

# 行政院國家科學委員會補助專題研究計畫成果報告

## 網路合作設計科學活動之環境、學習、與評估 子計劃一：網路小組設計與同儕評量學習之研究

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計畫主持人：孫春在 國立交通大學資訊科學研究所

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# 行政院國家科學委員會專題研究計畫成果報告

## 網路合作設計科學活動之環境、學習、與評估

### 子計劃一：網路小組設計與同儕評量學習之研究

#### Network-based Cooperative Design: Environment, Learning, and Evaluation

計畫編號：NSC89-2520-S-009-015-

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#### 一、中文摘要

本研究以現有遠距學習環境為基礎，以小組合作設計科學活動為主題，充分發揮網路環境中同步與非同步互動、累積式的概念建構、創造力之激發、設計與學習歷程之記錄等特性，完成網路合作設計環境之學習與評量研究。

設計是一種高層次的概念整合，並且著重創造力的發揮，可以具體實踐由做中學(Learning by Doing)的建構學習策略。設計活動加上小組合作與同儕評量，提供了一種新的遠距學習策略。

**關鍵詞：**合作設計，合作學習，網路學習，V圖，建構主義，社會會見購，思考風格，分組

#### Abstract

Based on theories of Social Constructivism, we employ a learning strategy in the network era, cooperative design, to realize learning through design on the domain of computer science. Consequently, the Vee heuristic proposed by Novak and Gowin was adopted as the design interface. It is expected through discussion and observation on peers' products, students can investigate the rationale behind a design product, to examine the connection between theories and observable events, and to modify their designs accordingly. A learning environment, the CORAL-View system was

developed and formative and summative evaluations were conducted to test and modify its functionality. The environment composed of three major components: an environment for scientific knowledge construction, a learning resource database, and a learner database. Specifically, it contained a team forming module, a structured discussion module, a Vee diagram design module, a log file management module, and other supporting functionality. Starting from focus questions of Vee diagram, 151 students grouped into 50 teams performed design task of Artificial Intelligence collaboratively. The evaluation results of student achievement and subjective perception toward the environment and network-based collaborative design process were both encouraging. Students produced creative and feasible design products using the system and regarded functions of CORAL-View were satisfactory.

**Keywords:** Collaborative Design, Cooperative Learning, Web Learning, Vee Diagram, Constructivism, Social Constructivism, Thinking Styles, Team Forming

#### I. Introduction

Without proper learning strategies and compatible pedagogical activities, the effect of network-based learning will be severely limited because the advantage resulted from

the flexibility of distance learning is generally negated by monotonic web courseware and unfocused on-line discussion. Therefore, innovative learning strategies tailored for network-based learning environments have recently been receiving more attention by researchers, such as Sun & Chou [1] and Thach & Murphy [2].

This study develops and evaluates a network-based environment that enables science and engineering undergraduates to learn by designing collaboratively. From a learning perspective, design involves conceptual changes and knowledge construction that emphasizes creativity and promotes higher order thinking. Furthermore, cooperative (or collaborative) design promotes brainstorming and cooperation between team members, thus increases the potential of stimulating imaginations, eliminating prejudice, building consensus, and actively making knowledge. Such a learning strategy is in concordance with two learning theories, cooperative learning [3] [4] and the Constructivism [5][6]. Moreover, most of the advanced engineering jobs in the business world today are performed as a team. Therefore, involving a major working style of future employment in university learning is meaningful and practical for students.

To implement collaborative design for college learning, some appropriate tools, design interfaces, courseware, partner recommendation process, and learning activities were developed. The Cooperative Remote Access Learning-View System (CORAL-View) that resulted was composed of three major components: an environment for scientific knowledge construction, a learning resource database, and a learner database. Then this CORAL-View virtual scientific learning center was formally evaluated herein to examine its usability, to verify collaborative design as an effective Web-based learning strategy, and to test the team recommendation procedure.

## II. Survey of Related Work

This section reviews previous research to further identify necessary characteristics of network-based learning environments and to

allocate the proposed learning system. Past research about network-based learning environments towards cooperative learning, cooperative learning and Social Constructivism, collaborative design as a network-based learning strategy, and Vee diagrams as design aide are reviewed. Related learning systems and strategies are also surveyed to compare them with the proposed model.

### **Network-based Learning Environment toward Cooperative Learning**

Interactive distance learning via the Internet has been receiving increasing attention with the rapid development of computers and networking. Investigations of the interactions between learners and systems have primarily focused on user access to multimedia instructional resources, the artificial-intelligence-based diagnosis of learning processes, on-line testing and remedy. However, these studies have not attended to the interactions between the learners and the teachers as well as those between the learners themselves. More than merely an enormous database of learning materials, the Internet is a medium on which learning communities can be formed to achieve mutual and continuous learning. Consequently, learner interactions in the form of goal-sharing communication toward a task-sharing collaborative design are emphasized from an instructional technology viewpoint.

Johnson & Johnson [3] and Slavin [4] among others have outlined effective cooperative learning principles as follows:

1. Positive interdependence among partners.
2. Promoting partners' interaction.
3. Individual accountability for learning the assigned material.
4. Training for collaborative skills.
5. Providing group rewards.

About the learning effect of cooperative learning, previous studies have proved that cooperative learning helps students gain basic skills, higher level thinking abilities (e.g., critical thinking), as well as highly valued prosocial behaviors and equity in the classroom [7] [8]. Past research has

confirmed that the manner in which a group is formed may also influence the learning effect in cooperative learning [7]. Some of the group member's characteristics that are closely related to learning and interaction include the following: help behaviors, ability, gender, personality, and socioeconomic status.

1. Help behaviors: Webb [9] found that students are more willing to assist each other in the cooperative learning process. There are three levels of information that are exchanged during mutual assistance: explanation, terminal help (e.g., the final answer of a question), and surface information. Members in a group tend to learn more when they ask for an explanation as opposed to terminal help or surface information.

2. Ability: More capable learners are more likely to offer explanative assistance. Therefore, an effective cooperative learning group includes both high and low ability people. Past studies found members in an all-high-ability group or an all-low-ability group often ask for terminal help and surface information. Moreover, members in an all-low-ability group actually hesitated to ask for any help.

3. Gender: There must be an equal number of boys and girls in the group to ensure everyone will receive enough assistance. If the genders are not balanced, boys normally obtain more assistance or are left with all of the problems when girls outnumber boys in a group.

4. Personality and socioeconomic status: Extroverted students can attain more explanative assistance than introverted students. Students with a higher social status are more active and thus gain more power in the group interaction.

Notably, putting learners into project groups does not necessarily entail collaboration. Slavin [4] confirmed that learning effects of the members would not improve as expected if the learning situation is not properly designed. One major drawback is the so called hitchhiker phenomenon: the ones with better domain knowledge or those who are more willing to express themselves typically

perform the larger share of the work while others just sit back to share the credit. The lack of understanding about others' work is also largely limited by this kind of teamwork.

Damon & Phelps [10] discovered that measuring the quality of the interaction between members could help differentiate cooperative learning from other methods of teamwork-based learning. Equality and mutuality are the main indicators for this measurement. The team members are more equal and begin to make equal contributions when they realize that each one has the same status in terms of abilities and resources. Learners are more willing to interact with peers, the information flow is more bi-directional, and the learning atmosphere becomes more friendly and open under such condition. Each learner feels more support from their peers and they are more interested to know about each other's work so as to achieve a better team product when they share ideas and resources.

Hooper [11] ascertained that a collaborative task structure is critical for team-based cooperative learning. Moreover, an incentive structure and a shared motive for the team members are also indispensable for encouraging collaborative behavior in a learning group. Mutuality is enhanced through various collaborative activities and positive interdependence is thus achieved. In this study, a team member recommendation module to select students in forming a productive team for collaborative design is developed herein based on the literature review above.

### **Cooperative Learning and Social Constructivism**

Social Constructivism has recently postulated learning and instructional principles similar to those of cooperative learning but with some novel perspectives. The Social Constructivists (e.g., Vygotsky [12]) argued that knowledge is constructed not only within a person's mind but also through social interaction in which people share (through mutual help or questioning) their ideas and thus reconstruct or modify old knowledge. They emphasized that authentic achievement may be gained through an

authentic learning environment where learners experience confusion and struggle exactly the same as in the real problem solving process among scientists [6]. Thus, the teachers' job is to create authentic environments for knowledge construction. Some elements of an authentic environment as suggested by Roth [6] are:

1. The learners experience acceptance of a learning group, as real scientists never solve problems without sharing professional knowledge and resources with colleagues.
2. The tasks for learners to solve need some degree of confusion and chaos as those real problems scientists try to solve.
3. The learners should have many chances to consult more knowledgeable persons.
4. The teachers are not authoritarian figures, but act more like knowledgeable old-timers who facilitate appropriate community-specific practices for the newcomers (students).

Resnick [5] proposed Distributed Constructivism and suggested two types of knowledge construction. First, learning as an active process in which the learners build up knowledge based on their experiences. Restated, learners make ideas instead of obtaining them from the teachers. Second, the learners become interested and begin to experience knowledge construction when they are devoted to realize products. Following this line, we choose design as the core learning activity because it links the goals of knowledge construction and learning by doing in a natural way.

Constructivism emphasizes the concept of knowledge as consensus. Distributed Constructionists thus advocate a form of pedagogy in which people participate in design and construction activities by discussing, sharing, and questioning each others' knowledge. In other words, both cognition and intelligence are involved in the interaction between the learner and the environment in which other participants and artifacts play an equally essential role as the learner's perception and conceptualization models. The artifacts, of course, are the products of design.

### **Cooperative Design: A Network-based**

### **Learning Strategy**

Design not only represents the mental practice of high-level concept integration but also realizes learning by doing. Consequently, implementing collaborative design in a network-based environment has demonstrated its potential in many dimensions such as interactive and inter-creative learning.

The styles of high level thinking can be divided into two categories: domain specific and domain general. Design, from this aspect, is usually considered domain specific. Design environments and assistant tools should be constructed to support the thinking process of domain experts since design is normally considered domain specific. Two representative examples are summarized for reference: the Collaborative Visualization (CoVis) system of Northwestern University and the Center for Design Research (CDR) of Stanford University.

The core concept of the CoVis project [13] is collaborative learning based on scientific visualization. Students are assigned collaborative design problems such as how to identify a proper mining site and propose a mining plan so that environment factors are taken serious consideration. Visualization tools are provided for the students to obtain high-level information and knowledge from scientific data banks. For instance, Climate Visualizer, Weather Visualizer, and Greenhouse Effect Visualizer jointly provide a vivid picture of the global environment. Moreover, students' connections to domain experts are built up via the Internet so that they can discuss concepts and methods commonly practiced in the field. The discussion is conducted in a structured framework so that the dialogue between students, teachers, and teaching assistants can be classified into categories such as question, answer, comment, supplement, and conjecture. Learning motivation and effectiveness are both enhanced in this environment.

The CDR [14] has developed courses to combine vital ideas such as computer-assisted design, synchronous design, collaborative engineering, acquisition

and indexing of design knowledge. Students try different tools and workflow and communicate with different domain experts on-line throughout the product design process. Various design and simulation tools are provided as learning by doing is heavily emphasized. The CDR focuses on mechanical design and keeps a close relationship with manufacturers. Industry initiates design projects via the Internet. Students form their design teams and then contact the project proposer on the network to clarify items such as problem definition, design concept, prototype schedule, test, evaluation, specification and budget. This sort of design project is very realistic since it reflects the current needs and wants of the industry.

The network-based design community supported by the above two programs is highly heterogeneous, which is deemed essential for innovation and performance. The students can observe how scientists identify and solve problems, explore state-of-the-art equipment, and perceive the teamwork process in a scientific community because scientists are invited to work with the students in the CoVis network. Industry experts involved in the CDR's projects not only aid the collaborative design but also identify innovative ideas through the discussion process with the students.

Although network-based collaborative design is a general learning strategy, the actual development of learning-through-design systems is domain specific as mentioned above. Design work in computer science was chosen to fulfill the design and learning targets in our science and engineering oriented learning system.

### The Vee Diagram as a Design Aide

We choose the Vee diagram, or Vee heuristic [15], as the theoretical and operational basis of the design aide in the network-based collaborative design system. Novak and Gowin ([15] proposed a Vee diagram as design aide for many scientific and technical design activities based on Constructivism. Their results have shown its effectiveness in helping people connect thinking with designing. Novak and Gowin

discovered that many people jump into a design process without enough knowledge to create an adequate project or to execute a routine design process without knowing why. Sometimes, people with profound knowledge may not select an adequate method to design. The Vee diagram attempts to solve the problems attributed to the disjunction between knowledge and action.

The Vee diagram contains not only explicit essential design factors but also an implicit design process workflow. As depicted in Figure 1, a Vee diagram consists of four components: Focus Questions, Events/Objects, Conceptual Activities, and Methodological Activities.

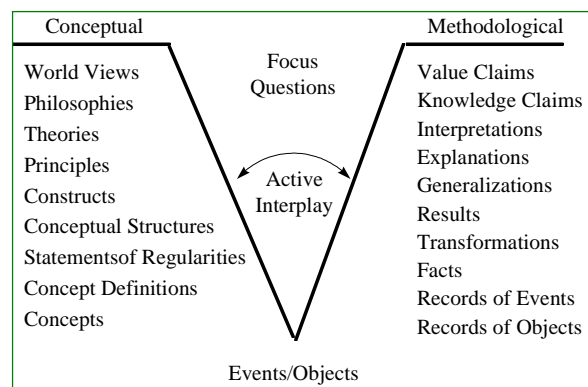


Figure 1. The Vee Heuristic

The Vee diagram reveals that although the meaning of knowledge is derived from events or objects, the recording of events/objects itself does not tell us the meaning and the reasons of the recording. Thus, the reason for choosing to observe and record events/objects as well as the concepts, principles and theories behind this selection must be explicitly known and expressed by the designer. This diagram focuses on building a connection, called an Active Interplay, between conceptual activities and methodological activities. In other words, it seeks to build a linkage between the thinking on the left and the doing on the right.

Novak and Gowin [15] derived concepts from the Constructivist paradigm of science philosophy that originated from Kuhn [16] when constructing the Vee heuristic. Constructivism considers all scientific observations and methods as theory-laden, in other words, every scientific activity is

influenced by current scientific concepts. Thus, the Vee heuristic is a type of metaknowledge (knowledge about knowledge) that can become an effective tool to help students perform metalearning and acquire metaknowledge.

### III. Learning System

After investigating related theories and systems, we developed a learning environment to realize the core concepts mentioned above, mainly a cooperative design environment on the Web. This system is named the CORAL-View (COoperative Remote Access Learning-View System). A formative and a summative evaluation were conducted to analyze the system's usability and the learning effect of Web collaborative design. The CORAL-View as a design interface, the team-forming module, as well as the formative and summative evaluations of the system are all described in this section.

#### **CORAL-View: The Cooperative Design Interface**

The CORAL-View system contains several subsystems described as follows:

1. A Vee-diagram module assist learners to connect knowledge with design procedure thus to learn by design. This module can also provide peer appraisal function to empower learner to evaluate and comment on each others' works.
2. A team-forming module suggests the partition of on-line learning participants.
3. A structured discussion module enables team members to construct, exchange, and compare ideas.
4. A logging file management module permits the instructor to monitor students' learning processes and provide feedback to the students.

Figure 2 depicts the conceptual framework of the CORAL-View system and Figure 3 illustrates the network organization of the system.

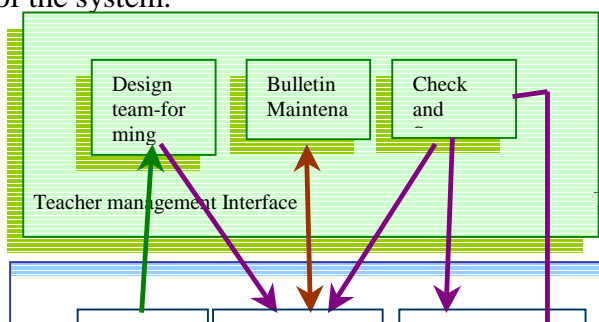


Figure 2: Conceptual framework of Cooperative Remote Access Learning-View (CORAL-V) System.

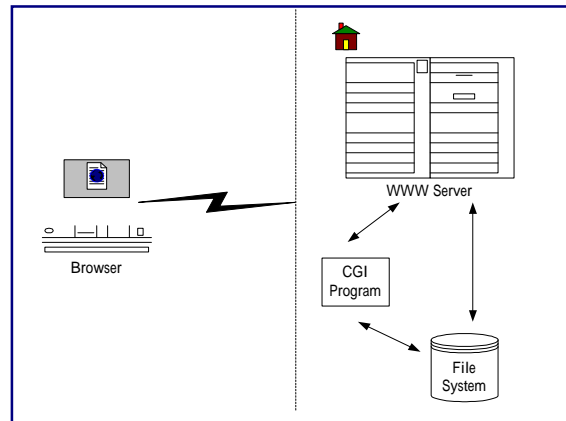


Figure 3: Network organization of Cooperative Remote Access Learning-View (CORAL-V) System

The CORAL-View system is designed to serve as a design aide, a class information distribution channel, a management center for students' project submission, a medium for peer interaction and knowledge construction, and a record storage for knowledge construction procedures to promote cooperative learning and social construction of knowledge. In addition to formal interaction through the CORAL-View system, teachers and students can also post information in a specialized BBS (Bulletin Board System) to express their opinions about the courses and the system.

Figure 4 is the CORAL-View system homepage. The original homepage was in Chinese but it has been translated into English for demonstration purposes. Students must register when they first enter the system. The "Experiment" hyperlink leads to a simulation tool of the Design module that designers can try various designing features in the middle of designing process and "Production" links to show end product in the Design module. Figure 5 depicts the first page of the Design module. "Example" leads to the View module where designers can take a look at peers' tentative works.



Team “Chat Room”, the interactive Structured Discussion module, enables students (within a team) to talk via the WWW, while “BBS” leads to a Bulletin Board System where students can post information that the entire class can access. The CORAL View system can be located at the following Web address: [sandy.cis.nctu.edu.tw/~colearn/page1.html](http://sandy.cis.nctu.edu.tw/~colearn/page1.html). Please note however, that the environment is in Chinese

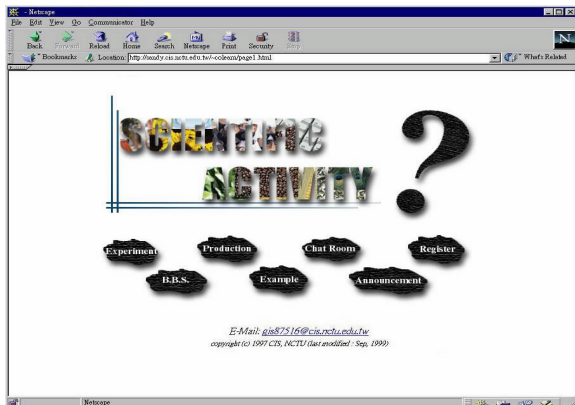


Figure 4: Depicted is the homepage of CORAL-View for the promotion of students’ collaborative design of scientific activities. Web address: [sandy.cis.nctu.edu.tw/~colearn/page1.html](http://sandy.cis.nctu.edu.tw/~colearn/page1.html).

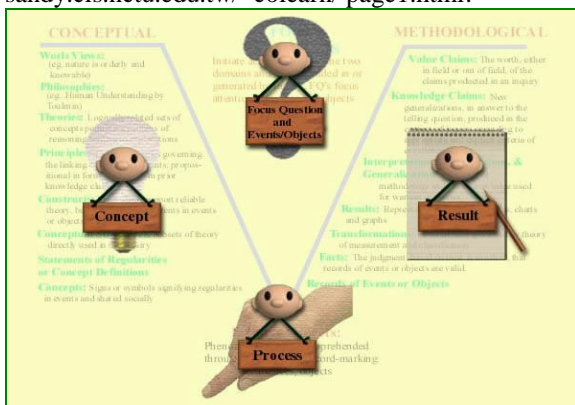


Figure 5: Homepage of Vee diagram for designing scientific activities.

### Team Forming Module

Beside the student design interfaces, the authors intended to embed a team forming recommendation procedure in the CORAL-View system. In doing so, we expected to organize teams that can learn cooperatively and effectively based on the grouping of the partners’ particular features. An artificial intelligence algorithm was designed following the Random Mutation Hill Climbing principle (RMHC) [17] to recommend and select an effective collaborative design team.

Any feature that a project manager seriously considers before forming a productive team may be taken into account as the algorithm input parameter. From the above literature review of cooperative learning done in primary and secondary schools, abilities, gender, personality (e.g. extroverted or introverted), and social status are among the critical features in forming cooperative learning teams. However, the main psychological variables for partner selection of this study are thinking styles [17]. Since it hopes to recommend an effective working team composed of equal-ability young adults within computer science academic fields.

Sternberg [18] defines a person’s preferred thinking styles as the tendencies in which a person uses his or her abilities. A metaphor of mental self-government is used to describe how people govern or organize their thinking and thus indicates a profile of thinking styles in performing mental governing. An individual seems to have a mental government to direct their thinking process when one has to allocate one’s resources, sets up priorities before making a complex decision, or responding to the changing world.

People tend to display three styles of working or thinking rules: legislative, executive, and judicial that are named as the functions of mental governance. Legislative people tend to create flexible working rules and avoid solving problems that need to follow pre-established rules. In contrast, executive people prefer to follow rules and to solve problems by pre-structured rules. Judicial people prefer to evaluate rules and solve problems that require comparing and analyzing multiple ideas. Sternberg [18] suggested Legislative and Executive people can work well together in cooperative learning. Moreover, people may have a different scope of thinking as internal individuals tend to be more introverted, less socially aware, and prefer to work alone, whereas external individuals tend to be extroverted, people-oriented, and prefer to work with people. External people appear to learn better in a cooperative learning



environment.

In our teaming forming algorithm, three students are randomly assigned to form a team and all teams are randomly separated into two groups, resembling and complementary. The differences of five thinking styles among three members in a team were calculated to represent members' features. The function of the algorithm is to change members of teams in order to achieve the goal that summation of member differences of the five thinking styles reaches minimum for teams in the resembling group and maximum for teams in the complementary group. One hundred cases of member-exchange are randomly generated from the initial partition in each iteration. The 100 cases are compared with the original one, and then the optimal case is retained while the others are discarded. This iterative procedure proceeds until the member-exchange produced no difference. Lin & Sun [19] provide a more detailed description and evaluation of the team forming recommendation algorithm.

### III. Evaluation of the Learning System

Assessment of the learning system can be divided into two layers: (a) a formative evaluation to verify the usability of the interfaces and functions provided by the CORAL-View system and the modification that resulted and (b) a summative evaluation consisting of experiments to validate the learning effect of the collaboration design and team forming modules.

#### **Formative Evaluation**

In formative evaluation, six experts, including two professors in computer science, two in computer human interface, one in educational psychology, and one in science education, have served as evaluators before users first use the CORAL-View system. Some comments about the advantages and disadvantages toward the CORAL-View system have been made. Two of the most important comments are briefly described in the below.

1. The initial Vee diagram in Design module just plainly showed titles of the components of Vee diagram as in Figure 1,

e.g. "world views" and "theories" in the left-hand side of conceptual segment, or "value claims" and "records of events" in the right-hand side of methodological segment. Experts suggested that designers may not be familiar with the Vee diagram per se and need more detail explanation about what kind of designing products should be filled in a particular component. Therefore, a modified Vee diagram was resulted with small floating windows to show explanation about the components and thus as a structural guide to aid designers to bring out a more adequate designing product.

2. An on-line psychological questionnaire distributor and data collector was built into CORAL-View system after experts suggested. Initially Thinking Style Inventory-Taiwan version [20] was planned to be distributed as a paper-pencil test. The on-line testing module enables students to fill in psychological questionnaire more flexibly in terms of time and location, ensure privacy while filling in personal information, and the responses were directly transformed into spreadsheet format for a further statistical process. The statistical results from the online testing module were sent as the input parameters of team forming module.

#### **Summative Evaluation**

The summative evaluation of the CORAL-View system was held for 6 weeks at an Artificial Intelligence class in the National Chiao Tung University in 1999. One hundred and fifty one students were involved in the evaluation and grouped into 50 teams with three or four students in one team. The detail process is listed in the following.

1. In the first week, students had to fill in Thinking Style Inventory-Taiwan version online and the team forming recommendation thus was performed.
2. Through the CORAL-View, the teacher announced prescribed team members, posted an ill-structured designing task that promotes true teamwork. And the CORAL-View system was introduced in the class in the second week.
3. Then the students had one week to discuss through Discuss module and BBS to

come out with a proper topic for their designing task.

4. In the fourth week, every team had to upload tentative designing products in the WWW home page format. Most teams handed in survey about the topics or trial-and-errors in the designing process.

5. Every team had to upload a complete design task in Vee diagram format in the fifth week.

6. In the last week, students filled in a questionnaire about their perception toward the CORAL-View system, toward on-line collaborative design as a college learning activity, and preference about their team members.

The results of summative evaluation can be described in terms of student achievement and subjective perception toward the system and learning process and in both aspects the evaluation results are encouraging.

Students' collaborative designing tasks were evaluated in three criteria, a) creativity (variety from other works) of the topic and the product, b) the degree that a design product show learners' understanding about Artificial Intelligence, and c) feasibility of the end product. The three raters were teaching assistants of the class who are doctoral students in computer science. Comparing with the performance in the previous assignment, the average creativity and feasibility scores were higher while understanding was about the same (see Table 1). Thus, it may implies that network-based collaborative design promote creativity and feasibility of a design product while team members' understanding about the course may need other styles of learning, such as reading text and materials, class learning, or even quizzes.

Evaluation Criteria	Mean	SD
Creativity	83.57	8.226
Understanding	79.81	5.761
feasibility	82.14	4.547
Total	81.84	3.458
<b>Previous assignment</b>	79.67	12.987

Table 1: Average achievement for 151 students in network based collaborative design.

Form the results of the questionnaire, student regarded the design task is suitable for the collaborative design process occurring through the WWW (average = 4.12 in a five-point Likert-style scale). Students perceived that the collaborative design process promoted their higher level thinking [21], such as creative thinking (average = 4.01), critical thinking (3.87), monitoring (4.34), and planning (4.25). Besides, students' satisfaction about the Design module (average = 3.97) and Upload procedure (4.35) were both high though some students critiqued about Discussion module and resulted a lower evaluation (3.66); however it is still higher than midpoint of three.

Six eight percent (N = 103) of the 151 students held positive opinion bout their partners recommended by the team forming module while the rest 32% expressed unfavorably. Most complains of partners were about unfamiliarity that makes team discussion fruitless and effort consuming, difficulty in setting up a meeting schedule among partners, and persistent absence of a partner.

#### IV. Concluding Remarks

The achievements of the network learning environment based on a strategy called learning-through-collaborative design are itemized as follows.

##### 1. Learning resource database

(1) We developed learning web sites for college computer science majors that provided courseware, simulation tools, testing and an evaluation environment to support the design process.

(2) Based on the need of the learners and their personal traits, we developed a recommendation system for student team formation. This partition system enables the network-based learning population to be organized in a manner that suits project-oriented teamwork.

(3) The interactive design interface enables learners to easily collect the necessary information for their projects, smoothly describe and share their experience and

innovation, as well as constructively evaluate and comment on others' products. Knowledge construction is effectively achieved in this type of accumulative learning.

## **2. An environment for scientific knowledge construction**

(1) According to the Vee Heuristics, we developed a design interface for college computer science majors to connect knowledge with design action that provided effective guidance for a complete and consistent design flow. Learners may learn through authentic design situation as soon as they log onto this environment.

(2) The basic concept was enhanced with groupware for collaborative design and peer evaluation so that structured knowledge integration can be established at both an individual and a cooperative level.

## **3. Learner database**

(1) Student models were developed under the framework of collaborative design based on the learners profile records.

(2) Diagnostic conclusions on the learners' knowledge construction and feedback were provided based on the observation on the design/communication process between the learners and the evaluation mechanism supported by the Vee Heuristic.

(3) The learner database can also provide necessary and updated information for the team-forming module.

## **4. Network-based learning theories**

(1) The possibility of distributed Constructionism in an Internet-based environment was also explored herein. Cooperative concept construction is a learning strategy worth further exploration. We believe that project-oriented and peer-evaluation-based learning effectively helps knowledge integration, and thus provides focused learning.

(2) The Vee-Heuristic design interface was designed from an information visualization viewpoint. This helped the learners to conceptualize their focus questions, to determine the items for observation, and to design the checkpoints to test the proposed hypotheses. It benefited both the learning design process and their group discussions.

## **5. A virtual scientific learning center**

(1) The on-line simulation tools can be employed to develop network-based design as mentioned above. Consequently, the students can practice learning-by-doing strategies via the Internet.

(2) The ultimate goal of this project is to create a virtual learning center for scientific and technology theories, experiments, and innovation. The results of summative evaluation about the CORAL-View system and team-forming module were both encouraging. The products of collaborative design can be accumulated on the Internet for future use in addition to the learning system described herein and for broader population beyond computer science undergraduates.

Instructional experiments were conducted on the various classes given by the investigators. The experimental results will be reported and discussed in separate papers in the near future. However, several remarks are included herein to highlight the proper environment for learning-through-collaborative-design.

Design represents a concept construction process that involves high-level thinking and communication and plays a critical role in many fields. Students who learn through design show more creativity as well as familiarity with the design procedure itself, which is essential in the industrial world. Students can learn in a more sophisticated and realistic way when they are asked to propose their own focus questions, analyze the observation and testing processes, and evaluate their design quality together. We also believe this innovative approach explores the capacity of interaction embedded in the Internet. Students on the network should not only interact with the learning materials provided by the learning systems, but they should also interact with their peers in a tightly connected manner.

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