行政院國家科學委員會補助專題研究計畫成果報告

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※ **網路合作設計科學活動之** ※
※ **環境、學習、與評估（總計畫）** ※
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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
共同主持人：袁賢銘　國立交通大學資訊科學研究所
共同主持人：蔡今中　國立交通大學教育學程中心

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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（總計畫）
Web-Based Learning through Collaborative Design: Principles, Environment, and Activities

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主持人：孫春在 國立交通大學資訊科學研究所
共同主持人：袁賢銘 國立交通大學資訊科學研究所
共同主持人：蔡今中 國立交通大學教育學程中心
計畫參與人員：謝崇祥 高宜敏 王岱伊 陳茵茵
國立交通大學資訊科學研究所

中文摘要

本篇論文中，我們將介紹一個適用於各種網路環境中合作設計的架構及方法。根據建構理論我們可以歸納出四個重要的因素：主動，模擬，互動，累積性。以這些為目標，我們發展出一個網路合作設計的環境，它以Ｖ圖為設計介面，利用思考風格分組，包含線上專題管理工具，討論頻道。之後，我們設計了一個以自然演化為主題的示範教學活動，透過模擬的方式讓學生由做中學，在這個實驗中我們可觀察、評估出這個系統能夠有效的提高學生的學習興趣並改善教學。

關鍵詞：

Abstract

We introduce in this paper a framework and guidelines for learning through collaborative design on the ever-popular Web environment. We first summarize important factors mentioned in previous constructivist theories and pedagogies and propose four goals for learning: Active, Simulative, Interactive/Inter-creative, and Accumulative, called the ASIA principles together. According to these goals, we developed an environment for collaboratively learning through design on the Internet. We describe the functionality of this environment, including a Vee-heuristic-based design interface, a team-forming algorithm based on thinking styles, an online project management tool, and discussion channels. We then describe an exemplar learning activity with natural evolution as the learning topic. A simulation package was developed to realize the goal of learning by doing. We conducted an experiment to validate the environment. Based on the observation and evaluation of the experiment, we conclude that the pedagogical principles are plausible and the environment is effective in stimulating interests and innovation of students.

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

I. Introduction

The importance of cooperative or collaborative learning has become more and more obvious, especially in an era that students are living in a computer and network environment in which interaction is a built-in feature (Crook, 1998). Collaborative learning, since its hand-shaking with computer-assisted learning (Hooper, 1992), distance learning (Thach & Murphy, 1994), and constructivism (Yakimovicz & Murphy, 1995), has found many ways to be embedded into learning systems (Silverman, 1995; Sun & Chou, 1996; Brush, 1998; Howe & Tolmie, 1998; Steeples & Mayes, 1998) in quite different manners.

Recently, the integration of constructive learning and distance learning on a Web-based environment has been receiving more and more attention. For example, learning through knowledge construction by means of hypermedia authoring has become a common practice (Nicaise & Crane, 1999). Moreover, various online schemes have been proposed to realize collaborative learning, such as co-authoring and peer evaluation (Sun, 1999). The former is a desirable learning strategy that found strong support from cognitive sciences; the latter a viable and flexible playground to explore new knowledge frontiers. Accordingly, a new paradigm of learning theory, *Distributed Constructivism* (Resnick, 1996), has emerged to provide a foundation for developing suitable learning systems and strategies to fully exploit the educational potential of the Internet.

From the angle of distance learning, distributed constructivism can be considered a social and cultural process among a community of network learners. In essence, constructivism emphasizes the concept of *knowledge as consensus*. This viewpoint is rather different from that of some distance education providers who utilize the Internet primarily as a tool for information transfer and communication. While traditional pedagogy emphasizes on knowledge transferring and skill training, in a constructionist learning environment, knowledge is built up in interaction with others. This concept deserves to be fully explored in a network-based virtual environment. New theories have been proposed to realize a framework of constructionist learning environment (Jonassen & Rohrer-Murphy, 1999).

Moreover, according to Resnick (1996), constructivism 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. 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. In other words, *learning by doing* is highly emphasized in this new learning paradigm.

Based on the desirables proposed in previous constructionist articles, we summarize four goals to achieve, they are Active learning, Simulative learning, Interactive/Inter-creative learning, and Accumulative learning. We call them the ASIA principles for short.

Active Learning

Even in an individual setting, active learning is essential in student-centered, self-paced, and/or project-based learning. Furthermore, as indicated by Steeples and Mayes (1998), the key benefits of collaborative learning include active learning and deep processing of information through requiring learners to invest mental effort. Proper learning activity design plays an important role in stimulating active learning. Explicit incentives can be used to promote motivations, but it is better to embed a natural form of participation in the environment so that a learner will start to get involved at the beginning moment.

Simulative Learning

Simulation provides an effective and cost-efficient way to realizing learning-by-doing on a network-based environment. Although there exist other ways to encourage students to manipulating artifacts via the network, e.g., in a tele-presence online experiment, simulation represents an economical and reliable approach for instructors to design learning activities on line. In the past, simulation was frequently conducted in the form of microworlds or role-playing games. We think that using software package to simulate scientific activities in a learning project provides a promising alternative.

Interactive and Inter-creative Learning

The interaction between the participants of a collaborative learning session is so obvious that its phenomena and effects have been studied in various aspects in previous studies. Here we try to proceed beyond the interactions implied by communication and coordination and to explore the new territory of inter-creation based on critical thinking and conflict resolution among the learning companions. How to group right people together may be the first step to trigger creativity. Moreover, proper groupware aimed for supporting creative thinking is essential to achieve this goal.

Accumulative Learning

Accumulation, or continuous knowledge construction, is another valuable asset of the web that should be fully exploited. From a system view, online works or trace of activities can be maintained for future use by other students so that resources are shared in a broad sense. More important, from a single student's view, she or he can visit the same learning site later when feeling the need of re-learning the subject or knowing others' opinions in a convenient and flexible way.

To realize the ASIA principles described above, we choose collaborative design as the core concept of learning activity because it put all the essential elements together in a natural way.

II. Survey of Related Work

Design, a form of high-level concept integration, as pedagogy has been investigated in the past. Properties and perspectives of design as a way to achieve constructive learning (Gargarian, 1996). A single student can learn from a design project not only the domain knowledge but also hands-on skills. This approach of learning by doing has been emphasized on certain fields such as engineering. On the other hand, learning design via teamwork with others provides even more benefits, such as communication techniques and learning companions' viewpoints (Murphy, Drabier, & Epps, 1998). Constructing a community of designers has become a promising method to achieve multiple goals at a time (Evard, 1996).

As indicated by Olson and others (1993), most tasks today cannot be done by a single person, but, on the contrary, must be accomplished by a group of people who share a common goal. Because of the complexity and time constraints of the tasks, most of them require collaboration. A similar phenomenon was observed in learning. The learning effect of a successfully cooperative group is much higher than the sum of the individual effect achieved by separate learners. In a learning group, members have to participate actively in discussion and share the leadership (Johnson & Johnson, 1994). Furthermore, the meta-cognition process is highly emphasized in collaborative learning. The different background and knowledge structures of other members will make the participants be aware of cognitive conflicts so as to seek resolution at a higher level or from a wider angle than before. From destruction and re-construction, the learners can make a renewed connection between learning materials and previous knowledge structures, thus achieve new knowledge (Forman & Cazden, 1985).

According to Slavin (1995), previous efforts to incorporating collaboration into learning at least include the following methods: Student's Term Achievement Division (STAD), Teams-Games-Tournaments (TGT), Jigsaw II, and Team Accelerated Instruction (TAI). No matter which method is adopted, the following six factors should be taken into consideration: group goals, individual accountability, equal opportunities for success, team competition, task specialization, and adaptation to individuals. In terms of performance, Hooper and others (1988) indicated that heterogeneous grouping has impact on learning achievement. Social modeling, in turn, plays an important role in heterogeneous student groups. Webb and others (1986) found that students tend to mimic each other's behavior. As a result, some educational researchers reminded us that interaction between students is likely to have the off-task side effect (Rysavy & Sales, 1991).

How to assemble a team remains a challenge for practitioners in many field, so does in collaborative learning. To investigate the learning effect and behavior of a learning group, it is essential to first identify the factors that have impact on group chemistry and interaction. In the past, achievement and gender were frequently used as attributes to compose homogeneous/heterogeneous learning teams. Since in this study our focus is collaboration, consequently, those variables closely related to communication and task sharing should be taken into serious consideration. In this study, we chose Sternberg's thinking style as the primary features for team-forming.

Sternberg (1985) proposed the Triarchic Theory about human intelligence in which he emphasized a single intelligence composed of three functions: contextual, experiential, and componential. He further expanded the concept of mental self-governance to thinking styles such that the mental process of creativity can be characterized in more detail. As we investigated creative design and cooperation together in this study, we felt that the thinking styles of participants in a collaborative design team play a critical role. Furthermore, to find connection between high-level mental activities, such as design, and intelligence, it is the patterns of intelligence rather than the types of intelligence that should be taken into account. Consequently, we chose some factors in Sternberg's thinking styles that we believed closely related to collaboration to form the possible patterns.

In Sternberg's framework (1997), thinking style can be viewed from five aspects, which cover 13 factors in total:

functions (executive/legislate/judicial), forms (monarchic/hierarchic/oligarchic/anarchic), levels (global/local), scope (internal/external), and learning (conservative/liberal). We selected two, functions and scope, out of these five aspects because we believed that they best represent the possible interaction patterns occurring in a learning group. Based on the two aspects and the corresponding five elements, executive, legislative, judicial, internal, and external, we developed an algorithm that employed combinatorial optimization techniques to recommend teams out of a given student body. It should be noted here that the team-forming task is not just to recommend a single team but to partition the whole student body to many teams at the same time, as usually required in instruction situations. The students were first asked to complete an online questionnaire that encoded thinking styles. After instruction experiments, we can analyze the learning effect, including design performance and mutual assessment, and the communicational and operational patterns observed during group collaboration.

How a group of people work together to make decision is a sophisticated matter (Baron, Kerr, & Miller, 1992), especially in ill-structured context such as design (Sherry & Myers, 1998). Thus, it is important to provide appropriate communication and design tools to alleviate their burden. Various models of collaborative learning (Hartley, 1996) should be combined with up-to-date groupware for design tasks to meet this ever-demanding goal. Guidance and tools have been tailored to meet new requirements in new environments (Petrie, Cutkosky, & Park, 1994). In this respect the previous studies on computer-supported cooperative work (CSCW) should provide useful insight and experience for learning system development (Olson, Card, Landauer, Olson, Malone, & Leggett, 1993).

Distributed constructivism provides an integrated view of the above goals and it can be discussed at three levels: discussing constructions, sharing constructions, and collaborating on constructions. Consequently, a large amount of structure is needed for students to exchange information and ideas. To realize the essential concepts in this theory, we developed appropriate tools, interfaces, courseware, and learning activities. To construct learning activities has many facets to consider (Webb, Troper, & Fall, 1995). For example, the role of critical thinking in collaborative learning has long been pinpointed (Adams & Hamm, 1990). In this environment we can then conduct instructional experiments in which learning processes are appropriately structured, guided, and analyzed.

In this framework, items for analysis include dialogue patterns (Bodzin & Park, 2000) or communication patterns (Gay & Grosz-Ngate, 1994), learning flow and portfolio (Chang & Chen, 1998). Since team is one of the core concepts in collaborative learning, team-forming and its consequences have been explored in the past, such as heterogeneous versus homogeneous grouping (Hooper & Hannafin, 1988). The dependent variables studied include achievement, interaction, learning efficiency (Hooper & Hannafin, 1991), time on task, and satisfaction (Klein & Pridemore, 1992)

III. System Description

In this section we first describe the framework of the learning system and the design of the learning interface. We then introduce the experiment design and schedule followed by important results and discussions.

The framework of the collaborative learning through design environment is composed of three components: user interface, management interface, and file system. The user interface can be further divided into two parts: inter-team interface and intra-group interface.

The learning system supports functions such as an experiment registration module for the teams to log on. To encourage collaboration on various levels and manners we provide an intra-team peer assessment area where participants can demonstrate their work and comment on that by other teams. Just like most existing cooperative learning environment, the system has a chat room and a BBS for students to discuss with each other synchronously or asynchronously. There is also a bulletin board on which the system manager can post administrative information. And we include an exemplar project for students' reference to learn the details of developing a scientific activity collaboratively on the web.

At the beginning of an experiment session, the students log in the system after having their identities verified. Then, they will enter the collaborative design interface. The experiment interface contains two parts: a function bar and an experiment procedure. The function bar indicates four working areas: intra-team peer assessment, inter-team chat room, BBS, and back-to-home.

This innovative learning environment benefits not only the students but also the teachers/researchers. For instance, an education investigator can observe the design and discussion processes both quantitatively and qualitatively without interference with the teamwork. Furthermore, when unbalanced discussion or workload sharing are found during an experiment session, the instructors can play a more active role to help solving the problems before they further damage the collaborative work.

The URL of the above web site for learning through collaborative design is as follows: http://sandy.cis.nctu.edu.tw/~colearn/page1.html.

IV. Experiment and Results

Experiment Subjects

We have conducted two experiments on college students. Our subjects were undergraduate students of National Chiao Tung University. The first experiment involved 155 students from an Introduction to Artificial Intelligence class, fall 1998, and the second involved 36 from an Evolutionary Computation class, fall 1999.

In the AI class given by this author, a focus question was assigned for the student groups to investigate. The question is: Assume you are a member in the Star Fleet, develop a procedure for judging the existence of intelligent lifestyles on a target planet. Obviously this is an ill-structured open question that has no ready or standard answers to it. On the other hand, the students on the EC class are told to propose their own focus question related to evolution theories. Online courseware on natural evolution and a Java-based simulation package was provided to this EC class and the students are asked to utilize the simulation tool in their scientific activity design.

In the following we report the primary observation of the first experiment on the AI class.

Team Forming

We employed the team-forming algorithm described above to partition 155 students enrolled in the AI class into 51 teams, with three members in 49 teams and four members in 2 teams. At the beginning of the experiment, all students were asked to fill an online thinking-style questionnaire (Lin & Chau，1999). Think style features were extracted from the questionnaire and used to form 26 heterogeneous (complementary) teams and 25 homogeneous (resembling) teams. By heterogeneity of a team we mean that the members in the team are different from each other in terms of the five thinking style elements: Executive/Legislative/Judicial and Internal/External. On the contrary, a homogeneous team has its members more or less similar in those aspects. Of course, the discrimination between heterogeneity and homogeneity is a matter of degree and has no clear cut.

Table 1 shows Cronbach's á coefficients which is an indicator for the internal consistency of the thinking style questionnaire. Since the á coefficient is a lower bound of other reliability measures, a high á value means high reliability. In this study, we found an á value of 0.9298 for the whole questionnaire, and the á value for each factor is between 0.6181 to 0.9021, thus we concluded satisfactory internal consistency of the questionnaire.

Table 1. Internal Consistency: á coefficient

Factors	α
Functions	
F1 Legislative	0.8733
F2 Executive	0.7790
F3 Judicial	0.7931
Scope	
F4 Internal	0.8653
F5 External	0.8728
Questionnaire	0.9298

We mapped each student's thinking style to a point in the 5-dimensional space defined by the five factors, Executive (E), Legislate (L), Judicial (J), Internal (I), and External (X). We then define the distance between two persons M and N, whose coordinates in the 5-D space are (E1, L1, J1, I1, X1) and (E2, L2, J2, I2, X2), respectively.

Distance(M,N)

$$= \sqrt{a_1(E_1 - E_2)^2 + a_2(L_1 - L_2)^2 + a_3(J_1 - J_2)^2 + a_4(I_1 - I_2)^2 + a_5(X_1 - X_2)^2},$$

in which (a1, a2, a3, a4, a5) is a weight vector to provide the flexibility of emphasizing certain factors in this definition. In this experiment, we set the vector to (1, 1, 1, 1, 1).

Based on the distance definition, we designed an objective function for the Random Mutation Hill Climbing (RMHC, Russell & Norvig, 1996) algorithm so that we can search for the optimal partition of the given student body.

Assume there are n students to be partitioned into 3-person teams. First we randomly generate a sequence of length n: Sequence = (a1, a2, a3, a4, …, an-1, an) in which ai represents a student, and (a(n/3)+1, a(n/3)+2, a(n/2)+3) is a tentative team. Now that we want to form half homogeneous teams and half heterogeneous teams, thus we can denote Sequence as follows.

Seq = (a1 , a2 , a3 , a4 ,…,an-1 , an)

= (B1 , B2), and

B1= (a1, a2, a3, a4, …, a(n/2)-1, an/2), representing homogeneous teams;

B2= (a(n/2)+1 , a(n/2)+2 , a(n/2)+3 ,…,an-1 , an), representing heterogeneous teams.

Now we define the distance sum of the i'th team:

di= [Distance(a3i-2, a3i-1) + Distance(a3i-2, a3i) + Distance(a3i-1, a3i)].

Thus, in turn, we define the sum of distance of all homogeneous teams:

SUM(B1) = ,

and the sum of distance of all heterogeneous teams:

SUM(B2) = .

Because the total distance within the heterogeneous group should be larger than that within the homogeneous group as much as possible, we define an objective function F = SUM(B2) - SUM(B1) for the search algorithm to optimize. In each loop of the RMHC program, we generate 100 new sequences by randomly swapping two students in the current sequence until further improvement is not possible. At the end, we obtain an optimal sequence, Sequencebest, as the final partition to be used in the experiment.

Experiment Schedule

The experiment was conducted from 12/07/98 to 12/18/98, a 12-day period. It was divided into four stages: (a) 12/07~12/08: registration and posting the topic; (b) 12/09~12/12: discussing related concepts and designing procedure; (c) 12/13~12/16: predicting possible consequences and discussion; (d) 12/17~12/18: finishing and concluding the experiment. In this paper we report the primary observation of the first experiment.

After the experiment finished, the designed activities are evaluated by the instructor and two teaching assistants. The assessment is based on the creativity, comprehensibility, and plausibility of the proposed method. Next, we analyze the relationship between the design results and the team-forming attributes. Moreover, during the experiment session, comments to improve the system are taken into account in a constant manner. If an immediate modification does not affect the tempo of the experiment, it is adopted as soon as possible.
Important

Experiment Results

For the above experiment conducted on the AI class, we proposed three research questions beforehand, they are:

1. According to the assessment on creativity, comprehensibility and plausibility, which type of teams (heterogeneous vs. homogeneous) perform better in terms of quality of design in this web-based cooperative learning situation?
2. Which type of teams (heterogeneous vs. homogeneous) receive more positive feedback from their members in terms of mutual evaluation among team members, collaborative process, and the learning-through-design environment?
3. Participants in which type of teams (heterogeneous vs. homogeneous) prefer to work with their current partners in future learning?

And the primary findings are as follows:

1. The homogeneous teams performed better in terms of quality of design, according to the assessment on creativity, comprehensibility and plausibility, in this web-based cooperative learning situation. This piece of finding is different from some results reported in previous research concerning homogeneity of team members. One possible explanation, according to the investigators' observation during experiment and afterward interviews with the participants, is that heterogeneous teams in general need more time to construct a positive pattern for interaction and cooperation. Since our experiment period was pretty short (12 days during a semester) for a project-based learning assignment, those heterogeneous groups might not have enough time to build up chemistry.
2. Both types of teams gave positive opinions toward the system functionality. They both appreciated their teammates, the design goals, the design process, and the design results. In summary, they thought positively about this collaborative learning-through-design environment and were willing to involve in future activities.
3. Participants in heterogeneous teams were more willing to work again with their current partners in future learning projects. As Sternberg (1998) has indicated, members with different thinking styles tend to have better cooperation. In this study, we found that the attitude of heterogeneous teams might re-confirm Sternberg's theory, but the performance of them may need more time to fertilize.

IV. Concluding Remarks

In this paper we introduced a web-based learning environment which supports an innovative learning strategy by means of collaborative design. We described the system modules and their interface design and functionality. Two instructional experiments have been conducted. The procedure and results of one experiment on an AI class was briefly summarized and discussed as an example to demonstrate the effectiveness of the proposed learning strategy. Based on the theoretical study and experimental observation, we found that the constructive learning, collaborative learning, and network-based learning embedded in this learning environment have a great potential to improve learning, not only in terms of the design skill but also in stimulating students' active mental setting and creativity. This approach is worth further investigation.

The analyses up to this point have been largely quantitative. In the future we should emphasize more on the qualitative aspect so that the nature of heterogeneous collaboration can be further studied. We are now data-mining the conversation patterns and management mechanisms developed in different types of teams. In particular, we should find the relationship between students' behavior and their categorization from the thinking style questionnaire. Hopefully, we will report more about student interactions in this environment.

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