Information-Access Characteristics for High Conceptual Progress in a Computer-Networked Learning Environment

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Abstract

The aim of the paper was to examine how elementary school students (grade 5-6) make use of two different types of networked database systems specially designed for intentional learning. Students were allowed to represent their thoughts and knowledge in the form of texts or graphics in the database, then collaboratively manipulate them for improving their comprehension of study topics in the classroom. As a framework for describing differences in the students' activities between those who highly benefited and those who did not, "Information-Access Characteristics (Perkins, 1993)" was considered. Results showed: (1) that students who highly benefited from their activities in the database significantly more engaged in knowledge-transforming activities which are considered critical to high conceptual progress, and (2) that a system affordance which allowed students to conduct their joint writing activities significantly prompted such a transforming activities at a joint-space of their collaborative learning.

1. Problem

Recent cognitive research on students' learning in the classroom has suggested the importance of development of learning environments where students authentically engage in knowledge construction (e.g., Bruer, 1993). Bereiter and Scardamalia (e.g., 1989) argued that students should be supported to engage in their intentional learning. Students bring their own inquiries into their learning activity, then collaboratively pursue the inquiries through building their collective knowledge. What students learn is not consequences from their learning activity based on problems given by teachers, i.e., learning from problem-solving (Bereiter & Scardamalia, 1989), but the learning process itself by which students engage in knowledge-building as effective collaborators in the classroom community.

Computer-Supported Intentional Learning Environments (CSILE) is a networked database system which encourages students' intentional learning through progressive discourse (Scardamalia & Bereiter, 1993). Students are allowed to externalize their thoughts in the database in the form of texts or graphics, then manipulate their represented knowledge in building further knowledge. The database is accessible to anyone who is registered as a member. Students can asynchronously collaborate through mutual commentaries. They can create comment notes to add their reflective thoughts on their friends' thoughts. Thus, students with CSILE work as members of the classroom community in pursuing their inquiries on study topics (Scardamalia, Bereiter, Brett, Burtis, Calhoun & Smith-Lea, 1992).

Because CSILE is a new technology not available in regular classroom learning, students' learning activity becomes much more rich and complex than ever. In CSILE, students are engaged in *overt* knowledge-building by manipulating their knowledge in the form of texts or graphics, rather than manipulating their *internal* knowledge structures. Furthermore, students share their represented knowledge with others so that anyone can build his/her knowledge through coordination of self and others' knowledge. Thus, students' knowledge-building on the network occurs through dynamic interaction among learners and their constructed knowledge database. How do students engage in this dynamic activity? How does the networked database mediate students' learning? These problems are pursued by analyzing students' computer-mediated activities from the perspective of distributed cognition (Salomon, 1993).

Distributed cognition, a recently developed concept, assumes human beings as part of a more global information processing system rather than as independent information processors (Salomon, 1993). Knowledge and mental resources for the global system are widely distributed across people and available tools. Our performance in a complex cognitive task is a process by which the distributed cognitive resources dynamically interact with one another. This process is the core of knowledge-building. Although individual learners cannot know and manipulate all the cognitive resources, they can collaborate with one another in constructing high quality knowledge which does not belong to any specific individuals but to a community of the learners (Bereiter, 1994). In this sense, CSILE is a networked environment where community knowledge is constructed. A goal of students' learning is to contribute to the knowledge-building in their classroom community as well as to advance levels of their understanding (Oshima, 1994). The process of knowledge-building which should be examined in CSILE classrooms is not only a process by which each student *internalizes* external information, but a process by which s/he *engages in knowledge-building in the classroom community*.

How can we describe human beings as part of a global distributed cognitive system? Because traditional cognitive science has focused on representation of human's internal structure, its approach is not appropriate for us to examine students' activity in CSILE. From the perspective of distributed cognition, Perkins (1993) proposed a new level of analysis of human mind, *cognition as information flow*. He defined *person-plus-surround* as a unit of analysis of cognition, and focused on information flow in the *person-plus-surround* system. Here, the focus of the analysis is no longer on how subjects' internal structures are constructed, but rather on how subjects work in the global system. To describe the information flow in a target global system, Perkins suggested the following information-access characteristics of the system:

Knowledge. When the global cognitive system functions in a task, various types of knowledge are used, from content-specific knowledge to higher-order knowledge such as monitoring and planning. In the present study, we focus on different types of descriptive knowledge in the database (discussed later).

Representation. How knowledge is represented is another important aspect. Because CSILE is mainly driven by written discourse, we focus on written form of knowledge.

Retrieval. Although necessary knowledge is represented in the system, it does not mean that we can always access it in a contextually appropriate way. Studies have shown: (1) that experts usually learn necessary knowledge and skills in a quite problem-based situation so that they can easily access the necessary knowledge in their work (e.g., Brown, Collins & Duguid, 1989); and (2) that authentic problem-based learning in a meaningful context can prompt learners' acquisition of knowledge which can be later retrieved in an appropriate way (e.g., Lampert, 1986). Here, we focus on (1) how learners use their own and others' knowledge represented in the database, and (2) how they manipulate the knowledge in advancing their comprehension.

Construction. "Construction" means physical or psychological spaces that support subjects to engage in knowledge manipulation and construction. The places are not necessarily placed in subjects' heads. In a *person-plus-surround*, we can use any available spaces such as a paper, a blackboard, and an electronic document. Recent studies on *effects with intellectual technologies* (Salomon, Perkins & Globerson, 1991) showed that computer support which allows learners to run and see their represented knowledge improves the learners' reflective processes in problem solving and helps them acquire higher levels of understanding (e.g., Nathan, Kintsch & Young, 1992). Here, we focus on two different spaces of collaborative learning in CSILE.

In the present study, we had two specific research questions. The first is what differences are there in information-access characteristics between students who benefit greatly from their activity and those who do not in CSILE. Through pursuing this question, we can acquire information for improving students' activities in such a way that they effectively engage in higher quality of learning. In addition to this, we examined differences in system affordances between the two different system configurations. Because of the system development, students have used different systems in different years. One critical shift in the system was from individual-note based to discussion-note based (Scardamalia, Bereiter, Hewitt & Webb, in press). In discussion notes, students are directed to engage in joint writing activities on a shared problem. Theoretically, it is expected that students can benefit from their engagement in such joint activities. However, it has not yet been discussed how such a shift in the system affects students' activity in CSILE. Therefore, we compared students' activities between the two system configurations.

2. Study Design

2.1. Curriculum Description

The present study examined two fifth- and sixth-grade combined classrooms taught by the same teacher which used different types of systems in two consecutive years. In the first year, twenty-nine students used a version of CSILE (the "first-year system") in which they reported their thoughts on a study topic, electricity, in their individual text or graphic notes. Hence, the database was a compilation of such individual notes. Students organized and advanced self and others' thoughts by accessing and commenting on the notes. In the second year, twenty-seven students used another version (the "second-year system") in which they reported their thoughts on a study topic, force, through dialogical written discourse on their collaborative problems in *discussion* notes. In discussion notes, students proposed problems to pursue and reported their thoughts related to the problems. Discussion notes were expected to have the following effects on students' learning: First, because a discussion note stated a clear problem, students were expected to engage in problem-based learning. Second, because a single note consisted of thoughts shared among students, students were expected to be involved in dialogical writing by reporting their written discourse, following their own discourse and that of others. In each year, before starting their CSILE learning session, they conducted classroom experiments and group work based on materials available in the classroom. The teacher in the classroom helped and encouraged students to collaborate with one another through the database system.

2.2. Data Source

Students' computer actions, such as text- and graphic-generation and revision were automatically recorded as tracking files on a hard disk of a main server. Information used in the present study contained (1) time and contents of text- and graphic-generation and revision, and (2) time and contents of database search. On the basis of the above information, the present study examined how students represented and manipulated the knowledge in the database.

2.3. Measures for Students' Basic Skills Related to Written Discourse Activities in CSILE

Students' basic skills related to their written discourse activities in CSILE were considered to affect their use of the system. Scores of reading, writing, and spelling in the Canadian Tests of Basic Skills conducted at the beginning of the academic year were used as measures of students' basic skills.

2.4 Measures for Information-Access Characteristics in CSILE

Knowledge. Students' written discourse in each note was divided into units of ideas, then each unit was categorized as one of three types of knowledge items. The first is *referent-centred* knowledge (Bereiter, 1992). This is definitional and descriptive information which clearly refers to a concept. It is easy for students to pick out this type of knowledge from their resource materials or their minds. The second is *problem-centred* knowledge (Bereiter, 1992). This is process-oriented information such as causal mechanisms which have potential to facilitate students' understanding. The third is *metacognitive* or *reflective* knowledge. Although it has been considered to rarely appear in an external form (Perkins, 1993), students, here, were asked to write down their reflection on their own learning. Two independent raters categorized the units of ideas (inter-rater agreement was over 90%), then frequencies of the categories were counted.

Retrieval. To analyze how learners manipulated knowledge represented in the database, two types of knowledge change from one knowledge item to another were identified: (1) *knowledge-widening*, and (2) *knowledge-deepening*. Knowledge-widening means that a new knowledge item develops by assimilating information in a preceding knowledge item. Knowledge-deepening means that a new knowledge item develops by accommodating information in a preceding knowledge item (see Appendix). Two independent raters assessed knowledge change from one item to another (inter-rater agreement was over 90%), then proportions of knowledge items which belong to eight categories of knowledge changes were calculated in either the solo-space or the joint-space. Furthermore, students' commentaries were categorized as follows: (1) *knowledge-widening-oriented*, (2) *knowledge-deepening-oriented*, or (3) *information-based*. Knowledge-widening- and knowledge-deepening-oriented commentaries mean commentaries which have potential to change target knowledge items in knowledge-widening and knowledge-deepening way respectively. Information-based commentaries are those which evaluate surface information in written discourse such as grammatical errors and misspelling.

Construction. Students are considered to engage in two different spaces of collaborative learning: the solo-space and the joint-space. The solo-space is a constructive arena where students develop their own understanding. Students' activity in the solo-space was examined by analyzing change in their written discourse from their own preceding discourse. The joint-space is another arena where students contribute to development of understanding in the classroom community. Activity in the joint-space was examined by analyzing change in students' written discourse from others' preceding discourse, and students' commentaries on others' discourse.

2.5. Data Analysis Design

To examine the two questions described above, we used a 2 (Type of Student) X 2 (Type of CSILE) factorial design for analyses of the measures.

Classification of students. Because we focused on students' progressive discourse as knowledge-building, the change in their explanatory discourse in notes from the beginning to the end was used for classification of students. We evaluated learning processes by which learners critically changed their explanatory discourses. For instance, in the initial stage of their learning, most of students did not have explanatory discourse in the sense that they did not have any clear understanding of what to explain. They wrote down their ideas such as "Electricity works because a light bulb is turned on," and "Electricity makes a light bulb light up." As Chi, Slotta and de Leeuw (1994) argued, higher levels of concepts such as electricity and force are not to be learned as matters but as problem-related or process-oriented. As far as students are stuck with the scientific concepts as *matters*, they cannot get into deeper understanding of the concepts. Indications of such a critical shift in epistemological ontology in students' learning processes were searched for as criteria for progressive discourse, i.e., knowledge-building. We sought to assess the variables for causes or effects and the relationships among the variables students considered in their explanatory discourse. Criteria for the evaluation are (1) improvement of scientific power of their explanatory discourse to explain their problems; and (2) degrees of elaboration and clarification of the relationships among the variables used in the explanatory discourse. On the basis of on the criteria, two independent raters assessed the improvement of learners' discourse from the beginning to the end through reading students' notes. Students who reached clear cause-effect relations, then improved their scientific powers to explain their problems were categorized as high-conceptual-progress learners. The remainder of the students, whose explanatory discourses on their inquiries were not conceptually changed during their learning, were classified as naive learners. Eight learners among twenty-nine in the first-year and ten among twenty-seven in the second year were assessed as high-conceptual-progress ones by the two independent raters, and the remaining were defined as naive ones (inter-rater agreement was over .90).

3. Results and Discussion

3.1. Comparison of Basic Skills Scores

A 2 (Type of Students) X 2 (Type of CSILE) MANOVA on the three basic skill scores showed no significant results (Wilks' Lambdas for available effects were .87 for Type of student, .99 for Type of CSILE and .95 for the interaction, all $ps > .05$).

3.2. Frequencies of Knowledge Items

We here focus on referent-centred and problem-centred knowledge items because these types of knowledge items contained information manipulated by students (Fig. 1). To examine differences in frequencies of the types of knowledge items, a 2 (Type of Student) X 2 (Type of CSILE) X 2 (Type of Knowledge) ANOVA was conducted. Significant main effects for Type of Student, $F(1, 52) = 28.6$, $p < .05$, and Type of Knowledge, $F(1, 52) = 9.9$, $p < .05$, were found. High-conceptual-progress learners generated more knowledge items than did naive learners. Furthermore, students generated more referent-centred knowledge items than problem-centred knowledge items.

3.3 Knowledge Change in the Solo-Space (Figs. 2-1 & 2-2)

Widening change in referent-centred knowledge from referent-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed a nearly significant effect for Type of Student suggesting that high-conceptual-progress learners engaged in the type of knowledge change more than did naive learners, $F(1, 48) = 3.8$, $p < .06$.

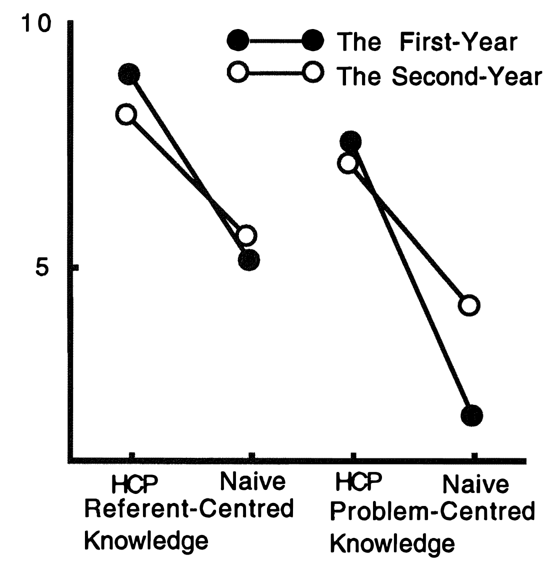

Figure 1. Mean Numbers of Knowledge Items Produced by Students.

Widening change in referent-centred knowledge from problem-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed no significant effects.

Widening change in problem-centred knowledge from referent-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed no significant results.

Widening change in problem-centred knowledge from problem-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed significant effects for Type of Student, $F(1, 41) = 4.8$, $p < .05$, and Type of CSILE, $F(1, 41) = 8.6$, $p < .05$. High-conceptual-progress learners in both years engaged in "problem-centred knowledge" change significantly more than did naive learners. Furthermore, students in the first year engaged in the type of knowledge change significantly more than did those in the second year.

Deepening change in referent-centred knowledge from referent-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed a nearly significant effect for an interaction, $F(1, 48) = 3.6$, $p = .06$. Post hoc comparisons by Newman-Keuls test showed that naive learners in the second year marginally more engaged in "referent-centred" knowledge change than did those in the first year.

Deepening change in referent-centred knowledge from problem-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed a significant effect for Type of CSILE that students in the first year significantly more engaged in "referent-centred knowledge" change than did those in the second year, $F(1, 46) = 4.2$, $p < .05$.

Deepening change in problem-centred knowledge from referent-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed significant effects for Type of Student, $F(1, 46) = 4.8$, $p < .05$, and Type of CSILE, $F(1, 46) = 11.0$, $p < .05$. High-conceptual-progress learners in both years engaged in "problem-centred knowledge" change significantly more than did naive learners. Furthermore, students in the second year engaged in the type of knowledge change significantly more than did those in the first year.

Deepening change in problem-centred knowledge from problem-centred knowledge. A 2 (Type of Student) X 2 (Type of CSILE) ANOVA showed significant effects for Type of Student, $F(1, 41) = 25.6$, $p < .05$, and Type of CSILE, $F(1, 41) = 7.3$, $p < .05$. High-conceptual-progress learners in both years engaged in "problem-centred knowledge" change significantly more than did naive learners. Furthermore, students in the second year engaged in the type of knowledge change significantly more than did those in the first year.

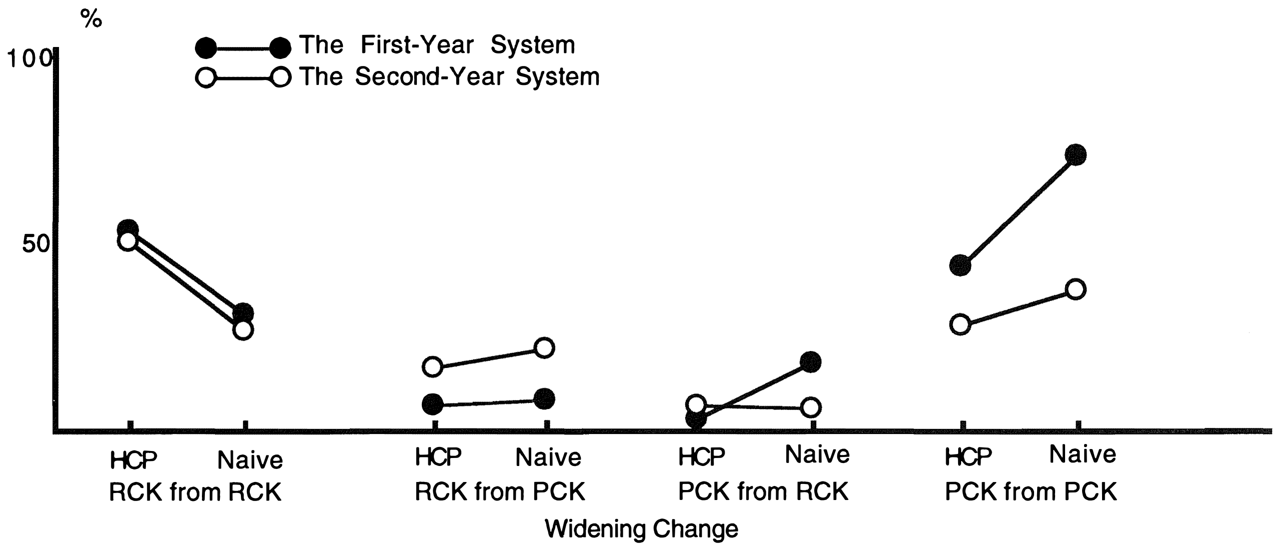

Figure 2-1. Mean Proportions of Different Types of Knowledge Items Produced in a Widening Way.

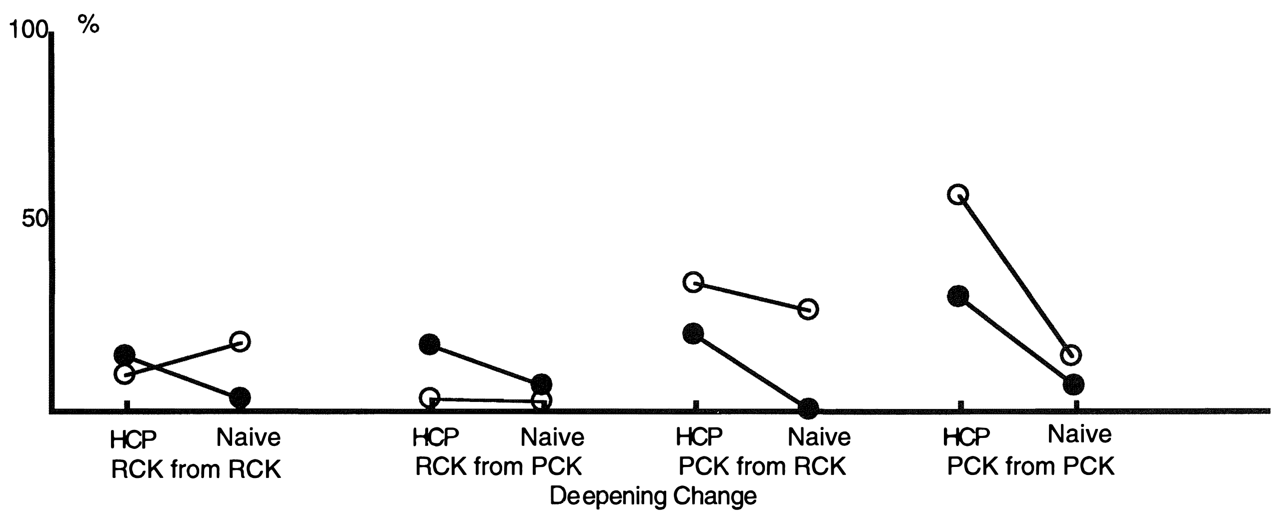

Figure 2-2. Mean Proportions of Different Types of Knowledge Items Produced in a Deepening Way.

3.4. Knowledge Change in the Joint-Space

Although we should have examined exactly the same knowledge changes as those in the solo-space, we had to merge some categories of knowledge changes and use a categorical analysis because of the small size of the data sample. The original 2 (Type of Student) X 2 (Type of CSILE) design was decomposed to simple comparisons.

Comparison of knowledge changes between high-conceptual-progress and naive learners. Since we had little data for knowledge change in the joint-space in the first year (Tables 1 & 2), we merged eight categories of knowledge change into knowledge-widening and knowledge-deepening. Chi-square analyses showed (1) that significantly more high-conceptual-progress learners manifested deepening change in knowledge from others' knowledge than did naive learners, $\chi^2(1, N=23) = 5.8$, $p < .05$; and (2) that both types of learners equally manifested widening change in knowledge from others' knowledge, $\chi^2(1, N=23) = 1.3$, $p > .05$.

Table 1. Frequencies of Students Who Showed or Did Not Show Deepening Change in Knowledge Based on Others' Knowledge.

Learners	Deepening Knowledge Change	
	Showed	Did Not Show
HCP	4	4
Naive	1	14

Note. Six naive learners were omitted from the analysis because they did not show any attempt to get involved in joint activities.

Table 2. Frequencies of Students Who Showed or Did Not Show Widening Change in Knowledge Based on Others' Knowledge.

Learners	Widening Knowledge Change	
	Showed	Did Not Show
HCP	4	4
Naive	4	11

Note. Six naive learners were omitted from the analysis because they did not show any attempt to get involved in joint activities.

Table 3. Frequencies of Learners Manifesting Each Type of Knowledge-Change in the Joint-Space.

Proportional Scores	Frequencies of Students	
	Naive	HCP
Widening Change		
RCK from RCK	6 (35.3)	9 (90.0)**
RCK from PCK	5 (29.4)	3 (30.0)
PCK from RCK	5 (29.4)	0 (0.0)*
PCK from PCK	6 (60.0)	3 (30.0)
Deepening Change		
RCK from RCK	0 (0.0)	6 (60.0)**
RCK from PCK	0 (0.0)	7 (70.0)**
PCK from RCK	0 (0.0)	3 (30.0)**
PCK from PCK	0 (0.0)	7 (70.0)**

Note. Numbers in parentheses are proportions. ** and * show significance in chi-square analysis at $p < .05$ and $p < .10$, respectively.

In the second year (Table 3), we analyzed frequencies of students in eight categories of knowledge change. Chi-square analyses showed the following: (1) More high-conceptual-progress learners showed deepening change in referent-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=27) = 8.0$; deepening change in referent-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=27) = 5.7$; deepening change in problem-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=27) = 5.7$; and deepening change in problem-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=27) = 5.7$ (all *p*s were less than .05). (2) More high-conceptual-progress learners also showed widening change in referent-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=27) = 7.6$, $p < .05$. (3) Marginally more naive learners showed widening change in problem-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=27) = 3.6$, $p < .10$.

Comparison of knowledge changes between the two systems. Because of the small data sample for the first year, we omitted comparison between the years within each type of learners. Chi-square analyses for comparisons between the years showed the following: (1) More students in the second year showed widening change in referent-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=56) = 10.0$, $p <$

.05; widening change in problem-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=56) = 4.5, p < .05$; widening change in problem-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=56) = 6.2, p < .05$; and deepening change in referent-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=56) = 8.6, p < .05$. (2) Marginally more students in the second year showed deepening change in referent-centred knowledge from others' referent-centred knowledge, $\chi^2(1, N=56) = 2.7, p < .10$; and deepening change in problem-centred knowledge from others' problem-centred knowledge, $\chi^2(1, N=56) = 3.8, p < .10$ (Table 4).

Table 4. Frequencies of Learners Who Manifested Each Type of Knowledge-Change in the Joint-Space between the Two Systems.

Knowledge Change	Frequencies of Students	
	First-Year	Second-Year
Widening Change		
RCK from RCK	8 (27.6)	12 (44.4)
RCK from PCK	0 (0.0)	8 (29.6)**
PCK from RCK	1 (3.4)	6 (22.2)**
PCK from RCK	2 (6.9)	9 (33.3)**
Deepening Change		
RCK from RCK	2 (6.9)	6 (22.2)*
RCK from PCK	0 (0.0)	7 (25.9)**
PCK from RCK	1 (3.4)	3 (11.1)
PCK from RCK	2 (6.9)	7 (25.9)*

Note. Numbers in parentheses are proportions. ** and * show significance in chi-square analysis at $p < .05$ and $p < .10$, respectively.

3.5. Frequencies of Commentaries

A 2 (Type of Student) X 2 (Type of CSILE) X 3 (Type of Commentary) ANOVA showed marginal and significant main effects for Type of CSILE, $F(1, 46) = 3.6$, $p < .08$, and Type of Commentary, $F(1, 92) = 5.3, p < .05$. Post hoc comparisons by Newman-Keuls test showed that students in the second year generated significantly more commentaries than did those in the first year, and that students in both years generated significantly more information-based commentaries than the other types (Fig. 3).

3.6. Summary of Information-Access Characteristics

Differences between high-conceptual-progress and naive learners. High conceptual progress was associated with frequent engagement in representing knowledge, and engagement in knowledge constructive activities. In the solo-space, high-conceptual-progress learners engaged in deepening change in their problem-centred knowledge as well as widening their referent- and problem-centred knowledge. This suggests that high conceptual progress happens through two types of information flow: knowledge assimilation, and knowledge construction. Through knowledge assimilation, such learners may contextualize new information in their problem situation. Then, they might construct a higher level of understanding through elaboration of information in referent- and problem-centred knowledge. Thus, high-conceptual-progress learners see the database as their externalized problem space, then elaborate that space through their learning activity.

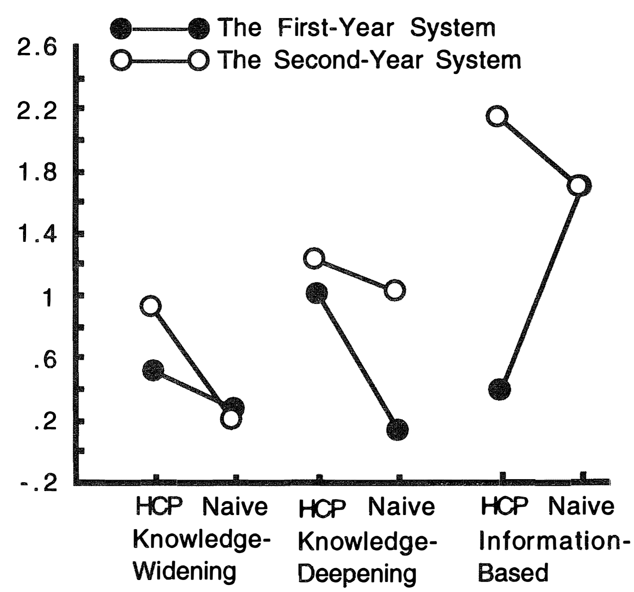

Figure 3. Mean Numbers of Different Commentaries.

The results of comparisons in the joint-space also emphasized the relation of high conceptual progress to students' engagement in deepening change from others' knowledge items. In particular, the results in the second year showed that high-conceptual-progress learners engaged much more in deepening change in knowledge from others' knowledge as well as assimilating others' referent-centred knowledge. These results suggest that high-conceptual-progress learners not only saw their database as their individual problem space, but also created a collective problem space.

Thus, students' active engagement in community knowledge-building consequently advanced their own level of understanding.

Differences between the systems. Differences in system affordances between the two years were quite evident. Students in the first year were much more directed to the solo-space of collaborative learning, whereas those in the second year were directed to the joint-space. This is because the second year's system provided students with discussion notes which have them naturally engage in their joint-space of collaborative learning. Characteristics of information flow engaged by students in the two years were also different in either the solo- or the joint-space. In the solo-space, students in the first year were more engaged in deepening change in referent-centred knowledge, whereas those in the second year were more inclined to deepening change in problem-centred knowledge. In the joint-space, students in the second year were more engaged in deepening change in knowledge and interactive information flows between the two types of knowledge. Problem-centred knowledge-building through interaction between the two types of knowledge is considered to be an effect of the discussion notes. Clearly defined problems in discussion notes are considered to have promoted students' concern with problem-centred knowledge. Furthermore, in the second year, most of students' individual knowledge was represented through peer written discourse centred around the problems. Coordination of their own and others' knowledge through dialogical written discourse might be more effective than individual notes in helping students to focus on information related to their own problems.

4. Conclusion

From the perspective of distributed cognition, the following points are worth emphasizing. First, high conceptual progress was associated with frequent engagement in distributed cognition. Advancement of individual knowledge relied much on distribution of information and active interaction among information sources. Interaction between learners and the database as a type of *person-plus-surround* system helps learners manage their learning processes. In particular, system affordances for students to monitor their thoughts at different times may be powerful. Students can manage distributed information or thoughts generated by themselves at different times. Results of knowledge change by high-conceptual-progress learners in the solo-space support this point. Furthermore, the second-year system also mediated collaborative learning among learners. Students manipulated others' thoughts at different times as well as their own thoughts. Here, distributed cognition occurs in another type of system, that of *people-plus-surround.* Results in the joint-space suggest that students should be aware of working in this type of system.

Second, some specific types of information flow are found to be critical to knowledge-building: knowledge transforming flows such as deepening change in problem-centred knowledge from referent-centred knowledge and deepening change in referent-centred knowledge from problem-centred knowledge. High-conceptual-progress learners were engaged in knowledge transforming information flows significantly more than were naive learners. This suggests that high-conceptual-learners were aware of different types of information and coordination among them, whereas naive learners lack such awareness. System support for naive learners to manage their represented knowledge in an externalized problem space should be further investigated on the basis of findings from cognitive science (e.g., Klahr & Dunbar, 1988).

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Appendix

An Example of Deepening Change in Problem-Centred Knowledge from Referent-Centred Knowledge.

ATOMS

Atoms are made out of protons and neutrons and electrons. In the middle of a atom, there is a ball called neutrons and near that, some balls, that contains electricity, called protons. That part is called the NUCLEUS of the atom. Also there are things that go very fast around the nucleus, they are called electrons. Each particle is either positive or negative. The amount of electricity in a particle is called its charge. A particle with a positive charge and a particle with a negative charge pull weakly at each other if the charges are small and strong if the charges are large.

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*** ELECTRICITY***

Try this:
Blow up two balloons. Rub them on a woolen sweater(i might work if you rub it on your hair too) and put on the wall. It will stick to the wall. Why does it stick to the wall? I think the explanation for this is, when you rubed on your woolen sweater(or on your hair), the some of the electrons from the sweater(or your hair) went into the balloon. So then the balloon had more electrons and it gave of the electrons that were extra to the wall. But after a short time the balloon will fall from the wall. That is because the extra electrons in the balloon will leak away

An Example of Widening Change in Referent-Centred Knowledge from Problem-Centred Knowledge.

How I Think Electricity Works

I think electricity works like this:there is electricity stored in a battery,and when you hook up a wire to that battery,and to a light bulb,the electricity from that battery runs through the wires,and into the light bulb,and the light bulb lights up.

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How I Think A Circuit Works

To make a light bulb light up,there has to be some kind of electric circuit for the electricity to run through. A circuit is usually made up of a few batteries,two wires and a light bulb.