Inducing a Shift from Intuitive to Scientific Knowledge with Inquiry Training

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Abstract

Recent research in science education has shown that students frequently fail to understand scientific concepts and principles, e.g., photosynthesis. In the present study, elementary-school aged children were trained in how to conduct a collaborative inquiry into photosynthesis. Concept maps and comprehension pretest and posttests were used to assess the effects of the training. Students who had received the training had concepts maps which contained significantly more accurate scientific relational links depicting a more functional understanding of photosynthesis, and they retained more subject matter knowledge than the students who did not receive the training. The research supports the importance of inquiry training to facilitate conceptual understanding of scientific knowledge and emphasizes the usefulness of conceptual mapping techniques as evaluative measures of students' conceptual change.[1]

Organization of knowledge: Its effect on accessibility and use of knowledge

Ideally, individuals should be able to access and utilize their knowledge when necessary. In practice this does not happen; acquired knowledge does not guarantee that it will be accessed (Bransford, Sherwood, Vye, & Rieser, 1986; Chi & Ceci, 1987). One solution to this problem, developed by researchers advocating the teaching of thinking skills, is that students need to learn skills in order to access and retrieve their knowledge (Nickerson, Perkins, & Smith, 1985). In contrast, another explanation is that the organization of a person's knowledge is said to be a more critical factor than the extent of a person's knowledge itself (Flavell, 1971; Prawat, 1989). The lack of well structured domain knowledge may result in a reliance on "world" knowledge which has often led to faulty inferential reasoning (Gobbo & Chi, 1986). Accordingly, the aim of this study is to examine the effects of inquiry training to promote better knowledge structures by motivating the "connectivities" in knowledge which will, in turn, enhance knowledge accessibility (Prawat, 1989). If accessibility is a function of the associative links or relations between nodes (Clancey, 1990), then the task is to be able to evaluate the organization of that knowledge from both a conceptual and a structural perspective. However, since we can only theorize about the content and structure of a person's knowledge, we use tasks requiring that individuals organize their knowledge explicitly (i.e., think aloud methods). This study used a reasoning task called concept mapping, which is believed to provide some access to the structure and content of students' knowledge, and would therefore provide a measure of students' shifting beliefs or conceptual change in science.

The results presented in this paper are taken from a larger study conducted by Coleman (1992) in which the effects of inquiry training were obtained. The training was designed to promote increased reflection, greater discussion, and reasoning, which was found to lead to more coherent and explanatory knowledge (as measured by students' explanations and their concept maps) and greater retention of the subject matter. Only the results from the concept mapping and comprehension tasks will be discussed here. The explanation data will be reported elsewhere (Coleman, in preparation).

Method

Subjects and Design

Subjects were forty-eight students (22 girls and 26 boys) enrolled in two grade 4/5 classes at two public schools, within a middle to upper class socioeconomic range. One was located in central Toronto, and the other in a suburb of Toronto. The students ranged in age from 9.5 to 11 years. All students were assigned to homogeneous groups (High and Average Intentional

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Learners) based on their responses to their individual Implicit Learning Theory Interview. The main purpose of this interview was to identify a learning stance or approach to learning called "Intentional Learning," which distinguishes itself as a problem-centered rather than routine-centered approach to learning (Bereiter & Scardamalia, 1989). It was believed that by prompting students, who don't naturally act in this way, to do so, they would perform more similarly to High Intentional Learners and exhibit greater knowledge advances than those students who were not prompted to do so. Twelve students who scored 80% or greater on the interview scale were assigned to the High Intentional Learning group. The remaining thirty-six students were then randomly divided into an Average Intervention group (experimental group) and an Average group (High, n=12; Average, n= 18; Average Intervention group, n= 18). Students within each Average group and the High group were then randomly divided into smaller groups, each containing three members per group.

Materials and Procedure

Comprehension tests on photosynthesis. All students were administered a comprehension pretest and two posttests in order to assess their understanding of photosynthesis and to verify that the groups did not differ significantly in their (prior) knowledge of the domain. The multiple-choice format tests ranged in difficulty levels on photosynthesis, and were constructed from the materials presented in the instructional unit and from a "think aloud" protocol of an expert botanist's description of the process of photosynthesis. The following are two test items taken from Posttest 1 and the Alternate (more complex) Posttest 2 (Rukavina, 1991):

Posttest 1:
How does carbon dioxide enter the plant?
a) Through tiny holes in the leaves
b) Through the roots of the plant
c) Through the flowers or buds on the plant
d) Through the stem

Alternate Posttest 2:
In what season do trees make the least amount of food? a) winter; b) spring; c) summer; d) fall

Concept Mapping. Concept mapping is a technique for examining specific changes in conceptual and propositional meaning (Novak & Musonda, 1991) and it serves as a tool for examining an individual's structural knowledge (Champagne, Klopfer, Solomon, & Cahn, 1980; Chi, Feltovitch, & Glaser, 1981; Novak & Musonda, 1991). A concept map is a graphic arrangement of a given set of concepts or words. It is usually depicted as a hierarchical network consisting of concepts (nodes) and their relations to other concepts (links). Similar to a propositional network, the links display the nature of the relationships between the concepts. In order to understand the function or meaning of scientific concepts, one must understand the relations between them. It is assumed that the more relations between concepts one understands, the more integrated the knowledge. The goal is to have a well-integrated functional understanding of a domain which can be illustrated by the number and type of valid concepts and relations depicted in the map.

All students learned a four-week instructional unit called "The Power Plant" (Roth & Anderson, 1987) on photosynthesis and plant reproduction given by their teacher. After two weeks of subject matter instruction, all students were given a concept map and a list of relational terms and asked to work collaboratively to label each link. The concept map contained 16 nodes and 24 non-labeled relations in total. Students were then re-administered the same concept maps after two additional weeks of instruction. An "expert" concept map on the subject of photosynthesis was constructed based on an expert's description of the process of photosynthesis (the expert was a professor in the Botany Department at the University of Toronto). The expert concept map was used to construct a mapping task to be given to the students. Before presenting the concept map to the students, all of the link labels between the concepts were removed (i.e., removing the nature of the relationships between the concepts), leaving the concepts and a skeletal structure or representation of the domain (see Figure 1). The expert's link labels, along with additional links, were presented to the subjects on a separate piece of paper. Students were required to "fill in" the link labels as part of the task, and the labeled links were used as dependent measures of the students' knowledge.

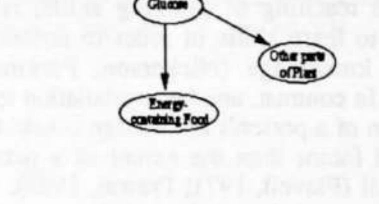

Figure 1. Portion of the photosynthesis concept map.

Inquiry training intervention. In order to promote higher-level thinking processes in science, students in the Intervention group were given inquiry training learning prompts (cues) which were in the form of written questions or prompts that they asked themselves or asked other members of their groups. The training required students to articulate, construct, and apply explanations, justifications and evaluations of each others' responses. Briefly, the learning cues were written on cards and placed in front of the students while they worked on the mapping task collaboratively. During the sessions, students were told to choose at least one of the learning prompts which best fit with how they were thinking, read it aloud, and respond to it. They were instructed to repeat this process after each decision regarding a relational link was made (see Table 1 for examples of the inquiry prompts).

Table 1. Examples of the Inquiry Prompts

Purposes and Prompts:

(a) To convey that it is important to evaluate one's own thinking or understanding by constructing explanations:

- Can you explain this in your own words?
- Can you compare how you used to think about this with how you think about it now?

(b) To convey that it is important to justify any evaluations of one's own or another's responses with an explanation:

- Explain why you believe that your answer is correct or wrong.
- How does your answer compare with another person's answer?

(c) To convey that their explanations should be based on the conceptions that one has been learning in class and not on one's everyday knowledge:

- What did we learn in class about this particular topic?
- Can you explain this using the "scientific" information that we learned in class?

Procedure for scoring concept maps. Relational links were first scored as correct or incorrect, then the correct relational links were rated as either "Intuitive" or "Scientific." Scientific links were those that were either referred to by the expert botanist's protocol, or were mentioned in the text on photosynthesis. Examples of Scientific-Correct links (in bold face) versus Intuitive-Correct links (in italics) are the following:

- Leaf cells **absorb/** *take in, suck up* water
- Minerals **travel/** *go* to the leaves
- Leaves **contain/** *have* leaf cells
- Leaf cells **release/** *give off, let out* oxygen
- Sunlight **is absorbed by/***goes in* chlorophyll
- Carbon dioxide helps to **produce/***make* glucose
- Stem **transports/** *moves* the glucose
- Roots **store/** *hold* glucose

Results

Comprehension pretest and posttests

It was hypothesized that there would be a significant difference between the High and Average groups and between the Average Intervention and Average groups with respect to students' knowledge of photosynthesis as measured by their performances on the concept mapping task and the photosynthesis comprehension posttests. A repeated measures multivariate analysis of variance was conducted in order to test whether differences existed between groups on their performance on the comprehension pre- and posttests. The between-subjects factor was group (High, Average Intervention, Average), and the within-subjects factor was the use of the pretest and posttest as the dependent variables. The means and standard deviations are presented in Table 2.

Table 2. Cell Means and Standard Deviations for Students' Pre- and Posttest Comprehension Scores.

Group	Pretest	Posttest 1	Alternate Posttest
High	Mean .31	.85	.71
	S.D .10	.15	.13
Average Interv.	Mean .29	.84	.65
	S.D. .11	.17	.08
Average	Mean .31	.74	.53
	S.D. .13	.19	.18

The results of the analysis revealed that the students did not differ in their degree of prior knowledge of photosynthesis at the outset of the study (as measured by the pretest). The analysis also revealed that there was a significant multivariate main effect for group ($\underline{F}(2,45) = 3.13, \underline{p} < .05$). Scheffe group comparisons indicated that the High and Average Intervention groups performed significantly differently from the Average group on the Alternate (more complex) posttest, although they did not perform significantly differently from each other. The High group and the Average Intervention group retained or learned proportionately more photosynthesis knowledge than the Average group who did not receive the intervention as measured by both Posttests. The

Average Intervention group's performance more closely resembled that of the High group which did not receive the intervention. In summary, it appears that the inquiry training facilitated greater comprehension or retention of students' knowledge of photosynthesis.

Results of the collaborative concept mapping task. A separate repeated measures multivariate analysis of variance was conducted in order to test group differences in their performances on the collaborative concept mapping tasks. The between-subjects factor was group (High, Average Intervention, Average), and the within-subjects factor was Learning Session (1, 2). The dependent variables were (1) Intuitively Correct Links, and (2) Scientifically Correct Links. The analysis revealed that there was a significant multivariate effect for group ($F(4,24)=5.46$, $p<.003$). Significant main effects were found for the proportion of Intuitively Correct Links ($F(2,12)=17.61, p<.001$) and for the proportion of Scientifically Correct Links ($F(2,12)=15.59, p<.001$). Bonferroni group comparisons indicated that the High and Average Intervention groups outperformed the Average group with respect to the proportion of Correct Intuitive and Scientific Links used on both trials. The High and Average Intervention Groups did not perform significantly different from each other. Thus, the High and Average Intervention students were making more correct and scientifically correct relational links in their maps than the students who did not receive the inquiry training.

A significant multivariate effect was also found for Trial ($F(2,11)=28.16, p<.001$). Group performance was significantly different on Trial 2 on the proportion of Correct Scientific Links used ($F(1,12)= 60.78$, $p<.001$). No significant difference existed between Trials on the proportion of Correct Intuitive Links ($F(1,12)=1.11, p<.31$). In addition, a significant multivariate main effect was also found for the Group by Trial Interaction ($F(4,24)=3.80, p<.02$). This interaction may be explained by a "leveling-off" in the number of Correct Intuitive Links on Trial 2. In contrast, the High and Average Intervention Groups gained and used more Scientific Links over trials than did the Average Group. In sum, this analysis revealed that over the two learning trials, the students who received the inquiry training were gradually making fewer intuitive links and replacing them with more scientific links (See Figures 2 & 3).

Lastly, Pearson correlations were used to examine the relations between performance on the concept maps and the comprehension posttests. A significant correlation was found between the Alternate Posttest and Scientifically Correct Links ($r = .42$, $p<.01$). It appears that the students who used more Scientifically Correct Links also retained or acquired greater comprehension of the subject matter.

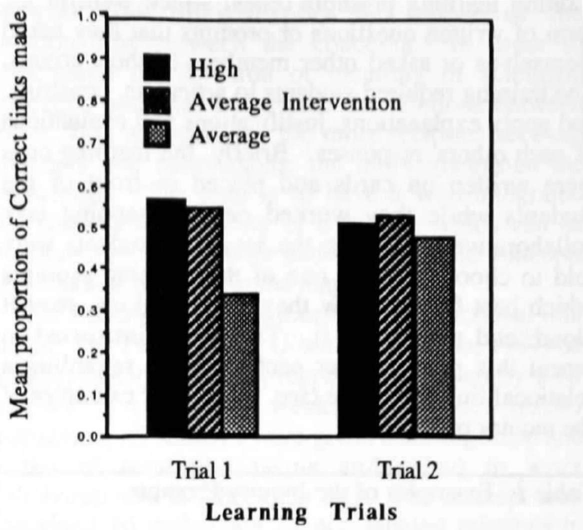

Figure 2. Mean Proportion of Correct Intuitive Links made by groups on the concept maps

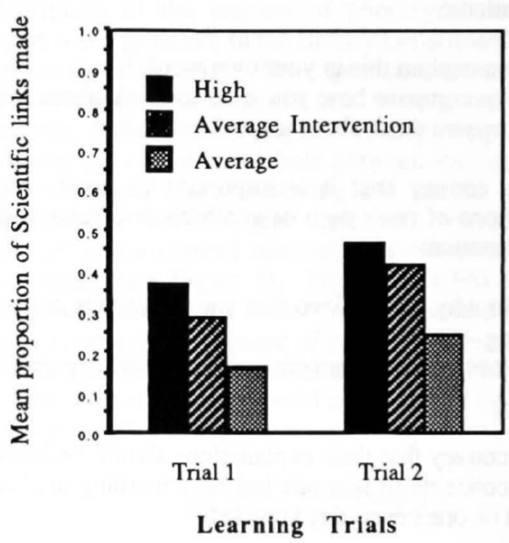

Figure 3. Mean proportion of Correct Scientific Links made by groups on the concept maps.

Shifting from Intuitive to Scientific: An Indication of Conceptual Change

Apart from the overall significant findings in favor of greater performances made by the Intervention groups on the collaborative concept-mapping task, the most interesting finding from the concept-mapping task is the shift that occurred in the nature of the students' labeled relational links.

If one follows the assumption that the link labels that were chosen represent the students' understanding of the relationship between the concepts, then, as students acquire more knowledge of photosynthesis, that change should be reflected in the nature of their link labels. The change that occurred can be described as a shift from *Intuitive* to *Scientific* links. It appears that, following the teachers' instruction, students begin to replace the "intuitive" labels of their links with more advanced "scientific" links. In addition, the same students were also found to learn and retain more photosynthesis knowledge than those in the nonintervention groups. Taken together, this suggests that they have achieved a more advanced or "scientific" relational understanding of the variables. It is possible that, as students acquire more domain knowledge, they begin to attach these scientific terms to their own intuitive terms and use the scientific terms with very little understanding. Over time, as they hear and use the scientific terminology, the students begin to make sense of those terms, and the scientific terminology becomes part of their own vocabulary which, in turn, facilitates deeper understanding.

Although the changes in the relational links are not gross semantic differences, they do not represent subtle changes. They reflect changes from intuitive colloquial relations to scientific terms as descriptions of the same phenomena. It is possible that these changes are indications of the transition that students make when they are beginning to learn new scientific theories or explanations. Students begin to abandon their own terminology and attempt to use the vocabulary of the scientists as descriptions of the same phenomena. Thus, becoming aware of the acceptability of scientific terminology or knowledge versus common knowledge appears to be a crucial factor in understanding different ways of treating scientific information (Caravita, 1990).

Why does this shift occur? One explanation is that the students are simply repeating the pertinent scientific terminology that they hear the teacher use or read about in their text, without displaying any understanding (akin to rote learning). However, this seems unlikely since the students who utilized the scientific terminology also acquired greater comprehension of photosynthesis. Another, more interesting, way of explaining the shift from "intuitive" to "scientific" understanding is by characterizing this shift as a developmental precursor to "form-function" reasoning.

According to cognitive developmental research, students organize their knowledge into discrete categories, principles or theories such as animate-inanimate objects; external-internal (Carey, 1985; Gelman, 1990); personification (Hatano & Inagaki, 1987; Inagaki & Sugiyama, 1988), including the distinction between intentional and nonintentional acts. These categories function as precursors for organizing their reasoning and thoughts of scientific concepts, and may be an important and potentially useful heuristic in the development of scientific understanding.

According to this view, as students initially form an understanding of a scientific process, they construct functional reasons or explanations which include personification and intentionality of the objects involved in the process (Hatano & Inagaki, 1987). For instance, by initially stating that "the roots suck-up the water from the soil," the student personifies a functional relationship between plant concepts by utilizing and attaching a human analogy which implies that the roots have intentional acts (i.e, sucking). Following two additional weeks of subject-matter instruction, the same student states that "the water is absorbed by the roots," thereby stating a functional relationship between concepts that is more objective and devoid of human-like qualities or intentions, and thus making it appear more scientific in nature.

What is particularly appealing about this view is that it does not depict students' reasoning as faulty by emphasizing their misconceptions. Rather, it describes their reasoning as necessary and systematic; utilizing their everyday or intuitive knowledge to move towards a more scientific understanding (Brown, 1990).

Concept maps cannot capture the dynamic nature of scientific knowledge and they give an impression that the knowledge is static in nature. The reader, however, should view the students' concept maps as a useful tool for capturing an impression or "photograph" of a person's scientific knowledge at a point in time.[2]

Lastly, although cognitive and social approaches to learning science have highlighted the importance of discussion for helping students achieve meaningful understanding, research on collaborative learning has generally not examined whether the nature of students' discourse will have differing effects on students' understanding of scientific phenomena. The present study offers support for the idea that collaborative inquiry training, which promotes explanation-driven modes of thinking about scientific phenomena, can induce a shift from an intuitive to a scientific view of a complex subject matter such as photosynthesis.

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[2] However, this should not be taken to mean that it represents the organization or structure of a person's knowledge found inside their head.

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