Conceptual Change in Students' Self-Explanations

in a Collaborative Hyper-Media Learning Environment*

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Abstract

This exploratory study examined how elementary school students make use of a collaborative hyper-media learning environment in constructing self-explanations. The target environment was a computer-networked database system in which students externalize their thoughts in the form of text or graphics, then elaborate their thoughts by structuring with links or by commenting. Thirty students in a 5th- and 6th-grade combined classroom participated in this study as part of their regular curriculum. The students studied "how heat affects matters." Contents of their discourse in the database were evaluated by two independent raters from the perspective of whether critical conceptual changes happened in the students' explanations, then the students were divided into High Conceptual Change (HCC) learners and Naive learners. Further, the same contents of discourse were evaluated by two other independent raters by from the perspectives of (1) what types of theories the students generated, and (2) how they analogically applied their theories to sub-domains of the study topic. Results showed: (1) that HCC learners more often made use of theories and more engaged in analogically applying their theories within or across sub-domains. Further in-depth case analysis manifested critical differences in movement in problem space between a HCC and a Naive learner. A HCC learner was found to move in problem space by applying theories across different sub-domains, whereas a Naive learner was found to move by applying different theories within the same task domains. The results suggest that explaining-based

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* This study was conducted with financial support from The Frontier Foundation, Japan. We thank the teacher and the students who participated in CSILE for their wonderful products through knowledge-building.

analogical activity should be systematically supported either by system affordance or by supporters.

Background and Problems

CSILE: A Collaborative Hyper-Media Learning Environment

In this paper, we examined a classroom community supported by CSILE (Computer-Supported Intentional Learning Environments). CSILE is a networked computer environment particularly designed to support progressive discourse. In CSILE, students write text or graphic notes to convey their theories. These notes reside in a communal database where other participants have access to them, and can work collaboratively to compare theories, find counterexamples, record new information bearing on these theories, provide constructive commentary, and generally work to construct higher levels of understanding (Scardamalia & Bereiter, 1996). The system supports students' active engagement with theories by providing: (1) note types that encourage theory formulation and analysis and sustained inquiry regarding problems of understanding, and (2) database search mechanisms that support students in the creation of a collaborative community in which they read each others' notes and work to advance the ideas contained in them (Fig. 1).

Studies showed that students in CSILE classrooms outperformed students in traditional classrooms in understanding difficult explanatory texts and acquiring basic skills (Scardamalia, Bereiter, Brett, Burtis, Calhoun, & Smith-Lea, 1992). However, mechanisms behind such an achievement have not been sufficiently clarified. To this aim, previous studies attempted to figure out how students act as a member of a community of their classroom. Some studies (e.g., Oshima, Bereiter, & Scardamalia, 1995) applied a framework of information-flow analysis (Perkins, 1993) to describe differences in learning activities between high-conceptual-progress and naive learners in the classroom supported by CSILE. Results of the studies showed that high-conceptual-progress learners were more likely to integrate others' ideas or thoughts with their own ones in the knowledge-transforming way. They did not only read and comment on others' thoughts, but also applied their thoughts to solve their peers' problems and attempted to build new theories. Further, the studies showed that such progressive problem-solving would happen more effectively by introducing students a collaborative space called "discussion notes" in which they can explicitly share problems to pursue.

The aim of this study is to take one step beyond the analysis done in the previous studies: to analyze types of knowledge students bring in the learning environment, and to discuss individual differences in manipulation of the knowledge. Previous studies also focused on types of knowledge, but its analysis was too general to discuss specific curriculum. This study further focuses on details of domain specific knowledge: (1) what domains of a study topic students cover in construction of self-explanations, (2) where specific knowledge comes from, internal or external resources, (3) how students engage in progressive problem-solving. To this end, we take the following methodological approach.

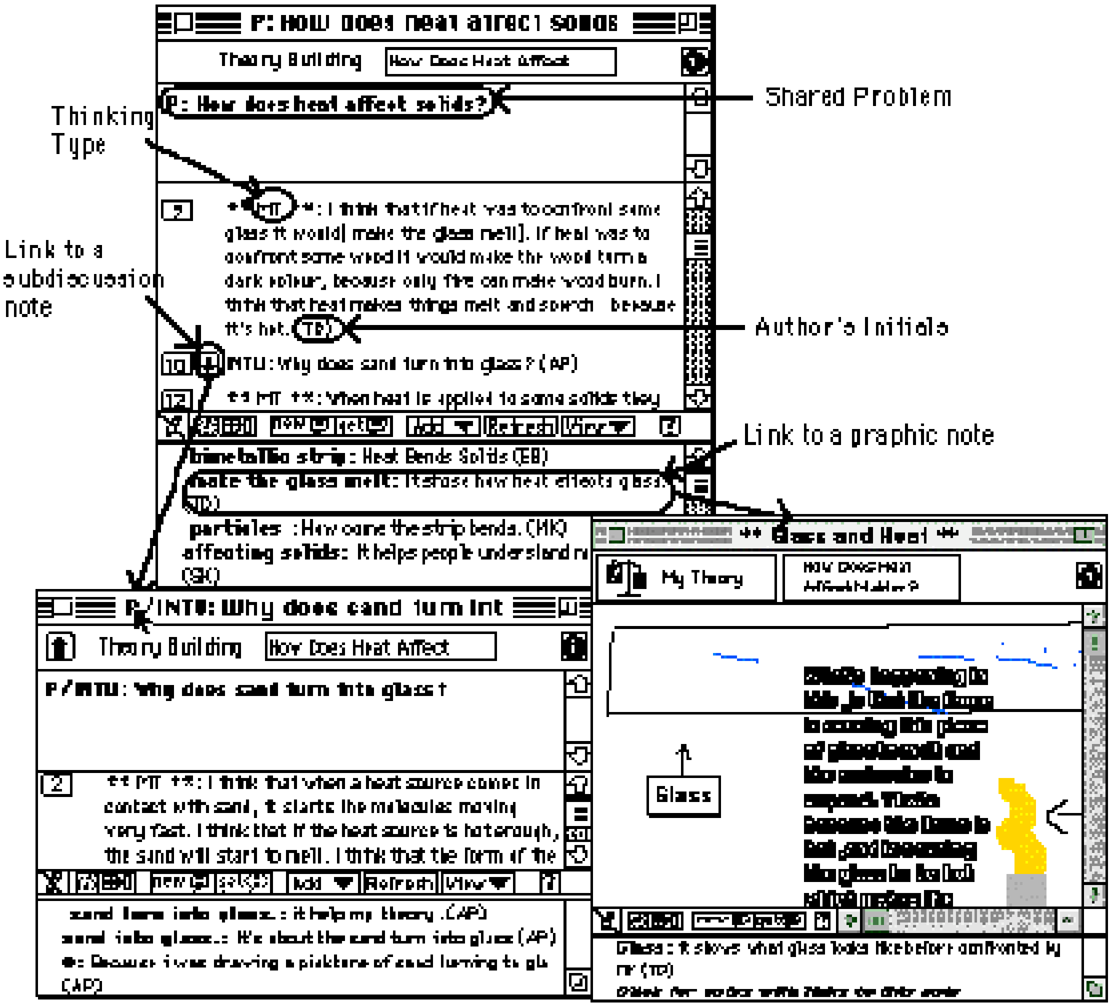

Fig. 1. An Example of Knowledge-Building in CSILE.

Methodological Issues

Category test for conceptual change. We focus on students' conceptual change as their achievement. Our concern is with students' conceptual understanding of a scientific phenomenon: "How heat affects matters." Conceptual change in students' written discourse in CSILE notes is evaluated based on Chi et al.'s *category test* (Chi, Slotta, & de Leeuw, 1994). The category test is a new method to assess which ontological tree(s) students attribute concepts to by classifying predicates the students used in their explanations. Based on progress in their conceptual understanding of heat, students are divided into High-Conceptual-Change learners and Naive learners.

Identification of students' theories in their explanations. Furthermore, for describing how students manipulate their knowledge in the database, we categorize theories used in their explanations. By referring to Vosniadou's idea of theory framework in conceptual change (Vosniadou, 1994), we identify types of theories each of which was based on the same framework of students' belief.

Analogical application of theories. For investigating how learners engage in progressive problem-solving, we shed light on their analogical application of theories. Inspired by Dunbar's observational study (Dunbar, 1995), we attempt to describe two different types of analogical applications of theories in CSILE. In this study, we create a problem space matrix of Theory by Domain for each learner, then describe how s/he moves in the problem space through analogical application of theories.

Study Description

Participants

Thirty students in a combined fifth- and sixth-grade classroom in a Toronto public school participated in this study. The school has an ethnically diverse, largely middle-class population.

Study Topic

The unit studied was a seven-week curriculum unit on heat and matter. Students conducted classroom experiments before they started CSILE sessions. During the CSILE sessions they recorded their theories about how heat affects matter and worked to provide explanations of the phenomena they viewed as part of the following experiments: (1) thermal expansion by using a ring and a ball, (2) heat conduction in different objects, and (3) heating bimetallic strips to see them bend.

How CSILE Sessions Worked

During CSILE sessions, students collaboratively engage in explanatory discourse on a shared problem. Students used discussion notes which require that they identify a problem of understanding and then enter the following note types: My Theory (MT), I Need To Understand (INTU), New Information (NI), and Comment (C). Students could then search the database by these entry types or by a variety of other attributes that CSILE records automatically (e.g., author) or that students assign to notes when they store them (e.g., topic or keywords). If they wanted to discuss a new problem that emerged in the course of pursuing the main shared problem, they created a sub-branch of the discussion note, and a subset of students pursued this line of inquiry while others continued with the central problem that they had identified. Students also generated graphic notes and created links between notes so that they could trace dialogical processes across different discussion notes, comment notes, and graphic notes.

The teacher had students focus on three main discussion notes, each of which dealt with a different form of matter, i.e., "How heat affects solids," "How heat affects liquids," and "How heat affects gases."

Data

Data used in this study were: (1) Contents of students' written discourse, and (2) log information of the date and time when students used CSILE.

Study Design

Students were first divided into High-Conceptual-Change (HCC) and Naive learners based on an analysis of conceptual change represented in the notes they wrote over the course of this investigation. Students' activities of using theories were then analyzed, with emphasis on the comparison of HCC and Naive learners.

Evaluation of Students' Conceptual Change

Conceptual change in students' written discourse in CSILE notes was evaluated based on Chi et al.'s *category test* (Chi et al., 1994; Slotta et al., 1995). The category test is a new method to assess which ontological tree(s) students attribute concepts to by classifying predicates the students used in their explanations. Two independent raters (inter-rater agreement = .95) classified concepts used in students' explanatory discourse as (1) material-based (e.g., heat as substance *having volume*), (2) process-based (e.g., heat as dynamic movement of molecules in objects), and/or (3) mental-state-based (e.g., molecules as substance *trying to avoid* heat).

On the basis of the category test of concepts used by students, two different types of learners were identified. Eight students who attained a process-based conceptual understanding of heat were classified as HCC learners, whereas the remaining 22 students were classified as Naive ones.

Identification of Students' Theories

Two other raters (different from those who rated conceptual change) independently identified learners' theories in CSILE notes, then discussed to create a taxonomy of the theories. Five categories of theory frameworks were finally agreed: (1) movement, (2) nature of substances, (3) density, (4) human metaphor, and (5) energy. Then they again independently categorized students' theories in CSILE notes into one of the five categories. The inter-rater agreement was .85. Disagreement was solved through their discussion.

The same two raters identified problem domains where learners used their theories to attain agreement of categories. Seven categories were finally identified: (1) heat conductivity, (2) change in modes of substances among solid, liquid, and gas, (3) change in shape, (4) change in color, (5) burning, (6) heat, and (7) others. Then they again independently categorized problems students raised in CSILE notes into the seven categories. The inter-rater agreement was .85.

Results

Comparisons of Theories in CSILE

Each learner's analogical application of theories was summarized in a problem space matrix (Fig. 2). Here, we analyzed: (1) frequencies of CSILE notes where students manifested their theories, (2) differences in frequencies across sub-domains.

A 2 (Conceptual Change) X 5 (Theory) ANOVA showed that both main effects and an interaction effect were significant, $F(1, 28) = 27.9$ for Conceptual Change, $F(4, 112) = 3.8$ for Theory, $F(4, 112) = 3.2$ for the interaction effect, all ps $< .05$. *Post hoc* comparison by

Tukey's HSD for unbalanced cells further manifested that HCC learners used density theories and human metaphor theories more often than did Naive learners.

A 2 (Conceptual Change) X 7 (Domain) ANOVA on frequencies of CSILE notes where students applied theories showed that both main effects and an interaction effect were significant, $F(1, 28) = 27.9$ for Conceptual Change, $F(6, 168) = 10.3$ for Domain, and $F(6, 168) = 6.1$ for the interaction effect, all $ps < .01$. *Post hoc* comparison by Tukey's HSD for unbalanced cells further manifested that HCC learners applied theories more often than did Naive learners in sub-domains of movement, nature of substances, density, and burning.

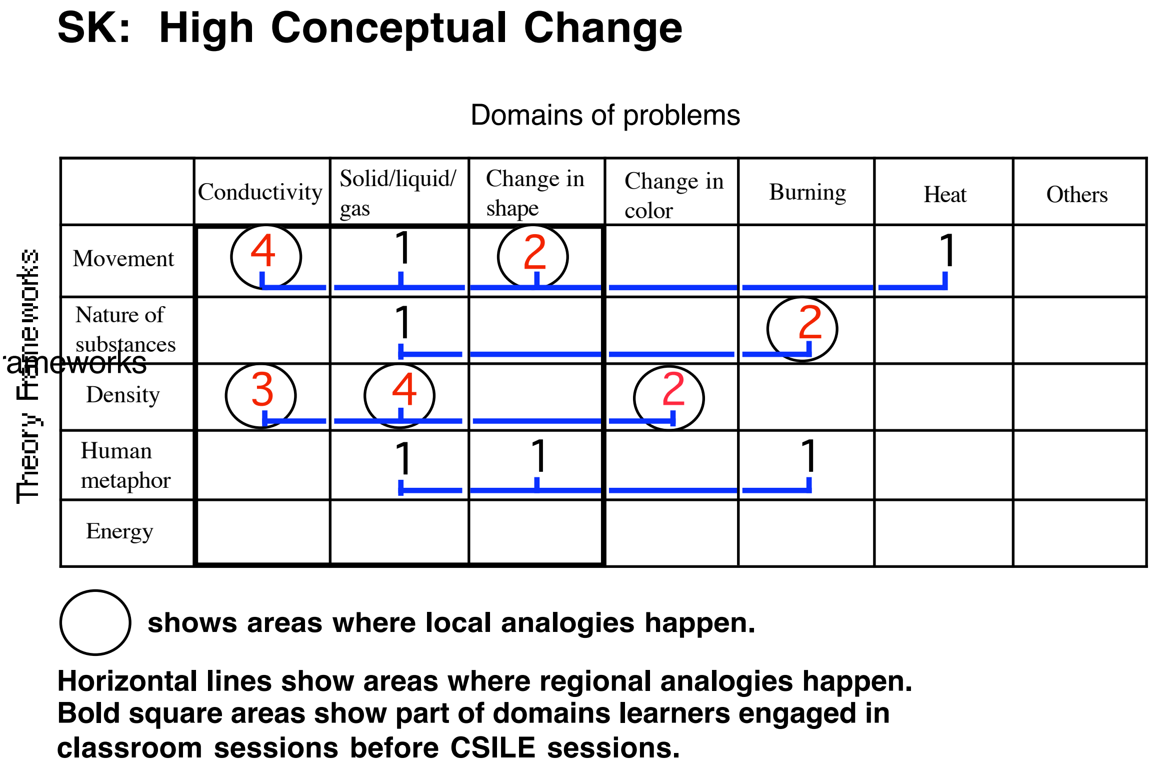

Fig. 2. An Example of Students' Analogical Application of Theories Across Different Sub-Domains of Study Topic "Heat".

Analogical Application of Theories

As Dunbar (1995) discussed, analogy is used by scientists to reason inconsistent data or hypotheses and to synthesize their ideas. He categorized scientists' analogies in laboratories into three types: (1) local analogy, (2) regional analogy, and (3) long-distance analogy. The local analogy means knowledge transfer within the same domain which does not require any critical change in problem spaces. The regional analogy means, on the other hand, knowledge transfer across different related domains which requires restructuring problem spaces. The long-distance analogy means mapping of knowledge to unrelated domains. Dunbar found that expert scientists use the first two analogies rather than the third one unlike we imagine. This result suggests that scientists' analogies are rather systematic strategies which lead themselves to more effective reasoning on their data and hypotheses. Therefore, our focus of analyses here was on students' use of different analogies, particularly local and regional ones.

Local analogy of theories. We defined that a student was engaged in local analogy when s/he repeated to use same types of theories in same sub-domains. In Fig. 2, circled cells were identified as areas where a student was engaged in local analogies. Multiple *t*-tests showed: (1) that HCC learners used more types of theories in local analogies, 2.1 for HCC learners vs. 0.2 for Naive learners, t (28) = 6.6, $p < .01$, (2) that HCC learners were involved in local analogies in more sub-domains, 2.3 for HCC learners vs. 0.2 for Naive learners, t (28) = 5.6, $p < .01$, and (3) that HCC learners more repeatedly engaged in local analogies, 1.4 times for HCC learners vs. 0.1 times for Naive learners, t (28) = 6.5, $p < .01$.

Regional analogy of theories. We defined that a student was engaged in regional analogy when s/he used same types of theories across more than two sub-domains. In Fig. 2, related cells were linked each other by horizontal lines. Multiple *t*-tests showed: (1) that HCC learners used more types of theories in regional analogies, 2.5 for HCC learners vs. 0.3 for Naive learners, t (28) = 7.5, $p < .01$, and (2) that HCC learners covered more domains in regional analogies, 1.5 for HCC learners vs. 0.4 for Naive learners, t (28) = 3.9, $p < .01$.

Movement in problem space through analogy. In addition to the above general analyses, we conducted an in-depth case analysis of movement in problem space by a HCC and a Naive learner. Each student's movement in a problem space matrix was described by splitting total process of her/his CSILE sessions into steps. We set boundaries between steps when learners had intervals of more than two days between sessions. With this criterion, total processes of CSILE sessions by both learners were split into seven steps. Here, for the limit of space, we briefly describe our findings. First, as we found in the quantitative analysis, in the initial steps, it was found that the HCC learner moved more often within domains which they had engaged in before CSILE sessions, whereas a Naive learner moved across domains related to classroom experiences before CSILE sessions and domains unrelated to the experiences. Second, as learning went on, both learners shed light on new theory frameworks. However, the HCC learner engaged in regional analogy of the theory framework to the experienced domains, whereas the Naive learner attempted to apply other theory frameworks to the same domains. Thus, from the results of the case study, critical differences in movement in problem space were found between a HCC and a Naive learner.

Discussion

Learners' Use of Theories and Conceptual Change

Results of the above analyses showed that HCC learners outperformed Naive ones in the use of theories. These findings support our previous research on problem-based learning and self-explaining in CSILE. In this study, a few more were found. First, HCC learners used theories more in particular sub-domains: (1) heat conductivity, (2) change in modes of substances, (3) change in shape, and (4) burning. The first three sub-domains were domains which they engaged in classroom sessions before CSILE. The fourth domain is considered a familiar one for learners in studying how heat affects matters. Second, HCC learners were not necessarily using more elaborate theories than those by Naive learners. HCC learners used two types of theories more: (1) density and (2) human metaphor. Obviously, human metaphors are primitive theories. Although HCC learners finally attained understanding of heat as process, they had not been in more elaborate stage of explanations before starting their study. Thus, these particular results lead us to conclude: (1) that learners' attainment of conceptual change does not result from their initial level of scientific knowledge, but (2) that intentional use of theories based on their experiences or knowledge facilitates learners' deeper comprehension of the scientific concept.

Learners' Analogical Application of Theories

Results showed that HCC learners outperformed Naive ones in the use of both local and regional analogies of theories. HCC learners engaged in local analogies: (1) with more various theories, (2) in more various domains, (3) more repeated times. In addition, HCC learners engaged in regional analogies: (1) with more types of theories, (2) across more domains. Thus, both local and regional analogies are found to be crucial to conceptual change. Further case analysis provided us with interesting findings. First, a HCC learner was more likely to engage in analogy within his familiar domains in the initial steps, then challenged new domains. Second, the HCC learner was more likely to apply new theories to domains related to his classroom experiences.

These results suggest us that, for attaining conceptual change, learners must not only more engage in analogy of their explanations, but also follow some systematic movement in problem space through their analogy. Keys to critical improvement of conceptual understanding are: (1) recognition and clarification of own understanding, and (2) integration of new thoughts and ideas into their own understanding.

CSILE Affordance to Support Conceptual Change

How did CSILE support learners in engaging with such progressive problem-solving? More concretely, we want to focus on a question: Why did HCC learners engaged in local and regional analogies more than Naive ones? Here, we discuss this question by a further brief analysis of students' use of CSILE. First, numbers of discussion notes in which learners participated were compared between the groups. A *t*-test showed that HCC learners were participating in more discussion notes than were Naive ones, 9.8 notes for HCC learners vs. 3.0 for Naive ones, $t\ (28) = 4.7$, $p < .01$. Second, frequencies of commentaries by learners were also compared. A *t*-test showed that HCC learners produced more commentaries on others' thoughts, 1.6 times for HCC learners vs. 0.3 for Naive ones, $t\ (28) = 4.3$, $p < .01$.

The results of the analysis suggest that HCC learners were more social than Naive ones in the database communication. CSILE provides learners with opportunities to consider what others are thinking on shared problems. Participation in a discussion note may prompt learners' reflection of their own ideas and others' ones. In such a situation, students would be able to think of applicability of their own theories to problems raised by their peers. Furthermore, participation in multiple discussion notes could be an opportunity to think of applicability of their theories to different sub-domains. In both opportunities, learners would be able to map others' theories to their own problems, or see how others apply similar theories to different problems within and across sub-domains. Although it has not yet been systematically analyzed, our case study also showed that the HCC learner shed light on new theory framework in working in discussion notes created by others.

Finally, we like to put our concern with collaborative learning environments. As suggested in the case study, Naive learners clearly showed some difficulties in coordinating what they had already understood and what they were working on. The Naive learner in the case study failed to apply new theory framework to his familiar domains to elaborate his understanding. This result suggests that we need some system or human support to help learners simultaneously manipulate different aspects of their knowledge.

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