feel interested in. Since hypertext systems support freedom of choice, many researchers believe they can provide important measures for analyzing learning behavior [4]. We focused on quantitative analysis of navigation paths.

#### D. Multimedia Presentation

Multimedia is defined as any combination of text, graphics, sound, animation, and video delivered by computer. A system that allows users to control what multimedia elements are delivered and when they are delivered and also provides a structure of linked elements through which the user can navigate is called hypermedia. Course contents in the CORAL system are presented in multimedia fashion. Multimedia presentations give students more control over learning and encourages them to make fuller use of their sensory capacities. They can use control buttons to play, stop, and pause the multimedia presentation of learning materials. As mentioned above, we also provide a multimedia communication interface that allows students to work together.

#### E. Graph-Theory-Based Measurements

To accomplish an objective model of learning via networks that can dynamically adjust student environments, we needed software to monitor the learning activities on the network. After appropriate interfaces and tools are installed, researchers can observe and record the learning behavior of students on networks. We know very well that each student has a unique way of reading and studying hypertext courseware. Consequently, *degrees of (non)linearity* among different students should vary. The concept of degree of linearity was the subject of previous studies, such as [5].

Note that a hypermedia system is generally a directed graph (a *digraph*). Navigation patterns thus become directed paths in the digraph. Since each node can be labeled with a symbol, directed paths can be represented as strings. The similarity between two navigation patterns is thus reduced to the similarity between two strings. The longest common subsequence between two strings can then be applied to evaluate the degree of similarity. We proposed a computational definition of degree of nonlinearity, called *Hyper Degree*, and then provided a method for computing it using the longest common subsequence (LCS) algorithm [6]. Based on this concept, we can define other metric or nonmetric measures between pairs of navigation paths. The primary advantage of

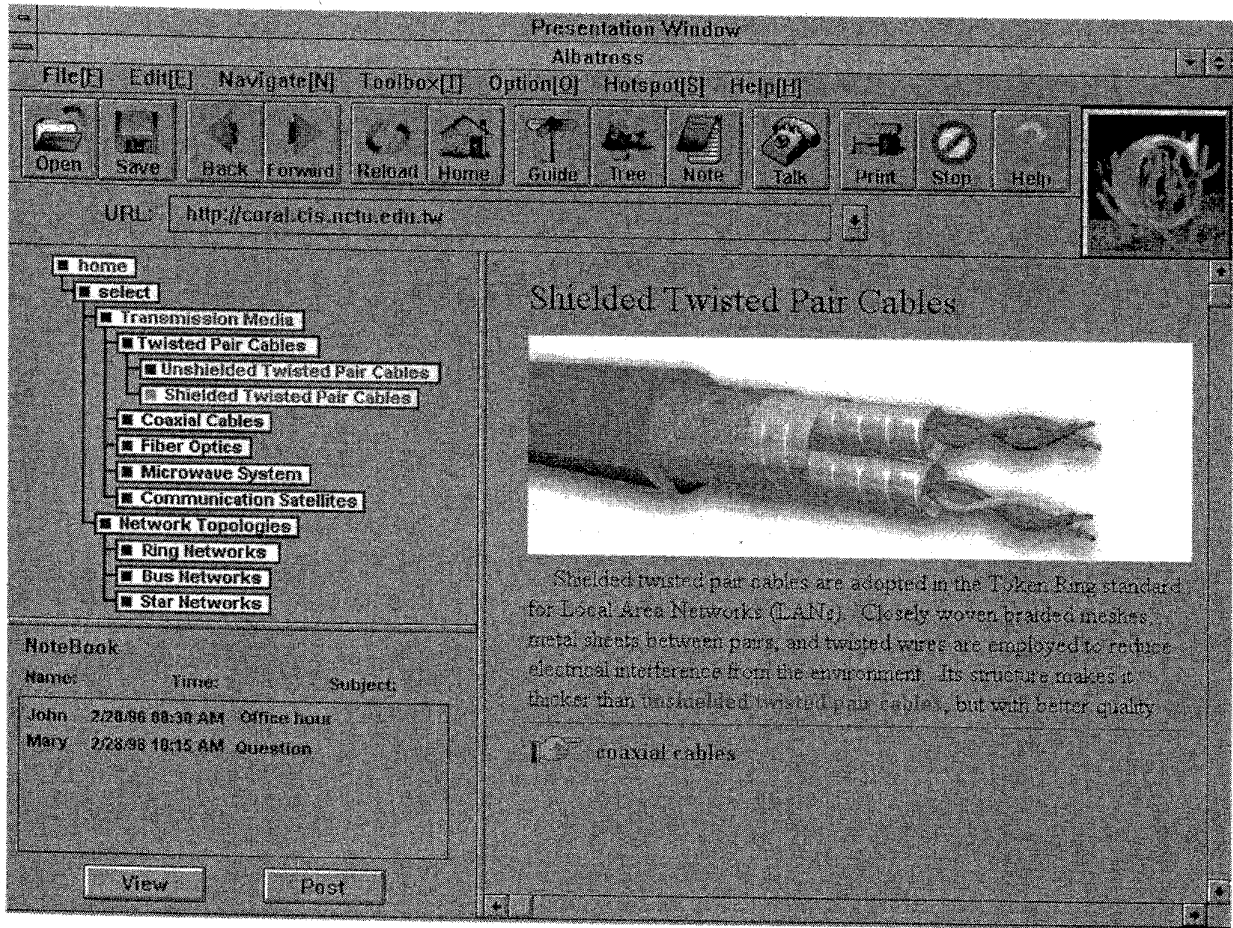


Fig. 3. Sample screen of the CORAL system. It includes a window for course presentation, a tree-like overview map, and the post.

these measures is that hypermedia modeling problems can be formulated as proximity or clustering problems.

#### F. Neuro-Fuzzy Analysis Models

Digital information collected by the recording software was used for student model construction and learning environment control. We used fuzzy theory and neural networks to build student models. Generally speaking, no matter which attributes were chosen, there was a certain method for grouping users, i.e., students, into categories. We believe that introducing the concept of fuzziness was important in learning-pattern analysis because most student groupings are fuzzy in nature. In many pedagogical studies it is desirable to associate navigation patterns with other measures of learning behavior. This is where *fuzzy classification* [7] demonstrates its strength. A fuzzy classifier considers the boundary between two neighboring classes a continuous, overlapping area within which patterns have partial membership in both classes. This viewpoint not only reflects the reality of many educational applications, but also provides a simple representation of potentially complex cause-effect relationships.

We also wanted the system to have the ability to learn and to update and fine-tune itself based on new information. Re-

cently, researchers have been trying to automate the classifier construction process based on training data sets. We proposed a method for using neural networks to accomplish this task. The model could first fuzzify important pattern attributes so that the fuzziness inherent in human behavior could be properly handled. We employed a neural network to complete the task of association. The architecture of the proposed model is shown in Fig. 4. For more details about this model, see [8] and [9].

Consequently, the fuzzy classifier mentioned above is implemented as a neural network so that mapping can be automatically achieved between the student profile (including information such as attitude, aptitude, and performance) and the student's navigation patterns. In general, neural networks allow many attributes (traits, features) to be analyzed simultaneously, thereby allowing more complex and subtle interactions among input attributes to be automatically identified.

### III. EDUCATIONAL FOUNDATIONS AND DESIGN STRATEGIES

This section describes the educational foundations for using information technologies in education, including distance education, cooperative learning, and constructivism. Design

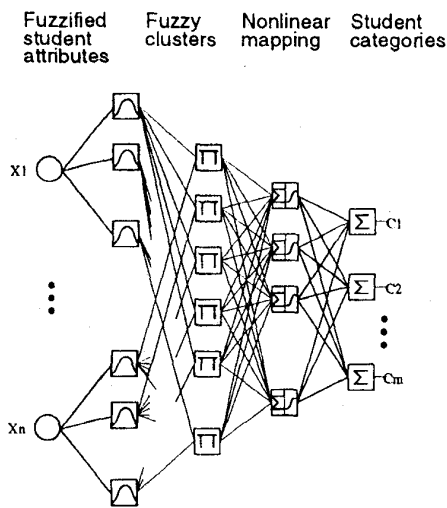


Fig. 4. Neuro-fuzzy architecture for student modeling.

strategies for the CORAL system based on these foundations are provided. The final part of this section outlines the instructional design for the course entitled Basic Computer Concepts (BCC's).

#### A. Distance Education

Distance education has a long history of development under a variety of names and theories. The basic idea of distance education is *teachers are apart from learners* [10], [11]. Garrison [12] categorized the information technologies and media employed in distance education. The first generation is represented by printed mail; the second by broadcasting that delivers analog audio and visual messages; and the third by the use of microcomputers to deliver instructional materials in digital form. We consider computer-mediated networks to be the fourth generation of technology used in distance education.

The major difference between microcomputers and computer-mediated networks is the possibility of having on-line, real-time interactions among teachers, between teachers and students, and among students. The first two generations of technologies used for distance education, printed mail and broadcasting, were basically one-way communications. Teachers needed to make special arrangements and efforts to receive feedback from students. Students had almost no way to communicate with other students using these kinds of technologies. Microcomputers provide chances for students to work more interactively with learning materials, but not with teachers or peers. With the rapid development of computer network techniques, on-line and real-time interactions make it possible for even solitary learners to work together in distance education.

One of the major design issues in distance education is how to motivate students to learn not only actively, but also interactively. Moore [13] pointed out three types of interaction in distance education: 1) the interaction between learners and learning content; 2) the interaction between learners and teachers; and 3) the interaction between learners and learners.

In order to promote all these types of interaction, design considerations for the CORAL system included the following:

- 1) providing students a *course overview* before each course. This ensures that students choose the right course at the right level at the beginning of their learning journey;
- 2) providing *self-test question(s)* at the end of each instructional node so students have a chance to reflect upon what they have just learned;
- 3) providing students with *multimedia presentations* of the content and user control buttons to manipulate the presentations;
- 4) providing a *post window* so that both teachers and students can leave messages such as assignments, meeting hours, questions, and responses;
- 5) providing students *audiovisual windows* to communicate with their teachers and other students. When a student requests the *talk* function from the menu bar, the system shows a list of all students in the same course who are on-line at the time. Students can form discussion groups by arranging conferences or by breaking in on in-progress conversations. After the discussion group is formed, students see other students' faces and hear their voices through the window while they are talking with each other;
- 6) providing students an *electronic whiteboard* to exchange information on-line. The whiteboard is juxtaposed with the audiovideo presentations so students can use it to type, draw, and paint. It is especially useful for presenting visual information such as mathematic formulas, graphs, and programming flowcharts.

#### B. Cooperative Learning

Johnson and Johnson [14] pointed out three types of *goal structures* that affect the ways in which students interact with each other and the teachers: 1) individual; 2) competitive; and 3) cooperative. In the past, computer-assisted instruction was applauded for its branching and management capacities that allow instruction to be adapted to meet individual learner's needs and learning styles. We consider that computer network-based learning not only preserves the advantage of providing individualized learning, but also supports competitive and cooperative learning.

When reviewing many research studies on cooperative learning, we found that the words *cooperation* and *collaboration* are sometimes used interchangeably but need to be distinguished here. According to the definitions provided by Chan *et al.* [15, p. 194], cooperation is "an activity in which each person is responsible for a portion of the problem solving," versus collaboration, which is "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem." We argue that computer network-based learning, such as that provided by the CORAL system, can be used for cooperative and collaborative learning, depending on how the system is designed and the task to be learned.

Many research studies have documented the effectiveness of cooperative learning in the classroom, e.g., [16]–[18], and its

problems such as the free-rider effects, e.g., [17], [19]. Some of the results from these studies and design strategies derived from empirical data may serve as a basis for constructing an interactive cooperative/collaborative learning system. For example, Adams and Hamm [16] suggested a group size of three or four is appropriate for solving mathematical problems cooperatively. Slavin [20] stated that clear group goals and conscience self-accountability among students are necessary for the success of cooperative learning.

The CORAL system was designed primarily to encourage cooperative and collaborative learning. To accomplish this, the system had to incorporate functions that facilitate communication and learning tasks arranged for cooperative work. Otherwise, students would be unable or unlikely to learn individually in conjunction with other students. Accordingly, we designed certain features into the CORAL system that promote cooperative and collaborative learning.

- 1) *Audiovideo windows*. These windows convey both verbal messages, such as voice, and nonverbal messages, such as facial expressions. Thus, they help increase the social presence of the system, that is, the degree to which the system permits users to experience others as if they are face to face [21].
- 2) *Private notebooks* and *shared notebooks*. The private notebook at each node can be used as a *bookmark* or a *footnote* by individual students. Each student can write down opinions or comments associated with that node. The information stored in private notebooks is saved in the client machines and can only be retrieved by the student who wrote it. The shared notebooks, on the other hand, serve as BBS's. The information stored in the shared notebooks is saved in the server machines. Every student who works on a particular node can read or post remarks to its shared notebooks.
- 3) A requirement that students form teams of two or three to do group projects, such as programming tasks.
- 4) In the future, a *student tutor* system, as suggested by Hiltz [2] will be included in the CORAL system. Since the CORAL system keeps track of each student's progress, by recording the number of nodes visited, the number of projects done, and examination scores, it can assign advanced students to help slower students. Students who help others will get extra credits in the CORAL system.

### C. Constructivism

Constructivism is a relatively new educational paradigm after the paradigms of behaviorism and cognitive theory. It has attracted the attention of educators in every discipline, especially those in science education. One reason constructivism is gradually gaining attention is that the recent advances in hypertext techniques support the basic ideas and claims of constructivism.

At the extreme philosophical level, constructivism denies that knowledge is an identifiable entity that can be transferred from one person, such as from a teacher to another person, say, a student [22]. Constructivism claims that students construct, or at least interpret, the reality or the body of knowledge based

on their experiences. This gives students more responsibility for deciding what to learn and how to learn it. The function of the teacher or instructional system is thus to support what the student decides to do [23]. In the constructivist view, an interactive learning system based on information technologies should support multiple perspectives or interpretations of reality, knowledge construction, and experience-based learning activities [22].

Although constructivism has become an increasingly important paradigm for education, it still remains a school of philosophy and needs further definition. Too few concrete design strategies from constructivism are available for teachers and designers to construct interactive learning systems based on information technologies. We tried to design the CORAL learning system along constructivist lines by incorporating these basic ideas.

- 1) Make courseware learning materials as rich as possible.
- 2) Give students authentic tasks on which to practice, for example, building a LAN system in their computer lab.
- 3) Encourage students to provide different solutions to given problems, for example, brainstorming innovative methods for preventing computer viruses.
- 4) Encourage students to navigate through instructional nodes and construct their own learning paths.
- 5) Encourage students to interpret new learning situations based on their existing knowledge and experiences.
- 6) Encourage students to discuss, debate, and work cooperatively.

### D. Instructional Design

A prototype course on BCC's was developed for the CORAL system. The specific learning unit on the computer network was complete and used as a supplement to, not a replacement for, a freshman BCC course. The design and development of the prototype course adopted the Instructional Systems Development (ISD) approach [24], [25] to prescribing optimal learning performance. This approach suggests the following steps:

- 1) Goal statement. Upon completion, students will have the basic concepts of the computer networks, such as architectures, protocols, etc.
- 2) Learner analysis. To our target learners—noncomputer science major freshmen—a questionnaire was disseminated to collect demographic data and entry behaviors. The questionnaire indicated that most of the learners had just graduated from high schools and had little knowledge of computer networks. Some had heard of BBS's or the Internet. Most of the learners indicated little or no experience in cooperative learning.
- 3) Content analysis. Basic topics in computer networks are specified, including hardware, software, data transfer techniques, protocols, applications, security, management, maintenance, etc.
- 4) Course development. We used the elaboration theory of instruction [26] to deal with our subject matter. The elaboration theory prescribes that instruction starts with a special kind of overview that introduces a few

general, simple, fundamental ideas. The reminder of the instruction presents progressively more detailed or complex ideas that elaborate on previous ones. This is similar to the *overview node* for hypertext writing suggested in [27]. In the overview node, each subtopic is a *hotkey* or an *anchor* built into the text. In the CORAL system, for example, an overview on computer network applications is presented in one node. Subtopics like office automation, BBS, file transfer protocol (FTP), and gopher are colored hotkeys in the text. The overview node gives each subtopic only a very brief description of each subtopic. After reading the content of an overview node, students can click on any hotkey to jump to another node for more details.

- 5) Evaluation. The course content was evaluated by an expert and 42 learners. The expert is an experienced computer science instructor who has been teaching computer networks for years. The expert checked the scope and correctness of the course. The target learners, on the other hand, were tested for misconceptions and ambiguous knowledge. The course was then revised according to the evaluation results. In the following section, we address the general concern of assessing a learning environment in more detail.

#### IV. RESEARCH ISSUES

We now describe issues we identified during the development of the CORAL project and briefly discuss them. These issues must be addressed before an intelligent distant cooperative learning environment can be established. The key issues include assessment of the learning environment, student modeling, interaction style, hypermedia navigation, aptitude treatment interaction, and new courseware content.

##### A. Assessment of the Learning Environment

To evaluate a distant cooperative learning environment, we need new tools as well as new standards. We have finished a hypermedia course on Basic Computer Concepts and have conducted a pilot experiment on the CORAL system. The assessment of the learning environment can be divided into two parts: *formative evaluation* and *summative evaluation*. Designers of educational technology use formative evaluation to define and refine their goals and methods *during* the design process. They use summative evaluation to determine whether a finished educational product is effective *after* it has been built [28]. Since the CORAL system was still under development, we focused on formative evaluation. In the meantime, we provided tools to collect information for summative evaluation in the near future.

For formative evaluation, we observed the navigation processes of three domain experts and 39 beginners. Questionnaires were given to these subjects to collect their opinions on the prototype system. We also used computer-recorded data to analyze the accessibility of each course unit. Based on the results of this process we identified a number of functions that could be improved and assembled a list of desirable features suggested by the students. In general, each item in interface

and courseware design should be evaluated in order to make the new learning environment consistent and complete.

In terms of summative evaluation, comparisons between the CORAL system and traditional learning environments are, without doubt, a most interesting research topic. As suggested by previous research, e.g., in [2], however, performance indices such as exam scores may not be comparable because too many factors differ between traditional classrooms and network-based hyperspace. Consequently, we concentrated on the analysis of learners' behavior and the connection between behavior and outcomes by embedding self-testing and exam nodes in the courseware. Learners will be clustered according to their behavior attributes, in navigation and communication, and the correlation between the clusters and the outcomes will be identified. Based on the results from this approach and other relatively conventional methods, we expect to be able to clarify the advantages of distant cooperative learning and how they vary with presentation techniques, interaction styles, courseware contents, and student characteristics.

##### B. Student Modeling

Instructional studies should focus on students. Thus, student modeling is an indispensable component of any computer-assisted learning system. When we enhance conventional computer-assisted learning systems by giving them hypermedia capacities supported by modern networking technologies, the importance and complexity of student modeling increase accordingly. Traditional topics, such as cognitive models, communication models, motivation, and learner expectations, to name just a few, have to be studied from brand-new angles. In addition, new phenomena, such as information overload and getting lost in the hyperspace, should receive close attention. We should keep in mind that a student in a network-based hypermedia learning environment is not only a courseware learner, but also a system user.

As indicated by Self [29], a successful student model should enable an intelligent computer-assisted learning system to answer questions such as "What can students do?" "What do they know about?" "What type of students are they?" and "What do they do during the learning process?" He described a student model as a four-tuple  $(P, C, T, H)$ , where  $P$  stands for procedural knowledge,  $C$  for conceptual knowledge,  $T$  for individual traits, and  $H$  for learning history. He introduced 20 functions of a student model divided into six categories: *corrective*, *elaborative*, *strategic*, *diagnostic*, *predictive*, and *evaluative*.

The participants in the CORAL project have been constructing student models in separate ways: *quantitative* and *qualitative*. Since knowledge stored in a hyperspace is *modular* (each unit represents a node) and *structured* (units are connected by links), the overall learning processes of students should be modeled based on *constructive epistemology*. Navigation paths can be viewed as ways of constructing knowledge. Thus, common patterns in the paths are considered types of learning at a behavioral level. In the CORAL project, qualitative analyzes results reflect these patterns, thereby allowing us to identify what student characteristics are implied by given navigational patterns. We believe that this information provides valuable

insight and a vital supplement to existing student-modeling dimensions in the *intermediate states* proposed by VanLehn [30]. In the near future, we will extend the scope of student modeling from *navigation* in educational hypermedia to *constructing* educational hypermedia, particularly in a cooperative manner. We believe that *learning by constructing* is a highly promising pedagogical strategy for a network-based learning environment such as CORAL.

### C. Interaction Style

Interaction is a key factor in computer-assisted learning systems. Interaction styles can be explored in two directions in a computer-mediated-network learning environment: from the *human-computer* direction and from the *human-human* via network direction. Interaction should be studied in a social and technical context. No matter what type of interaction we have in mind, one critical question to ask, as indicated by Miller [31], is "What conceptual models are offered by the underlying system?"

Human-computer interaction has been thoroughly discussed in many instructional technology areas, such as *instructional multimedia* and *situated learning*. On the other hand, human-human interaction has been the focus of *cooperative* and *collaborative learning*. Here, we are still discussing the interaction issues within the CORAL framework. Since the human-computer interaction is largely constrained by the Netscape-like browser we employed, we focused on inter-personal communication.

### D. Hypermedia Navigation

A fundamental question for evaluating a tutoring system is "What is the relationship between the system architecture and student behavior?" Since the CORAL system is based on a hypermedia architecture, the study of learners' behavior, i.e., navigation through hyperspace, becomes very important. With built-in recording functions, we were able to collect hypermedia navigation information about users. In general, the purpose of monitoring and analysis of hypermedia navigation is twofold: 1) to answer substantial questions about how students use the courseware in terms of routes and methods of navigation; and 2) to illustrate systematic use of the monitoring and analysis tools from collections of raw data in the form of time-stamped protocols. Together, the results can shed light on substantial theoretical and pragmatic issues [1].

A navigation path can be decomposed into at least two components: the *navigation sequence* and the *linger time* at each hypermedia unit (node). Because each student has a unique learning order and duration in visiting nodes in a hypermedia system, we took them as important measures. In this project we also adopted measurements of multimedia resources, such as how many times a function is applied, to understand what functions students prefer to use.

The task of defining similarities among navigation patterns plays an important role in understanding the hypermedia learning process. Several researchers have discussed such problems, but (dis)similarities between students' navigation patterns were not quantitatively defined. As mentioned before, since a hypermedia course can be represented by a directed

graph and a navigation path can be represented by a visiting sequence on the graph, we defined several quantitative measurements based on graph theory. Other pattern-matching techniques may also play a role in the future.

Providing good navigation guidance has also become an important research area because of the massive amount of information on networks. Designers of navigation guides for educational purposes should take more factors into consideration than those who design simple information retrieval guides. For example, an indicator of the percentage of already-visited courseware nodes and a map that leads students to where they should visit next are essential tools for guaranteeing the completeness of learning.

### E. Aptitude Treatment Interaction

The motivation behind aptitude treatment interaction (ATI) is that students with different aptitudes should be given different tutoring, interaction mechanisms, and courseware content. In traditional classrooms, this goal is difficult to achieve because of limited resources. By contrast, it is possible to specially tailor courseware contents and presentation interfaces for students in a tutoring system like CORAL. For example, students whose perceptual style is more visually oriented may prefer graphic presentations, tables, and charts, while students who are more acoustically oriented may prefer narrations and earcons. Students with different cognitive styles (e.g., field dependent or field independent) may benefit from different hypermedia structures (e.g., rigidly structured or loosely structured). Based on results of the student modeling and interaction style analyzes discussed above, ATI shows promise for computer network-based instructional study.

After student models based on navigation patterns are constructed, new students who show similar patterns can benefit from accumulated experience. In other words, dynamic pedagogical planning becomes possible.

We used a fuzzy neural network to achieve a mapping between the student profile, including information such as attitude, aptitude, and performance, and student behavior in terms of navigation patterns. In general, neural networks allow many attributes (traits, features) to be analyzed at the same time, thus more complex and subtle interactions among input attributes can be automatically identified. Conventional statistical methods usually make many assumptions about the data; by contrast, a neural network can be considered a *nonparametric* tool because we do not need *a priori* knowledge about its internal parameters. Since they are represented by weights, they can be identified via a learning algorithm.

### F. New Courseware Contents

An abundant and interesting courseware database is indispensable for the success of a computer network-based environment. In addition to the course on BCC's we have been developing, we provided a courseware development environment for faculty members at National Chiao Tung University (NCTU) to construct new courses, including Calculus, VHDL Digital Systems, etc. We expect this new approach to



teaching and learning to have a profound impact on science and engineering education.

New pedagogues should be taken into meaningful account when we design new courses so that the advantages of distant cooperative learning can be fully exploited. In the CORAL project, we pinpointed one aspect: *active learning*. The importance of active learning, i.e., encouraging students' engagement and participation, has long been known. Realization of this concept suffers, however, from limited expression and communication channels, and, sometimes, from perceived challenges to tutors' authorities. Network-based environments encourage students to express themselves to teachers as well as to peers. Courseware designers should stimulate participation by using pedagogical techniques such as role playing and collaborative writing.

#### V. CONCLUDING REMARKS

The CORAL system is being developed at NCTU, in northern Taiwan, with ten faculty members and more than 30 graduate students involved. Supported by the National Science Council (NSC) of Taiwan, the CORAL system is in its first three-year funding period. Distance education is one of the pilot applications under the Taiwan National Information Infrastructure (NII) project. The CORAL system is considered a leading project in distance education in Taiwan, and it will be one of the first systems implemented on the testbed.

To read the CORAL courseware, a student uses a standard personal computer that is accessible to the Internet. The browser software, used by the student to navigate in the hypermedia courses, is available via network. The software copyright has already been transferred from NCTU to NSC. The standard personal computer is powerful enough for most communication tools, except the audiovideo windows. Extra equipment, such as a camera, microphone, speaker, sound card, image card, and high-speed network card, is needed to support the audiovideo windows. Since the CORAL system adopts a modular design policy, however, students can use the basic functions via a standard personal computer and learn cooperatively.

The above discussions show that various information technologies have already been applied to engineering and science education. We believe that the use of information technologies will encourage development of even newer methods, tools, and environments for instruction and learning. The promises they provide are exciting and their expected impacts on engineering and science education will be immense. Furthermore, information technologies bring us new perspectives for research, not only on the technologies themselves, but also on the philosophy, strategies, and tactics of instruction and learning. We expect that more research will be conducted on the application, and more interactive learning systems like CORAL will be developed to benefit our science and engineering students.

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