

Scardamalia, M., Bereiter, C., Hewitt, J., & Webb, J. (1996). Constructive learning from texts in biology. In K.M. Fischer, & M. Kirby (Eds.), *Relations and biology learning: The acquisition and use of knowledge structures in biology* (pp. 44-64). Berlin: Springer-Verlag.

*(NOT FINAL VERSION)*

## **Constructive Learning from Texts in Biology**

Marlene Scardamalia, Carl Bereiter, Jim Hewitt, and Jim Webb

**Abstract.** In schools, discourse usually plays a part in the constructive process. We have been developing and experimenting with Computer Supported Intentional Learning Environments (CSILE) that combine the educational advantages of collective discourse with the tactical advantages of individual written and graphic work. In this paper we track three successive classes of grade 5-6 students working on the same biological topic (body systems). We find that students take a more goal-directed and constructive approach to using text information: (1) when students create a context for figuring out how things work by advancing their own provisional theories in advance of taking information from texts; and (2) when students identify gaps in their own knowledge.

**Keywords.** Constructive learning from text, biology learning, inert knowledge, problem-centered knowledge, situation model, CSILE, collaborative learning, problem centered student research.

Passive learning from texts is often lamented. The typical elementary school biology text presents information in a topic-detail organization that is efficient for assembling and memorizing facts, but that is relatively useless for the pursuit of understanding. Students who passively take in what the texts present may end up with inert knowledge, difficult to apply and rapidly forgotten. Their actual understanding of biology, which is to say the problem-centered knowledge they call upon to make sense of the world and of stories and discourse in the real world, tends to be based on informal experience and hence deviates in many ways from scientific knowledge. As a reaction against such passive learning, many educators favor "hands-on" methods which have weaknesses of their own (Roth, 1990) but which in any event cannot cover large parts of the terrain of biological knowledge. Therefore, the production of more active and constructive learning from authoritative sources remains a significant goal for instructional research.

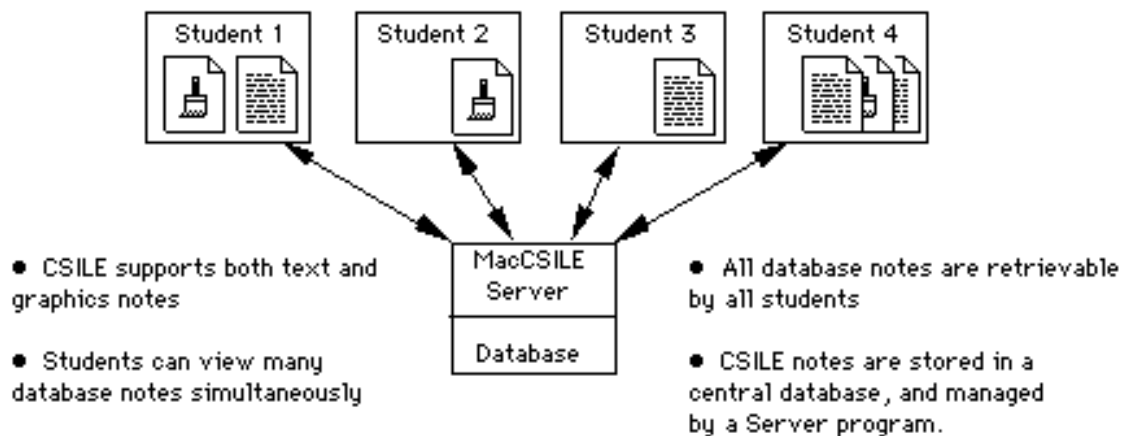
What constitutes constructive learning from texts? It means more than constructing a textbase-- a macropropositional representation of what the text says (Kintsch & van Dijk, 1978). It means bringing one's own mental models to the text, using them to identify significant text information, and revising one's mental models through efforts to reconcile model and text. This we take to be part of what Kintsch (1988) means by construction of a situation model, as distinct from constructing a textbase. In such cases it is the organization of the situation model—the model of that aspect of the world addressed by the text—rather than the organization of the text itself which dominates. Assuming that the students' mental models have been organized in ways that facilitate practical action and making sense of the world, they are likely to provide a better framework for organizing new information than the topic-detail framework typically provided by texts. We suggest that this is true, even if the student's mental model is naive, simplistic, even seriously in error. It at least provides a way of bringing new information obtained from texts into the process of understanding, and in this way there is the possibility of improving, perhaps even restructuring the mental model.

In schools, learning from texts is seldom a solitary endeavor. Discourse usually plays a part, even if it is only the recitation characteristic of conventional pedagogy. Whether discourse is of this ritualistic kind or whether it involves a more natural give-and-take of ideas, school discourse is likely to focus on what the text says, on achieving a consensual representation of its content (Heap, 1985). Thus, in Kintsch's terms, it is concerned with constructing a textbase. According to the considerations set out in the preceding paragraph, however, it would be educationally preferable to focus instead on the students' own mental models and on the implications that text information has for them.

Although many educators might endorse this proposal as being in accord with their constructivist and child-centered philosophies, they would likely find it difficult to implement. How are the individual mental models of 30 or so students to be brought out for discussion and used as frameworks for considering the significance of text information? Daunted by the tactical difficulties of doing any such thing through the medium of class discussion, teachers are likely to resort instead to having the students do individual "projects," in which they produce documents based on their own reading and deliberation. But such projects are famous for inducing passive use of text material—copying or paraphrasing text material and placing it into an organization much like the organization of the book or encyclopedia article it came from.

## Computer Supported Intentional Learning Environments

The computer-supported learning environment that we have been developing and experimenting with over the past 6 years, may be seen as an effort to combine the educational advantages of collective discourse with the tactical advantages of individual written and graphical work. Computer Supported Intentional Learning Environments (CSILE) is a networked system built around a communal database into which students enter text and graphic notes (Figure 1). Stored information is made public by default so that children may easily examine each other's contributions and work with one another. Access to database materials is provided by a flexible retrieval utility that permits complex searches by author, topic, and other attributes. Through this mechanism, students share their learning goals, theories, wonderings and discoveries.



**Figure 1.** CSILE: A networked system for sharing text and graphics notes.

A typical collaborative episode is shown in Table 1. Here, one grade 5 student makes a general inquiry about cells. A second student, seeing the question on the database, responds with helpful information.

**Table 1.** A Typical Collaborative Episode in CSILE

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Problem: Do cells keep you alive? - Julie.

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Dear Julie:

I think I can help you. Nothing can live without cells, and if something doesn't have cells, it is not a life form. - Cheryl.

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The CSILE program allows students to move easily between individual and collaborative work. At an individual level, the database serves as a written record that

allows students to return to ideas, set goals, construct plans, list questions, and record hypotheses. These writings are then made available to everyone, and become the framework of collaborative discussion. In this way, each learner is provided with the opportunity to describe their personal mental models, which in turn feed the knowledge-building activities of the classroom. This has several advantages over traditional groupwork activities. In comparisons of CSILE to face-to-face groups, we found that student contributions are quantitatively more equal over CSILE than when class discussion is their sole means of communication (Cohen, 1992). All participants have equal opportunity to express their ideas, and all participants have an equal voice. We believe this not only benefits the individual student, but it exposes the class to a greater variety of ideas than they would normally encounter in face-to-face situations.

The technology itself is neutral as to what students do with text information and with their own mental models. At one extreme, CSILE may be used simply as a medium for doing "projects" of the conventional kind, with the benefit of text editing, color graphics, and storage and retrieval functions. At the other extreme, through its commenting functions and capabilities for collaborative building of networks of charts, it may be used for sustained collaborative inquiry. In this paper we shall report and examine a progression that took place over three successive years in the way grade 5-6 students worked on a biology topic in CSILE. The classes did not start at one extreme and move to the other, but the Year 1 class showed much of the behavior that has been associated with conventional "projects." The Year 3 class shows a decided shift in the direction of more collaborative inquiry, focused on their own mental models, their own questions and efforts to make sense of biological phenomena, rather than on what the available texts happened to present. The changes in procedure that brought this shift about were relatively minor, but apparently powerful in effect, and part of our effort in this paper will be to understand how they worked.

## Method

We track three successive years of students' work on the same topic in a single junior-level class. Each year there was a common structure to what went on in the classroom. Approximately 32 grade 5-6 students received a brief introduction to the major systems in human biology: circulatory, immune, skeletal, respiratory, reproductive, and nervous systems. They were told to form themselves into groups and identify topics for research. The overview might be considered an introduction to the vocabulary of human biology, clustered more or less in the manner of a table of contents of popular curriculum material (see Table 2). Student work was entered into the CSILE database in the form of text or graphic notes, where it could be commented on by other members of the working group as well as by other students in the class.

**Table 2.** Topical Organization of Curriculum Material

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*Source*

*Topics*

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Harcourt, Brace, Janovich, 1980	Animal Structure and Function: Digestion, Respiration, Transportation, Excretion, Coordination, Reproduction; Cell Structure and Function and Heredity
Suzuki, David (1987); Toronto: Stoddart Publishing Co.	Looking at Looking at You, Your Skin, the Body. Your Bones, Your Muscles, Your Heart and Blood, Your Lungs, Your Digestive System, Your Brain and Nerves, How You Communicate

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## Year 1 Observations

In Year 1, nine student groups were formed, with two to five students per group. The nine groups selected topics as indicated in Table 3. As the table indicates, student inquiry focused on loosely structured ideas held together by broad topics of the sort found in curriculum materials. Students worked out among themselves the various topics that different students in the group would pursue. Figure 2 shows the self-titled, self-designed "Respiratory System" group's plan of study, a rather disjointed array of issues. This approach was typical.

**Table 3.** Examples of Student-Selected Research Topics, Year 1

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### **The Skeletal System: group of 3 students**

The spinal cord, the rib cage, the foot, the thigh, the knee, bone, the hand

### **Cells: group of 3 students**

The nucleus, chromosomes, genes, nerve cells, muscle cells, white blood cells, skin cancer

### **The Respiratory System: group of 4 students**

The lungs, smoking, origin of cigarettes, the mouth, asthmatics, the heart, respiration, asthma

### **The Senses: group of 3 students**

The ear, the nose, the eye, blindness, deafness, nasal congestion, nosebleeds, odor

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various body systems, along with explanations of the workings of these organs and some suggestion of interrelationships between body systems.

When asked to set out issues that they wondered about, clarifying what they knew already and what they needed to find out to advance their understanding, we found students claiming to know facts of the sort set out in their textbooks:

**Muscles:** "I know that muscles are made up of muscle tissues, and tissues are made up of muscle cells. Muscular dystrophy is the number one disease of muscles."

**Endocrine System:** "I know that the endocrine system produces hormones...the parathyroids and thyroids are organs in the endocrine system and both help make hormones."

And when they wondered about things, they tended to wonder about the kinds of things you go to an encyclopedia or textbook to find out. For example, "What are the organs of the respiratory system?" "How are bones formed?" "What is the axial skeleton?" Generally, in Year 1, inquiry driven by student interests paralleled textbook approaches to the study of biology. It makes sense that their models for how to study are based on textbook models, since they are the only models they are likely to have had contact with.

Over the course of their study there was minimal integration of concepts. A common strategy was to collect a set of facts from an authoritative source and then reproduce that information in CSILE. On only a few occasions did students try to use their own knowledge as a basis for their research or attempt to make sense of how biological systems work. Their most productive research episodes seemed to occur when they stepped outside the static formulation of issues and topic groupings presented in textbooks. At this point they (a) identified novel, interesting research contexts for their investigations, (b) engaged in inquiry based on everyday phenomena, and (c) focused on problem-centered accounts of phenomena, trying to understand how things work. Such occasions were rare, but the resulting activity suggested the benefits of an inquiry-driven, knowledge-centered approach, which we experimented with in years 2 and 3.

Some students in year 1 generated inquiries that were unlike the standard text-based questions that dominated the class database. These "I wonder" questions had the potential to engage students in novel, interesting research studies that would significantly advance their understanding of biological processes. About a dozen such questions were identified during the Human Biology unit. Examples:

**Muscles:** "What's happening when you have a stiff muscle?" "What would happen if you didn't have muscles?"

**Endocrine System:** "What does the endocrine system use to make hormones?"  
"What types of defects afflict hormones?"

**Diseases:** "How do the medications for skin cancer work?"

Finding answers to the questions in the research materials was difficult, precisely because these questions were wonderment rather than text-based. Consequently, students

often identified interesting research problems, but had trouble advancing on them. Some students recognized that the textbooks were not providing them with all the information they needed. For instance, one child working on the endocrine system followed up his question-asking session by entering 7 notes into CSILE's database. Notes were titled: Pituitary gland, pancreas, adrenal glands, thyroids, parathyroid, kidney, and thymus. Material seemed to be copied from textbooks. Then he wrote the following note:

My answer to the question how endocrine organs know when to produce hormones is that the pituitary gland sends hormones which stimulate the other organs such as the adrenal glands to create hormones, *however, I don't know how the pituitary gland knows when to produce hormones*. My answer to what hormones are made of is, hormones are made of organic material(*my source did not say what type of organic material*). My answer to why we need hormones is we need hormones to regulate our body and to maintain homeostasis. My answer to the question can defects in the endocrine system be environmentally caused or caused by genes that were passed on or both is both.

Here we see the student's original questions played an important role in shaping his research. We have italicized statements showing that the student understands that textbook material does not provide all the necessary information, and that there remain gaps in his understanding. Questions like these motivated the development of an "INTU" (I Need To Understand) facility in year 2 for identifying knowledge gaps, and bringing these gaps forward for progressive refinement. A parallel and integrated "NI" (New Information) facility was added that encouraged students to record new information that they found in the course of their investigation. We stressed "new information" rather than "answer" to clarify the iterative process of finding relevant, though not sufficient information, reframing problems of understanding in light of new information (a new "INTU"), and progressively advancing in an area of inquiry as opposed to more textbook based, question-answer processes.

Other profitable inquiries in year 1 arose out of student curiosity relating to everyday phenomena. Textbook writers acknowledge the need to start with everyday events that students can relate to, but there are dramatic differences in how the textbook writers proceed and how students proceed. For example, D. C. Heath's "Focus on Science" text starts by having students take a deep breath and placing their hands on their chest so that they can feel their ribs expand and their diaphragm move. Silverstein and Silverstein (1969) have students hold their nose and breathe through their mouths as part of their exploration of the gateways to the respiratory system. In CSILE, a child who wanted to know about the role of the diaphragm in relation to hiccuping wrote a "what I know" note. In it, she claimed to know that "everyone has their own individual laugh"--which led her to question how and why we laugh. Why are there individual differences? Reading these "hiccuping" and "laughing" notes inspired another child to ask "What is happening inside your body when you sneeze?" and "What is snot?"

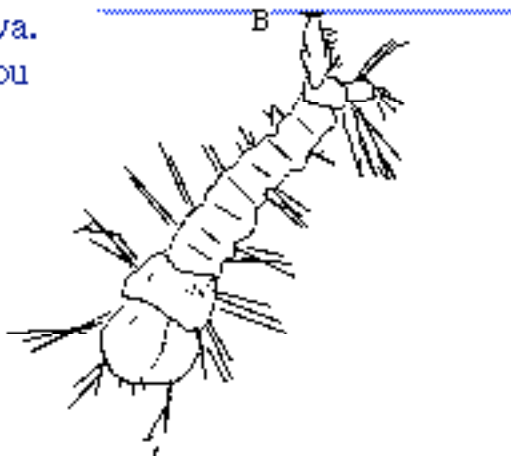
Again, they did not continue their investigations--perhaps because of limited classroom time, but likely because the reference material was obscure, and difficult to obtain. Additionally, the failure of classroom resources to address these questions may

have caused students to question the value of their inquiries. That is, if questions are not addressed in classroom textbooks, then perhaps they are not good questions to ask. Students following this line of thought begin to place a higher value on the reference material than on their own wonderings, and shift the focus of their studies accordingly. In years 2 and 3 we attempted to deal with this issue by organizing the database around student-generated problems, and by placing greater emphasis on student questions, intuitions, and beliefs.

Another year 1 student wondered about respiratory systems for animals besides humans. This led to the following statements and questions: "I don't know how insects breathe, but they do not have lungs." "How can there be a gas (oxygen) in a liquid (water)?" "How do whales breathe differently from humans and fish?" In attempting to answer her questions she discovered that whales have lungs like humans, whereas fish have gills. Thus whales must come out of the water to breathe whereas fish must get oxygen from the water. This led to an extended set of notes about how humans, insects, and whales breathe--with pictures of human and whale lungs, grasshopper and human trachea, etc. Then came the issue of aquatic insects.

more aquatic insects

This is a mosquito larva.  
It uses a snorkel, as you  
can see, to breathe.  
When it is out of the  
water, the top of the  
snorkel opens.  
Underneath, it  
tightly closes.



This is the valve on the end of a mosquito larva's snorkel



OPEN



CLOSED

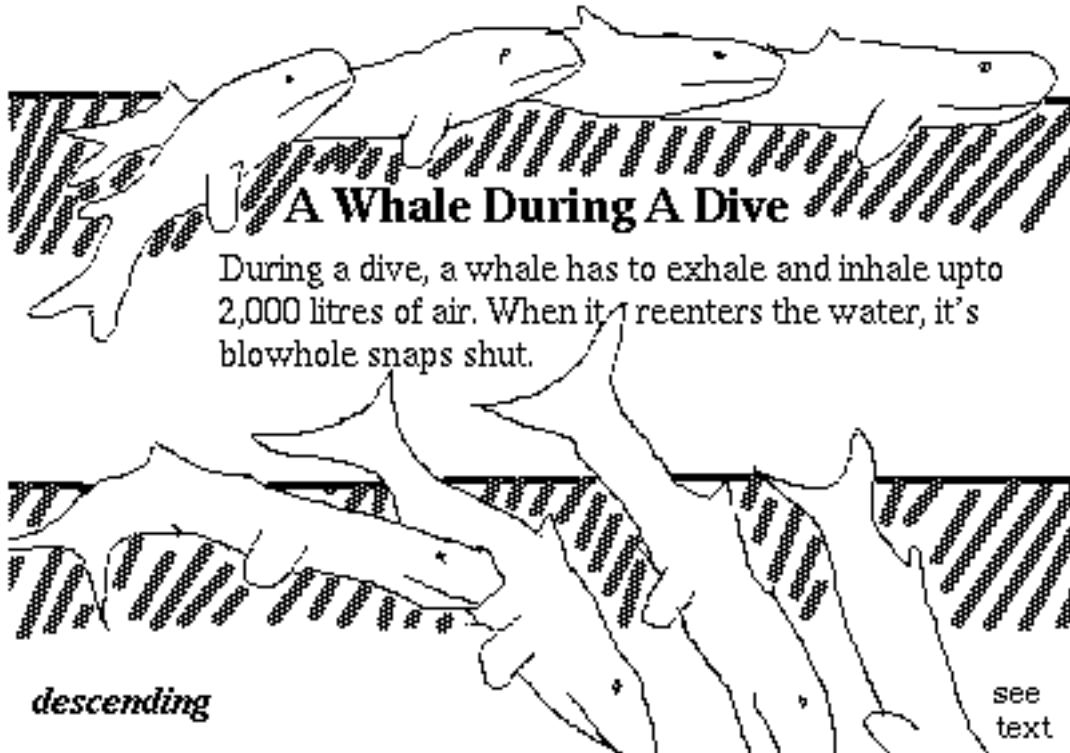


SIDE VIEW closed

Figure 3. Breathing and aquatic insects, year 1.

## whale diving

*ascending*



**Figure 4.** How Whales Breathe. Whales are mammals and they have lungs like us. That means they have to come to the surface to breathe. Whales can hold their breath much longer than people: the baleen whale can hold it's breathe for up to 40 minutes, and the sperm whale for up to 75 minutes. Whales store much more of their oxygen in their muscles (about 41%,) and we store only about 13% in our muscles. We breathe through our mouthes, but whales breathe through their nasal passages. During a dive, they exhale through the blowhole. Then they must take several deep breaths to restock their muscles with oxygen. They have to do all this with 2 000 litres of air in a limited time. After this, the blowhole closes tightly. The heart beat slows down, and so does the blood flow, except to the heart and brain.

Figures 3 and 4 compare aquatic insects and whales. The whale picture is annotated, explaining that whales can hold their breath much longer than people--from 40 minutes (baleen whales) to 75 minutes (sperm whales), and whales store much more oxygen in their muscles. She even notes that the whale's heart beat slows, as does blood flow, except to the heart and brain. Again, we see deepening inquiry leading to interrelationships between systems: in this case respiratory and circulatory systems. As in the prior case, the student-generated inquiry leads to interesting research topics approached from a novel perspective. Further, we begin to see signs of the kinds of supports for inquiry that are provided by students commenting on each other's notes. The

student who dealt with respiration from the point of view of hiccuping and laughing read the whale note, offering this comment:

This note tells me a lot about how whales breathe. But you should try to find out why they can hold their breath longer than humans and explain how large the baleen and the sperm whale are so that I could get an idea of what size creature you are talking about and that would make it easier to understand why they need so much air. Otherwise an excellent note.

Progressive problem-centered research episodes like these, were rare in the year 1 database. In subsequent years we introduced collaborative group discussion tools that provided increased support for these sorts of shared knowledge-building activities.

To summarize findings from Year 1, for the most part students wondered about the kinds of things found in textbooks, and asked questions of the sort that can be answered with the right text. Their concerns clearly were mediated by the kinds of issues that textbook biology enculturates them to think about. Accordingly, on the first pass what they claimed interest in and wished to understand matched information presented in textbooks. Their text-based and mental models, insofar as we were able to tap them, were similar.

We see in a few situations the beginnings of a problem-centered approach to learning that has potential for more profound understanding than textbooks afford. Our goal in subsequent years has been to tap this potential more effectively and to create contexts for more sustained inquiry. The approach we have taken is to organize the study around student-generated problems, and to facilitate collaborative inquiry through the introduction of "group discussion" notes. We have also provided facilities that encourage the expression of theories, and the sharing of knowledge gaps and new information. Our overall challenge is to come to terms with two serious problems highlighted by our efforts to engage students in self-directed research. First, student inquiry was modeled after textbook accounts of biological processes, which represent a topical/structural approach to learning. In the hands of young students we find more fragmented treatment of these topics than would be the case if the contents of these texts received more systematic treatment through teacher-directed pacing of contents. Second, while there was some explanation-driven inquiry, the students did not get deeply into problems.

### **Years 2 and 3 Observations**

Year 2 was a transitional year in which several new procedures were introduced that were consolidated in Year 3. The results in Year 2 were also transitional, showing a mixture of characteristics of the Year 1 results and those that were to emerge more strongly in Year 3. Consequently, we focus on Year 3. Our efforts in Year 1 aimed to create conditions for extended inquiry of biology text material by bringing students' mental models to the fore. We met with limited success. In subsequent years we delayed introduction of relevant text material in an effort to loosen the links between students' personally-constructed and curriculum-textbook models of learning biology. Further changes included:

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**Table 4.** Examples of Process Problems, Year 3

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**Brain Cells:** group of 3 students

P: What kind of cells are there in the brain, and how do they differ from the other cells in the body?

P: How does the brain store information?

P: What do neuron cells look like and how do they work?

P: What are the different parts of the brain and what are they used for?

**Lungs:** group of 3 students

P: How do the lungs separate the oxygen from the carbon dioxide.

P: How does smoking affect the lungs?

P: What do lungs do ?

P: How do the lungs protect themselves from the dirt we breathe, and how do they get rid of the dirt that is in the windpipe on its way to the lungs ?

P: What diseases affect the lungs, and how do you catch them?

P: How do the lungs work?

**Muscles:** group of 2 students

P: Why does the muscle increase in size when it is flexed, and decrease when relaxed?

P: How do your muscles get bruised?

P: Does the size of muscles affect your strength?

P: Does the motor neuron run through, or attach, to anything else besides the muscle fibre and the motor end plate?

P: Can cartilage contract?

P: If the motor neuron is a nerve that sends electrical pulses to your muscle does it give your muscle a shock?

P: Why are you weak and tired after using your muscles for a long period of time.

P: How do your muscles get bruised?

P: How do muscles make us move?

P: How do muscle fibres contract?

**The Eye:** group of 3 students

P: Where is the eye's control panel located.

P: What causes an eye to blink ?

P: How does every thing give or reflect light and how can a eye see that.

P: I have researched the eye and the camera and found they are very similar in many ways. I have written this note because I found that both the eye and the camera see a picture upside down. I would like to know why that happens and how.

P: How the Eye sees colour.

P: How does the eye function?

P: How is the eye similar to a camera?

P: How does the message that the eye is sending get to the brain?

P: How does colour blindness occur?

The students employed a direct approach to problem-centered inquiry. Each group identified a topic of interest, as in the previous year, but they had to reformulate their interests in terms of "process problems." Examples of process problems appear in Table 4. All subsequent investigations were organized around these problems, instead of around topics as they had been in Year 1.

Students were encouraged to access mental models more directly. New thinking types were introduced that frame problems more directly in terms of personal statements of belief: "my theory (MT)," and "I need to understand (INTU)." In Year 2 we noted that statements of "my theory" occurred considerably less frequently than in Year 3. In Year 3 students were encouraged to write their theories in advance of looking at text material. After students formulated their theories, they were encouraged to specify what they need to understand (INTU) in order to evaluate their theory. It is at this point that they were encouraged to look at texts, adding "new information" (NI) notes.

A "group note" format was established. All of the students working on the same problem made entries into a common note rather than having each student write separate notes that could only be aggregated through searches of the database. The goal was to increase interaction among students and thereby support more extended inquiry.

The teacher took on the role of expert learner in the class. His communications with students, both on and off CSILE, focused on the questions students were struggling with, and ways in which they could deepen their inquiry and clarify their personal theories. Some examples of his CSILE comments are shown in Table 5.

Other than these four changes, the unit on human biology was conducted much as in the previous year, starting with a brief introduction to major body systems. In Year 3, twenty-eight students formed eleven groups and selected topics as indicated in Table 4. The students used the same resource materials, worked in the same small groups, and continued to make frequent trips between their desks and the CSILE computers. In terms of classroom organization, there were no outward differences. But the way the students approached biology changed dramatically. Consider, for example, the contrast in how students approached the topic of cells. For the most part, Year 1 notes read like material out of an encyclopedia. Research consisted of gathering facts from various sources and re-writing them in CSILE (see Table 6). The facts were not necessarily related, nor were they in any particular order. But in Year 3, students were engaged in a substantially different type of research (see Table 7). Here we see an interesting mix of probing inquiry and statements that conveyed students' naive understandings. Their ideas about biological processes were brought forward in forms that we believe could enliven and deepen biology education. Differences between the Year 1 and Year 3 outputs are also evident at the organizational level. The topical / structural approach of Year 1 (Table 3) was completely replaced by a problem-centered approach in Year 3 (Table 6).

**Table 5.** Teacher Comments, Year 3

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- This is very interesting. Have you any theories on why nerve cells don't grow back in some species, such as ours, but they do grow back in species such as salamanders (I think). I thought we were supposed to be the most evolved form of life! Also, do you know whether it is possible to transplant nerves the way we transplant kidneys?
  - I think this is a very interesting note. I was wondering if you were going to consider how the cells differ in function? For example, do they have any special structures that enable them to communicate with other cells?
  - You raise some interesting points in this note. I wonder what antigenetic proteins are? Could you explain that? What do you suppose the relationship is between antigens and antibodies?
  - This is a good problem Barb. Another disease you might be interested in is emphysema. I think this disease is on the rise in our society, at least. Do you have any ideas on why?
  - Lynn, I find it very interesting that red blood cells have no nucleus and are not able to reproduce. Do you have any theories on why that might be?
  - Perhaps you could try to find out what a stroke is and how it affects the brain. The findings might give you some clues as to how the brain stores information.
- 

**Table 6.** Cell Research, Year 1

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## Cells

Cells are made up of atoms. Cells are the smallest common unit of life we study. There are about 10 trillion cells in your body right now. The cells in your body might look like something you might find in the sea or ocean. They might have tentacles or hair or even spikes. Cells can't be seen by bare eye. You would need a really good microscope. When you put cells together you make tissues. All living things are made of cells. Some small things that live in the sea only have one cell. Bacteria is the smallest kind of cell. Nerve cells are the largest kind of cell. Some nerve cells are three feet long. The cell membrane gives food and oxygen for the cell to eat to make energy. Plant cells are bigger than animal cells therefore are easier to see. Plant cells and animal cells differ in many ways. Such as animal cells need oxygen to live and plant cells need carbon dioxide to live. Most plant cells can make their own sugar substance. It is made of the energy from the light and water and carbon dioxide. This substance is called photosynthesis. Each cell in your body has its own personal job. Cells do not live very long except for brain cells which you should have for life. The jelly like stuff in the cell is

called cytoplasm. The nucleus controls the cells reproduction. The blood brings digested food to the cell. Cell is a latin word that means "a little room". The cell became known after they invented the microscope because you couldn't see the cell with your bare eye. When carbon dioxide gets near the cell, the cell will not let it in. The organelles are like our organs.

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**Table 7.** Cell Research, Year 3

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**Problem:** How does the eye function? (BN)

**My Theory:** I think that the muscle in the eye can let it go in any direction it wants so that it can see anything without turning the head around. Also I think that there is a special part of it that can allow the brain to see the picture rapidly and still have a good look at it. (BN)

**I Need To Understand:** What the muscles of the eye do. (BN)

**New Information:** The eye is in the nervous system. Special senses such as the eye, are called the sense organs. There are six muscles attached to the eyeball that can move it in any direction the brain wants it to. The muscles of the iris can make the pupil increase or decrease its size. (BN)

**My Theory:** I think that there is almost a kind of filter behind the eye where the picture goes through transforming it into waves which the brain understands. (NT)

**I Need To Understand:** How the eye sends pictures to the brain. (BN)

**New Information:** I have gotten some new information on the eye. I have read that every object gives or reflects light. The eye reads that reflection and sends its message to the brain where it can be identified. (BP)

**New Information:** There is a black panel behind the eye which absorbs the light and makes sure none can get out. (NT)

**New Information:** An object that the eye is focusing on gives a ray of light and goes by the cornea, the aqueous humor, the pupil, the lens, the vitreous humor and then it reaches the retina. When the light hits the cells of the retina they react the nerve cells and then the optic nerve brings the message to the visual cortex hitting part of the brain which reads the message. (BN)

**I Need To Understand:** Why the pupil increases and decreases. (BN)

**My Theory:** As I already found out that the muscles of the iris can increase or decrease the pupil, I think that when there is a strong source of light the iris tries to protect itself

from the light and uses its muscles to decrease the pupil and when it is doing so the eyelid slightly closes. (BN)

**New Information:** Everything the eye sees is really light reflecting off the object. (NT)

**I Need To Understand:** How the parts of the eye help get to the message to the brain. (BN)

**New Information:** When an object gives the light it hits the curved surface of the cornea. After leaving it, the iris increases or decreases the pupil and it goes by. If there is a strong source of light the pupil will decrease to shut off light that is not needed. After the light rays pass the pupil it passes the curved lens then it passes the vitreous humor and hits the retina where the light rays meet. If the light rays meet on the retina the image is clear and if it goes inside or in front, the image will be blurred. Then the light passes the retina and goes through the nerve cells to get to the rods and cones. The cones are in about the center of the retina, they also do most of the seeing during the day. They give clear images with a lot of detail. The image is brought by the optic nerve and is read by the brain. (BN)

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This new focus on student-generated inquiry allowed us to better observe student situation models and the evolution of these models during the learning process. We made the following observations:

**Student-generated theories:**

**A context for figuring out how things really work**

In Year 1, students rarely expressed their theories about biological processes. But in Year 3 their theories provided a context from which they could begin to figure out how things work. Theory-construction was encouraged even in situations in which the student knew little, or nothing, about the underlying processes. Consequently, many student theories were simplistic, or contained misconceptions. For instance, the following child began her investigation of cells by proposing that each limb has a specialized cell type:

**My Theory:** I think cells tell all the parts of the body what they are supposed to do. So an ear cell tells an ear what to do, an arm cell tells an arm what to do and leg cells tell a leg what to do.

Initially, we were afraid that misconceptions such as these might be propagated among students. But a study of classroom beliefs determined that this was not the case (Burtis, Chan, Hewitt, Scardamalia & Bereiter, 1992). Students seemed to recognize that entries labeled as "my theory" were attempts by their peers at understanding biological processes, and not necessarily scientifically accepted explanations. Instead, theories provided a foundation upon which the learner could build an investigation, and begin a discussion with peers. Bringing the situation model to the fore led to new ideas and questions, as can be seen in the following example:

**My Theory:** I think that antigens and antibodies are the same. I think that antibodies kill germs in the body. Maybe when these germs ( if they are the same germs) enter the body again the antibodies kill them before the disease develops. That is my theory on why you usually only have chicken pox once. I wonder why you have colds more than once then! I think that the antibodies in your body do not always destroy some diseases or viruses because they do not recognize them as a harmful substance. That is my theory on why some diseases, such as Aids cannot be naturally cured.

Later, this student discovered that antigens and antibodies were not the same, and also learned how vaccinations work with the immune system to fight disease.

**Student-generated questions:**

**A context for identifying gaps in understanding**

As follow-up work to their statements of belief, or their analysis of text material, student in Year 3 formulated "I Need To Understand" statements. Examples of these entries are shown below:

**I Need To Understand:** How when you are sleeping, do you keep breathing and not stop and die?

**I Need To Understand:** How muscles are kept from falling off the skeleton.

**I Need To Understand:** How does the nerve cell send messages?

**I Need To Understand:** When the veins bring the blood containing carbon dioxide and other waste products back to the right chamber of the heart how does it get rid of it?

**I Need To Understand:** HOW does the blood take the oxygen from the lungs? How does it deliver it to organs? Why does our body need oxygen?

**I Need To Understand:** Why do red blood cells have no nucleus and do not reproduce?

**I Need To Understand:** How does the long-term memory store the information?

These inquiries subsequently led to deeper investigations of the subject matter. Some problems that began as an investigation of a single organ (e.g., "How do the lungs work?") produced sub-questions that broadened the investigation into a study of an entire biological system (e.g., the circulatory system). Overall, students demonstrated a remarkable capacity for figuring out what they needed to know to advance their understanding. They seem to have greater insight into their mental models than curriculum writers have (Leinhardt, 1990). Almost all INTU statements inspired further, deeper discussion although few were completely resolved. But in contrast, many Year 1 questions were not addressed at all.

### **Student Research: Finding information to fill gaps in understanding**

Year 3 students found relevant, though seldom complete information regarding the issues they raised. Most of their information was found in reference books from the library, CD-ROM materials, or the encyclopedia, and then entered into CSILE as "New Information" entries. Two examples are shown below. The first example is taken from an investigation that began with the problem, "How do the lungs separate the oxygen from the carbon dioxide?" The second example is from the problem, "How do muscles make us move?".

**New Information:** When the oxygen comes into your lungs from the bronchial tubes, it passes through a wall of something called alveoli. A alveoli looks like a bunch of balloons mashed together. Inside the alveoli are some tiny blood vessels, called capillaries. After the oxygen passes through the alveoli and capillary walls, it gets sucked into the red blood cells. The red blood cells need more oxygen, and they have been traveling around your body collecting carbon dioxide. By the time the red blood cells get back to your lungs, all their oxygen has been turned into carbon dioxide. They have a lot of carbon dioxide to get rid of, and a lot of oxygen to bring in.

**New Information:** The steps of a muscle contracting in a arm. 1-your brain sends an electrical message through the axon of the motor neuron. 2- the motor neuron stimulates the muscle fibre. 3- this makes the muscle fibers enlarge, so the muscle can contract. 4- now the arm can move. It may seem like a long proses, because the way I'm explaining the steps one by one, but this all happens in a split second.

As in Year 1, these students extracted information from various resource materials, and brought the knowledge back to CSILE. But the Year 3 students were guided more by their own developing model, and less by the organization of the textbook. In Year 1, students extracted information somewhat indiscriminately from the texts available to them. In Year 3, they tended to sift out those materials that were relevant to the problems they were trying to solve. Personal knowledge needs guided their research efforts. Unfortunately, inadequacies in the resource materials frequently blocked students from moving deeper into problems.

### **Revised Explanations**

Year 3 students almost always revised their explanations before the termination of the investigation. Curiously, they rarely used "My Theory" to express their revised explanation, preferring to use "New Information" instead. The one exception to this occurred during an investigation of color blindness. The initial theory is shown below:  
**My Theory:** I think that it happens by the lense getting damaged and a certain quality of it being lost.This quality,(I think), enables the eye to see things in colour.

After some further questions and the acquisition of additional information, the student produced the following revision:

**My Theory:** When the light rays reach the retina, they pass through nerve cells to reach

the rods and cones. The cones lie mainly in the macula, a small area near the center of the retina. They are less sensitive than the rods and respond only to pretty strong light. They are responsible for colour vision. The rods cannot see colour and I think that colour blindness is caused when the cones are damaged and only the rods are left which can't see colour.

Revised explanations are useful because they make knowledge advances apparent to the student, as well as to other readers of the database. The tendency for year 3 students to express these revisions in "New Information" statements was initially surprising to us, but upon reflection, a logical product of an explanation-centered programme. Rather than use "New Information" to simply list facts gathered from their research investigations (as they had done in year 1), the students were also attempting to synthesize those facts into a coherent, logical, explanation. "New Information" entries like those in part (c), and the revised "My Theory" shown above are examples of students attempting to build increasingly more explanatory models of biological processes during their investigations.

## **Discussion**

Why should such small changes in procedure and shifts in emphasis produce such a change in the way students used texts in learning? It appears that getting students to venture their own "theories" in advance of getting into texts is crucial. Finding an adequate theory to explain phenomena then becomes the guiding purpose, resulting in a more goal-directed and constructive approach to text information. Our own "theory" about this phenomenon is as follows: As suggested at the beginning of this paper, constructive learning from text requires bringing one's own mental model to the text. But what if you do not have a mental model to bring? We cannot be sure whether this is the case with the students we have been working with or whether they have mental models that are not brought to mind. The result is the same in either case: If they start reading texts, with no mental model of their own brought into the process, they are inclined to read passively and to be dominated by the text model (which is not a theoretical model that the text may be referring to but the topic-detail model of the text itself). What the Year 3 procedure does, we believe, is get students to construct provisional mental models, which they can then bring to texts. A testable but as yet untested hypothesis is that this results in new information being organized according to the mental model rather than according to the text structure. In any event, it leads to more active, constructive processing of text information, with greater relevance to problems of understanding.

We find that students are initially reluctant to present provisional mental models. They know that they are just making something up and that they lack essential information. One of the virtues of getting them to do so is that it sets them up for the next step, INTU ("I need to understand"), in which they try to identify the information they actually need to produce a more adequate theory. There are probably other ways of getting students to develop or activate mental models in advance of going into texts. Biology experiments, observations, and so on might provide stimulus and some basis for theorizing. But if our interpretation is correct, "hands-on" activities will only be effective if they are carried forward to the point where students produce their own provisional

explanatory models.

In follow-up experiments we plan two classes of activity: to link students with biology experts and to take advantage of the pockets of local expertise that arise from student specializations. With regard to the former, we expect to demonstrate that CSILE students need less access to content specialists than is typically assumed, and when they have expert access, they make better use of it. Procedures used in Year 3 foster local specializations, because individual students do a great deal of thinking about specific issues such as blood clotting, breathing, etc. The database that they construct via CSILE allows students to begin viewing their work in the aggregate. We believe that local pockets of understanding will expand in fascinating ways as students who have studied a process deeply make contact with others who have studied related but different phenomena deeply. Overall, we plan to continue creating profitable contexts for student inquiry. Using new knowledge media and new knowledge processes, we hope to expand student understanding of biology.

## Acknowledgements

The authors wish to acknowledge the generous support of Apple Computer, Inc., External Research Division; the James S. McDonnell Foundation; the Ontario Ministry of Education under its block transfer grant to the Ontario Institute for Studies in Education; the Ontario Ministry of Colleges and Universities through the University Research Incentive Fund; and the Social Sciences and Humanities Research Council of Canada. We are indebted to the Grade 5-6 students at Huron Public School who contributed their time and talents to this project. We are also grateful to Peter Rowley, Earl Fogel, Wayne Liu, Russell Owen, and Alan Rosenthal who made the software modifications necessary for this study. Finally, we'd like to acknowledge the efforts of the entire CSILE team, without whose contributions the work reported here would not have been possible.

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