Network-based Cooperative Design: Environment, Learning, and Evaluation[1]

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Abstract

In this paper, based on theories of social knowledge construction, we employ an important learning strategy in the network era, *cooperative design*, to realize the concept of *learning through design* on the domain of scientific activity development. We adopt the *Vee heuristic* proposed by Novak and Gowin as the design interface. Through discussion and observation on others' products, students are able to investigate the rationale behind a certain design, to examine the connection between theories and observable events, and to modify their own designs accordingly. We believe that the students can achieve the goals of active and interactive knowledge construction in this learning environment.

This research project includes the development of the proposed learning environment, the planning of design-based learning strategies, the conduction of instructional experiments, the evaluation of learning processes, and the promotion of the learning system. The investigators focus on three inter-related research topics: learning based on group design and peer appraisal, knowledge construction via mutually supported design, and the evaluation of cooperative design environment and collaborative design of scientific activities, respectively.

We have developed the learning environment and conducted pioneering experiments after testing and modifying the functionality of the learning system. The environment includes a student team-forming module, a structured discussion module, a peer appraisal module, a log file management module, and other supporting functionalities. Important interfaces and functions are described in this paper.

The students in the courses given by the investigators were the subjects of the instructional experiments. Based on the focus questions provided by the instructor or generated by the students themselves, they designed scientific activities in a

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collaborative manner by using the Vee diagram supported in the learning environment. We conducted formative evaluation of the developed environment and identified several items for logging. The activities produced were tested for their validity so that a web homepage of scientific activities can be accumulated continuously. Based on the data in log files, we conducted quantitative analysis; further, we observed the behavior of certain individuals and groups for qualitative evaluation.

I. Introduction

The primary purpose of this study is to develop and evaluate a learning strategy based on cooperative design in a network-based environment. From the viewpoint of learning, design provides a form of high-level concept construction, and emphasizes the stimulation and development of creativity. On the other hand, from the angle of assessment, design is a knowledge integration process that incorporates important factors of constructive learning such as concept comprehension, learning by doing, analysis/synthesis, and self-evaluation. As a result, it introduces an approach to assessing learning in a wholesome manner. Besides, we put efforts on collaborative learning in this project to exploit the capability of an Internet-based environment. Collaborative design focuses on brain-storming and cooperation between team members, thus endorses the potential of stimulating imagination, eliminating prejadice, building concensus, which have become the fundation of constructivist learning. Consequently, we decided to choose collaborative design as the primary form of learning activities.

We adopt *Distributed Constructionism* (Resnick, 1996) as the primary learning theory behind this project. Some distance learning schools treat the Internet as a tool for information transfer and communication, thus emphasize the provision and management of courseware or the search for pedagogical resources; on the contrary, constructionism views the Internet as a media for concept construction which helps the students learning via constructionist activities. According to Resnick, constructionism consists of two types of construction. First, it views learning as an active process of the learners who build up knowledge based on their experiences. In other words, they *make* ideas instead of *obtaining* them from the teachers. This viewpoint is based on Piaget’s constructivist theories. Second, when the learners devote themselves to realize products they feel interested in, they can achieve the best learning effect in terms of knowledge construction. Following this line, we choose *design* as the core concept of learning activity because it put together the goals of active learning and learning by doing in a natural way.

Constructivism also emphasizes the concept of *knowledge as consensus*. Distributed constructionists thus suggest a form of pedagogy that many people participate in the activities of design and construction. In other words, both cognition and intelligence are considered the result of the interaction between the learner and the environment in which other participants and artifacts play an equally important role as the learner's perception and conceptualization models. The artifacts, of course, are the products of design.

Distributed constructionism can be discussed at three levels: discussing constructions, sharing constructions, and collaborating on constructions. To realize the essential concepts in this theory, we developed appropriate tools, interfaces, courseware, and learning activities. The resulted learning system is based on network-based learning theories, and is composed of three major components: an environment for scientific knowledge construction, a learning resource database, and a learner database; together, they present the profile of a virtual scientific learning center.

II. Survey of Related Work

To further identify the characteristics of the network-based learning environments and to allocate the proposed learning system in this important trend of technology and learning, we first investigate previous research in this section. The topics include network-based cooperative learning, cooperative learning and social constructivism, collaborative design as a learning strategy, design of scientific activity as a pedagogical subject, and the assessment of collaborative design of scientific activities. We also survey related learning systems and strategies and compare them with the proposed model.

Network-based Learning Environment: Toward Cooperative Learning

Along with the fast development of computers and networking, interactive distance learning via the Internet has been receiving more and more attention. In the past, interactions between learners and systems have been investigated in many ways, such as the access of multimedia instructional resources, the artificial-intelligence-based diagnosis of learning processes, on-line testing and remedy, etc. In this new environment, self-regulated learning models, such as that proposed by Palincsar & Brown (1989), have been verified as effective strategies in learning languages and sciences. Furthermore, Pintrich & deGroot (1990) and Zimmerman & Martinez-Pons (1990) described the roles of strategies such as planning, self-monitoring, and self-adjustment in the learner's process of meta-cognition. The advantages and limitations of these strategies have been investigated in various network-based learning situations since then.

However, an even more important type of interaction, i.e., that occurs between the learners and the teachers, or between the learners themselves, should be explored in more detail. The reason is obvious: the Internet is not just a huge database of learning materials, it is, more importantly, a medium on which learning communities can be formed to achieve mutual and continuous learning. Consequently, from the viewpoint of instructional technology, we now emphasize on how to promote the level of learner interactions, in particular, from goal-sharing communication toward task-sharing collaborative design.

It should be noticed here that putting learners into project groups does not necessarily entail collaboration. As mentioned in previous research works, if learning situation is not properly designed for a group, learning effects of the members will not improve as expected. One major drawback is the so called hitchhiker phenomenon, i.e., the ones with better domain knowledge or more willing to express themselves usually do larger share of the work, while others just wait to share the result. Another issue is that one member's understanding about others' work is largely limited after this kind of teamwork.

Based on these findings, Damon & Phelps (1989) indicated a measure to differentiate cooperative learning and other methods of teamwork-based learning, i.e., to measure the quality of interaction between members. Two indicators for this measurement are *equality* and *mutuality*. Cooperative learning must provide higher level of equality, in terms of authority and accountability, and mutuality, in terms of information exchange. When equality is high, a learner is more willing to interact with peers, thus the information flow is more likely bi-directional, and the learning atmosphere becomes more friendly and open. When mutuality is high, a learner feels better support from peers, thus more interested to know others' work so as to achieve better effect.

From this viewpoint, Hooper (1992) indicated 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, positive interdependence is thus achieved.

Cooperative Learning and Social Constructivism

Cooperative learning as an instructional strategy for students in various levels has been widely researched in the paradigm of social constructivism for a long time. To achieve effective cooperative learning some principles have been outlined in prior research, such as in Johnson & Johnson (1990) and Slavin (1995), as follows:

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

Previous studies have shown that cooperative learning helps students gaining basic skills, higher level thinking abilities (e.g., critical thinking), as well as achieving some goals that educators highly value: prosocial behaviors, and equity in the micro-situation of a classroom (Cohen, 1994; Quin, Johson, & Johson, 1995). Previous research also indicated how a group is formed may influence the learning effect in cooperative learning (Cohen, 1994). Some of the group member's characteristics that are closely related to learning and interaction have been identified, they are: help behaviors, ability, gender, personality, and social economic status, as described in the following.

1. Help behaviors: Webb (1987) found that in the cooperative learning process, students are more willing to exchange assistance. 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. If members in a group tend to ask for explanation other than terminal help or surface information, they learn more.
2. Ability: More capable learners are more likely to offer explanative assistance. Therefore, forming an effective cooperative learning group, it is better to have high and low ability people in a group. 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: Only when boys and girls are equal-numbered, everyone in the group is likely to obtain enough assistance. If genders are not balanced, boys usually get more assistance. Besides, when girls outnumber boys in a group, girls tend to leave all the problems for boys.
4. Other variables: Outward students can get more explanative assistance than inward students. Students with higher social status are more active and thus gain more influential power in the group interaction.

Recently, *social constructivism* has postulated learning and instructional principles similar to those of cooperative learning but with some new perspectives. The social constructivists (e.g., Vygotsky, 1978) 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 the authentic achievement may be gained through an authentic learning environment where learners experience confusion and struggling as what would happen in the real scientific problem solving process among scientists (Roth, 1997). Thus, teachers' job is to create authentic environments for knowledge construction. Some elements of an authentic environment suggested by Roth (1997) 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 degrees of confusion and chaos as those real problems scientists try to solve.
3. The learners should have chances to consult more knowledgeable persons.
4. The teachers are not authoritarian figures, but more like a knowledgeable *old-timers* who facilitate newcomers (students) in appropriate community-specific practices.

Collaborative Design: A Network-based Learning Strategy

Without proper learning strategies and compatible pedagogical activities, the effect of network-based learning will be largely limited because the advantage resulted from the flexibility of distance learning is usually negated by monotonic web courseware and unfocused on-line discussion. Therefore, innovative learning strategies tailored for network-based learning environments have been receiving more and more attention. For instance, the introduction of PBL (Problem-Based and/or Project-Based Learning) has become an essential part in many web-based learning systems. Study reviews, problem solving, and discussion are commonly employed in a group project conducted via the Internet. Benefits such as exchange and sharing of information, maintenance of learning motivation, stimulation of innovation, accumulation of learning effects have been repeatedly reported in previous research.

Among various types of learning activities, design not only represents mental practice of high-level concept integration but also realize learning by doing. Consequently, to implement and experiment learning through collaborative design in network-based environment has shown its potential in many dimensions such as interactive and inter-creative learning.

The styles of high level thinking, in terms of knowledge domain, can be divided into two categories: domain specific and domain general. Design, from this aspect, is usually considered domain specific. Consequently, design environments and assistant tools should be constructed to support the thinking process of the domain experts in their design procedures.

To further explore the domain specific characteristics in learning through design, we briefly summarize two representative examples 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 (Pea, 1993) is collaborative learning based on scientific visualization. Students are assigned collaborative design problems such as to identify a proper mining site and to propose a mining plan so that environment factor is 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 dialog between students, teachers, and teaching assistents can be classified into categories such as question, answer, comment, supplement, conjecture, etc. Learning motivation and effectiveness are both enhanced in this environment.

CDR (Petrie, Cutkosky, & Park, 1994) develop courses to combine important ideas such as computer-assisted design, synchronous design, collaborative engineering, acquisition and indexing of design knowledge, etc. Through the process of product design, students try different tools and workflows, discuss on-line with different domain experts. Various design and simulation tools are provided in this learning environment, learning by doing is heavily emphasized.

CDR focuses on mechanical design and keeps a close relationship with manufacturers. Industry initiates design projects via the Internet. After student design teams are formed, they contact the project proposer on the network to clarify items such as problem definition, design concept, prototype schedule, test and evaluation, specification and budget, and so on. This sort of design project is realistic and reflecting the current needs and wants of the industry.

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

Domain of Collaborative Design: Scientific Activities

As mentioned above, network-based collaborative design is a general learning strategy, but the actual development of learning-through-design systems is domain specific. In our science and engineering oriented learning system, we choose scientific activity as the design and learning target. Our decision is based on several factors described in this section.

First, designing scientific activities requires students to understand theories and integrate concepts. In addition, to establish an effective and interesting activity, they must employ their capability of innovation. Moreover, in our cooperative learning setting, students are asked to evaluate others' work. Thus, students are required to push themselves beyong what to do and how to do a design, and enter the area of appreciate and understand others' design. This type of learning activity is considered high level cognitive processes of analysis, synthesis, and assessment, which are critical in science and engineering education.

Second, based on previous theories and practices of science education, many effective tools for design assistence have been developed. Among them, *cognitive maps* and *Vee heuristic* have been employed in classroom. With these tools, the processes of concept construction and design can be represented explicitly so that it can be observed and analyzed effectively. This sort of in-depth information can directly help meta-cognition of the students.

Third, the results of design, i.e., the scientific activities achieved through the learning, designing, and evaluation process, can be accumulated on the network. They can be tested and modified in a recursive manner, i.e., one activity can be included in other ones. The consequence of this network testbad can be given back to the designers/learners as feedback. More important, the contents of network laboratory can be accumulated to support the growing on-line science community.

We choose Gowin's Vee diagram, also known as the Vee heuristic, as the theoratical and operational basis of our design aide because it contains not only explicit essential factors but also an implicit workflow of a design process. As depicted in Figure 1, a Vee diagram consists of four components: Focus Questions, Events/Objects, Conceptual Activities, and Methodological Activities. As indicated by Gowin, this diagram helps us to understand that although the altimate meaning of knowledge is derived from events or objects, the recording of events/objects itself does not tell us the meaning of the recording. Thus, to know the reason behind the events/objects, we must know the reason why we choose to observe and record them, and the concepts, principles and theories behind this selection. The focus of this diagram is to build a connection, called an Active Interplay, between conceptual activities and methodological activities. In other words, to build linkage between the *thinking* on the left and the *doing* on the right.

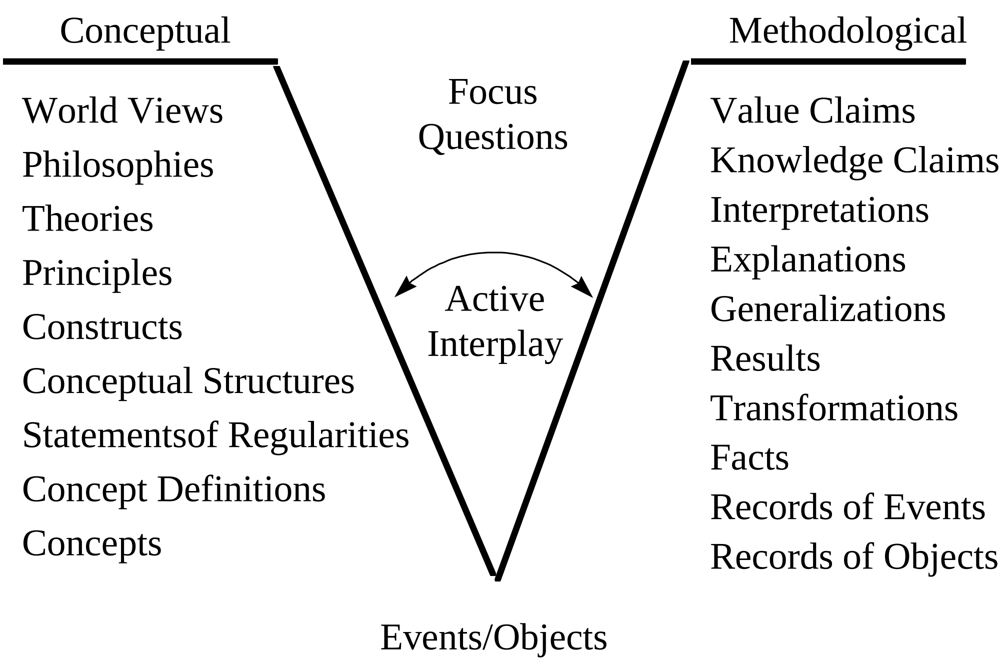

Figure 1. The Vee Heuristic

Obviously, the Vee heuristic is induced from the constructivist paradigm of science philosophy originated from Kuhn (1962). Constructivism considers all scientific observations and methods theory-laden, in other words, every scientific activity is influenced by current scientific concepts (Duschl, 1990; Tsai, 1996). From a deeper point of view, Vee heuristic is a type of *metaknowledge*, or knowledge about knowledge. It can become an effective tool to help students performing *metalearning* and acquiring metaknowledge.

Assessment of Collaborative Design of Scientific Activities

Since Bloom (1956; Krathwoh et al., 1964; Harrow, 1972), instructional goals have been contemplated in three categories: cognitive domain, affective domain, and psychomotor domain. How to achieve higher level goals in cognition such as analysis, synthesis and evaluation, how to articulate an affective environment, and how to integrate abstract concepts and psychomotor techniques, have long become challenging goals for traditional classrooms. We believe that by learning through collaborative design on the network, we have a great chance to resolve these issues as a whole. Accordingly, we need an integrated assessment model to evaluate this new environment and strategy for learning.

Since we employ the Vee diagram as the design interface, naturally, we adopt the assessment methods associated with the Vee diagram as the basis of formative and summative evaluation. Both the learning effect and the learning process are investigated. We record qualitative and quantitative data during discussion sessions so that communication patterns can be analyzed to identify critical factors that benefit collaborative learning. With a collaborative design environment, a learning subject of scientific activity design, and the brainstorming among learning companions, we expect the students to approach the learning target from a new angle. In other words, when they try to figure out what the characteristics a good scientific activity should possess, and discuss ideas with each other via the network, they are capable to avoid the traditional situation of students as knowledge receivers. On the contrary, they can now play a more active role and have a better opportunity to visualize their own learning processes. This type of *metacognition* is essential in constructionist learning.

In addition, we took into account Bloom's framework of instructional goals to develop an evaluation mechanism for promoting good focus questions. This measurement should be able to reflect students' ability at the level of assessment for the following reasons. First, since the students must evaluate the importance of a design topic and compare it with other alternatives before selecting it as their focus question, they must be able to make judgment based on their understanding of the domain knowledge. Second, to develop a consistent activity of successive steps, they must identify first the rationale behind the activity and its connection to the focus question. To evaluate the strength of the connection is also a sort of high-level assessment. In terms of cognitive structure or schema, when a team of students can propose a good focus question and then develop the experimental steps, their schemata must be more coherent than that of others. Moreover, the cross links among their concepts should also be more sophistigated than those of others. Again, this is not only an important indicator to tell the difference between a novice and an expert but also an indispensable stage of conceptualization.

III. Learning System and Assessment

After investigating related theories and systems, we developed a learning environment to realize the core concepts mentioned above. It contains several subsystems such as a team forming module for suggesting a partition of on-line learning participants, a structured discussion module for project members to construct and exchange ideas, a peer appraisal module for them to evaluate and comment on others' work, and a logging file management module for the investigators to explore the learning processes and provide feedback to the students. We describe the interface and the team forming in more detail in the following. We then introduce the assessment of the proposed environment, including the evaluation of the learning system and the learning process.

CORAL-View: The Interface

We developed a cooperative learning environment on the World Wide Web, and named it *CORAL-View* (COoperative Remote Access Learning-View System). Figure 2 depicts the framework of CORAL-View that can be accessed at the WWW address in the caption. However, the displays of the environment are in Chinese.

(Insert Figure 2 here.)

Figure 2: Framework of Cooperative Remote Access Learning-View System. Web address: sandy.cis.nctu.edu.tw/~colearn/ page1.html.

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

Team Forming Module

Beside the ordinal interfaces of a cooperative learning environment, the authors intended to embed a team forming recommendation procedure in CORAL-View. In doing so, we expected to organize teams that can learn cooperatively and effectively based on the grouping of partners' thinking styles. The recommendation algorithm is illustrated in the methodology section, and the main psychological variables for partner selection are thinking styles (Sternberg, 1998) that has never been studied yet.

In forming cooperative learning teams, we designed an artificial intelligence algorithm following principle of Random Mutation Hill Climbing (RMHC, Russell & Norvig, 1996). This algorithm used loadings from an exploratory factor analysis (principle component method) of thinking styles as the input features. The factor analysis based on 154 subjects' responses showed that items designated to 4 thinking styles, Legislative, Judicial, Internal, and External were remained intact. However, 8 items of Executive thinking style were separated into two factors, Executive-Procedure and Executive-Principle. Therefore, each student's six loadings of thinking styles became the input of the team-forming algorithm.

At first, students were randomly assigned to teams and all teams were randomly separated into two groups, resembling and complementary. The function of the algorithm is to change member(s) of team(s) within or between groups in order to achieve the goal that summation of member differences (of factor loadings) reaches minimum for teams in the resembling group and maximum for teams in the complementary group. In each iteration, 100 cases of member-exchange are generated randomly from the current partition; and for each case, the chance is greater to change fewer members. Then we compare the 100 cases together with the original one, the optimal case of them remains, the rest discarded. This iterative procedure proceeded until member-exchange produced no difference.

Assessment

The assessment of the learning system can be divided into three layers. The purpose of the first layer is to guarantee the learning system helps learning. We developed and conducted formative evaluation to verify the usability of the interfaces and functions provided in the learning-through-collaborative-design system. For the team-forming system, we examined the characteristics of collaborative design and suggested learning and personal variables that are important for team organization. We then conducted experiments to validate the effect of collaboration resulted from the team-forming system.

The second layer of assessment is targeted on the collaborative tasks/processes occurring in the learning environment. How meaningful learning happens in the interactions of collaborative learning tasks and cooperation patterns among the learners? We first investigated factors involved in learner interaction within a team, such as the level of discussion, the style of help seeking, the model of peer appraisal, etc. We then categorized collaborative design tasks according to the attributes proposed in previous research (Cohen, 1994; Baron, Kerr, & Miller, 1992; Steiner, 1979) such as structured or ill-structured tasks, divisible or unitary tasks, maximizing or optimizing performance criterion, etc. We also considered four types of task demands, i.e., how a task demands the contribution from the participants and how they put together their individual resources: disjunctive, conjunctive, additive, or discretionary. We are now investigating what types of combination of tasks and collaboration inspire meaningful learning.

The third layer of assessment focuses on the design of scientific activities. We employed the logging facility built in the Vee-diagram-based design interface to record learner's behavior. As mentioned before, the interface helps the learners to address issues according to science theories, to derive validation and experimental methods, and to stimulate new knowledge structures. The issues, theories, methods, and structures are all visualized on the interface and recorded in the system so that it not only benefits the process of design but also the process of assessment. For example, we can examine the correlation between the design performance, the meta-cognition ability of the designers, and their traditional testing scores, to verify that Vee diagram can effectively reflect social knowledge construction activated by collaborative design.

IV. Concluding Remarks

This paper introduce a network learning environment based on a strategy called learning-through-collaborative design. The important achievements are itemized as follows.

(1) Learning resource database

  (a) We developed learning web sites for high school physics and biology studies on which we provide courseware, simulation tools, testing and evaluation environment to support necessary for the design process of scientific activities.

  (b) Based on the need of the learners and their personal traits, we developed a recommendation system for student team forming. With this partition system, we can organize the network-based learning population in a proper manner for project-oriented teamwork.

  (c) With the interactive design interface, the learners can easily collect necessary for their projects, smoothly describe and share their experience and innovation, constructively evaluate and comment on others' products. Knowledge construction is achieved in this type of accumulative learning.

(2) Environment for scientific knowledge construction

(a) We developed a design interface for scientific activities based on the Vee Heuristics. It provides effective guidance for a complete and consistent design flow. When the learners log onto this environment, they enter a natural situation of learning through design.

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

(3) Learner database

(a) Based on profile records of the learners, student models were developed under the framework of collaborative design.

(b) Based on the observation on the design/communication process between the learners, and the evaluation mechanism supported by the Vee Heuristic, we drew diagnostic conclusions on the learners' knowledge construction, and provided feedback information for them.

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

(4) Network-based learning theories

(a) We explored the possibility of distributed constructionism in an Internet-based environment. Cooperative concept construction is a learning strategy worth of further exploitation. We believe that project-oriented and peer-evaluation-based learning effectively helps knowledge integration, and thus provides focused learning.

(b) We developed the Vee-Heuristic-based design interface from a viewpoint of information visualization. It helps the learners to conceptualize their focus questions, to determine the items for observation, and to design the checkpoints for verify or falsify the proposed hypotheses. It benefits both the design process of the learners and the discussion process between themselves.

(5) Virtual scientific learning center

(a) As mentioned above, the on-line simulation tools can be employed to develop network-based scientific experiments. Consequently, the students can practice learning-by-doing strategy via the Internet.

(b) The ultimate goal of this project is toward a virtual learning center for scientific theories, experiments, and innovation. In addition to the learning system described in this paper, the results of design, i.e., the scientific activities produced by the experiment designers, can be accumulated on the Internet for future use.

We have conducted instructional experiments on various classes given by the investigators. The experimental results will be reported and discussed in separate papers in the near future. We make several remarks here to highlight the 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 will not only comprehend the learning subjects better, in terms of design factors, but also get familiar with the design procedure itself, which is very important in the industrial world. To ask students proposing their own focus questions, analyzing the observation and testing processes, and evaluating their design quality together helps them to learn sciences in a more sophisticated and realistic way. We also believe this innovative approach exploits the capacity of interaction embedded in the Internet. Students on the network should not only interact with learning materials provided by the learning systems, but also interact with learning peers in a tightly connected manner via the network.

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