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ABSTRACT

Discrepant questioning is a teaching technique that can help students "unlearn" misconceptions and process science ideas for deep understanding. Discrepant questioning is a technique in which teachers question students in a way that requires them to examine their ideas or models, without giving information prematurely to the student or passing judgement on the student's model. This strategy prompts students to see the contradictions in their own model. This study focuses on the analysis of small group tutoring sessions on human respiration. Four 2-hour classes were held with a group of 4 eighth-grade students. The group included two boys and two girls and was ethnically diverse. The students were instructed with a Standardized Teaching Sequence based on model construction and criticism theory developed in 1998. The instruction was organized around five individual target models related to the microscopic structure of the cell; internal structure of the cell; and the digestive, circulatory, and respiratory systems. Evidence suggests that students had a marked increase in comprehension of human respiration. Quantitative analysis showed that the small group had an overall significant mean difference of over three standard deviations on the pre- to post-test. (MVL)

# Discrepant Questioning as a Tool To Build Complex Mental Models of Respiration

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# DISCREPANT QUESTIONING AS A TOOL TO BUILD COMPLEX MENTAL MODELS OF RESPIRATION

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Research in science education shows that students often fail to retain knowledge gained in the classroom. There may be two reasons for this. First, many teaching methods do not allow students sufficient opportunity to process knowledge, to understand deeply enough to integrate new knowledge with old. Second, research shows that many students have misconceptions, ideas that they have gained through their own experience that are different from scientists, ideas. Misconceptions can prove to be quite resilient, and students often "bounce back" to their former ideas after a short while.

Discrepant questioning is a teaching technique that can help students "unlearn" misconceptions and process science ideas for deep understanding. Discrepant questioning is a technique in which teachers question students in a way that requires them to examine their ideas or models, without giving information prematurely to the student or passing judgement on the student's model. This strategy may also be called dissonance producing, because it prompts students to see the contradictions in their model, the ways in which it is unworkable. Evidence suggests that students in classrooms where discrepant question was a major part of the curriculum produced dynamic models of respiration, constructing complex concepts into an integrated whole.

According to Tweney (1987), all science involves an attempt to construct a testable mental model of some aspect of reality and involved in most kinds of problem solving tasks and in most kinds of inferential reasoning. "The self creates a new and different world - a cognitive

[1]construction- and the representations created become models and theories in science; as images are pictures of reality, the act of imagining is the manipulation of mental pictures as opposed to the manipulation of concrete objects."

Unfortunately, many students have difficulty building testable mental models and understanding concepts in science. It may be that some of this difficulty is due to students' inability to develop mental models, which requires integration of causal and dynamic knowledge with static knowledge (Gobert & Clement, 1994). While expert's knowledge is relational, held in complex conceptual models, making it easily stored, quickly retrieved, and successfully applied, students' knowledge is often rote, therefore easily forgotten and not readily transferable to similar situations (Glynn & Duit, 1995). Traditional education fails to make students aware of their own capacity for mental imagery and does not provide much opportunity to develop this inner resource (Greeson & Zigarmi, 1985). Even those teachers who realize that students need to actively construct conceptual models rather than memorizing lists of unrelated facts often are not sure how to facilitate constructive learning (Glynn & Duit, 1995).

It has long been a common learning strategy for students in biology to memorize long lists of words, categories, and definitions. Unfortunately, definitions have been shown to tend to freeze a mental model which may be appropriate when the goal is simple assimilation or rote memorization without change in the mental model. When the goal is the evolution of a mental model, the simple memorization of definitions may serve only to rigidify the process and thereby stifle further change (Tweney, 1987). According to Tweney, "Do we want to freeze so much

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conceptual material in the minds of our students? What happens to the capacity to modify one's mental models if we do? If we aren't showing them how science works, can we really expect them to become scientifically literate in the sense needed for today's world?" (Tweney, 1987).

Several strategies have been suggested for encouraging the development of mental models of complex ideas (Glynn and Duit, 1991; Gobert & Clement, 1994). Short interviews, discussions, demonstrations of familiar phenomena, and discrepant events may activate existing mental models. Subsequent construction can then be supported by asking students to find relations, map concepts, and draw analogies. In addition, using think aloud strategies, asking the student to explain both right and wrong answers may be useful.

In order to support the construction of five concepts determined important in understanding respiration, the curriculum included a combination of strategies mentioned above. It was believed that this sequence would lead to dissonance, construction, criticism, revision, and questioning on the part of the students and ultimately to a complex mental model of respiration. In this pedagogy, it is the teacher's role to provide prompts, questions, and sources of dissonance to support this construction cycle in the student. One specific strategy employed in the current research is discrepant questioning. In this paper we will take a closer look at this one strategy. We recognize that this is just one of many strategies that work in union to promote the development of complex mental models, but we consider it to be a very important one.

## Model Cycling

Discrepant questioning is a teaching technique that can help students "unlearn" misconceptions, make rational decisions about what they believe, and process science ideas for deep understanding. Discrepant questioning is a technique in which teachers question students in a way that requires them to examine their ideas or models, without giving information prematurely to the student or passing judgement on the student's model. This strategy may also be called dissonance producing, because it prompts students to see the contradictions in their model, the ways in which it is both workable and unworkable. Evidence has shown that students in classrooms where discrepant question was a major part of the curriculum produced dynamic models of respiration, constructing complex concepts into an integrated whole. To better understand the role of discrepant questions within the larger picture of mental model construction, Figure 1 provides an schematic of a typical cycle of mental model construction.

A typical cycle of mental model construction may occur in the following fashion: (1) a discrepant event, observation, discrepant question, teacher model, or discussion is introduced that (2) triggers dissatisfaction with a prior model. This may be in response to prior conceptions expressed by the students or a teacher recognized discrepancy in student models ($M_1$). Then, (3) through the use of other models, hands on activities, discrepant questioning, or analogy the student begins to build another model, $M_{1a}$; (4) once $M_{1a}$ is developed, it is criticized and defended. (5) The model is applied to a new situation, and (6) the model is reevaluated in light of new information and understanding. In simple or shallow misconceptions, $M_{1a}$ may become the final model consistent with the scientific model, and my be called the $M_2$. In more complex conceptions, however, this may only be a beginning step in a cycle which will repeat itself many times until the final model is reached. Following step (6), other discrepant events, observations, and analogies may be introduced to instigate another model cycle, with each cycle assisting the student in developing more and more sophisticated models. This becomes a rich cycle of concept development, criticism, and revision along with application to new situations.

A key element of this model cycling is that the student is not left with mere dissatisfaction with a prior model but in repeated cycles is simultaneously helped to criticize and construct new mental models. The major factor in this model is the constant reliance on the student's reactions, need for support, questioning, and reasoning that is going on within the steps of the cycle (Rea-Ramirez, 1998). To provide this support results of our research has suggested that the use of certain questioning strategies play an essential role.

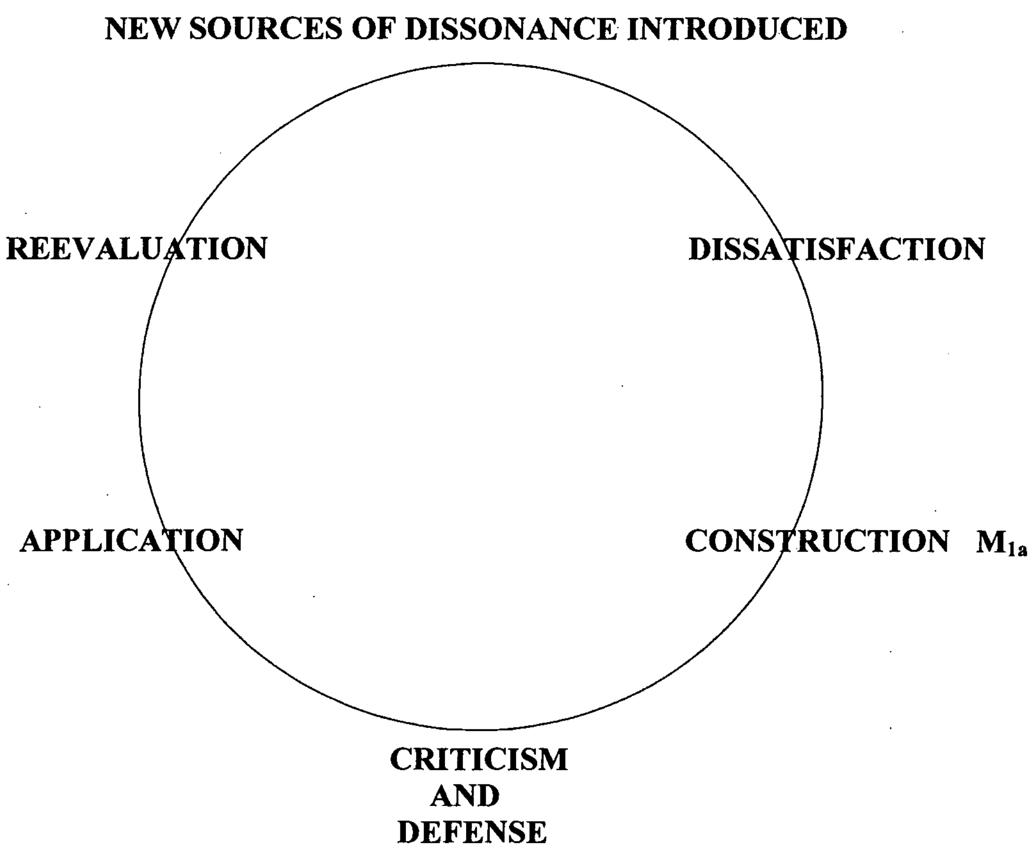


**Figure 1.** Model cycling occurring in a spiral fashion. Over all, cycles are under the control of the teacher but affected by student's mental model construction cycles.

The introduction of dissonance plays a critical role in the modeling cycle. Where proponents of learning cycles recommend introducing a lesson with exploration, the modeling cycle relies heavily on sources of dissonance to initiate mental model construction within the student. Where others describe process skills and knowledge attainment, this model suggests that what might be most important is appreciation for the way students are developing understanding. Mostly, however, it suggests that it is the student who controls the learning and the teacher who helps facilitate that process, providing scaffolding and encouragement. It is the actual mental model construction that occurs within the mind of the student that is critical, not the lesson plan, or the curriculum guide, or covering the material. Students may actually vary in their reactions to dissonance and to cycle sequences. This suggests that numerous cycles may also be occurring within the larger modeling cycle that represents the cognitive construction process within the student. These repeated cycles might be thought of as a coiled spring laid out along the circle produced by one turn of the model cycle with each coil of the spring representing a small step in the model construction (Figure 2). What is occurs during each coil is what becomes primary in the student-teacher interaction. This is where discrepant questioning plays a major role in the criticism – construction cycle.

Discrepant questioning may take on several forms. Some questions are deep while others were shallow. Questions are viewed as shallow or deep depending on the amount of dissonance necessary to cause dissatisfaction with at model and promote model construction. Questions are used before, during, and after the model construction process. Before the model construction process, the teacher may use "open-ended questions" or "What if" questions to detect the students' initial understanding ($M_1$) of the Target Model. During the model construction process, the teacher may use several kinds of questions to help the students build a more sophisticated model ($M_2$) of the Target Model. The teacher uses Questions to direct the students' thinking in building and criticizing models when the students appeared to have had more preconceptions of the topic.

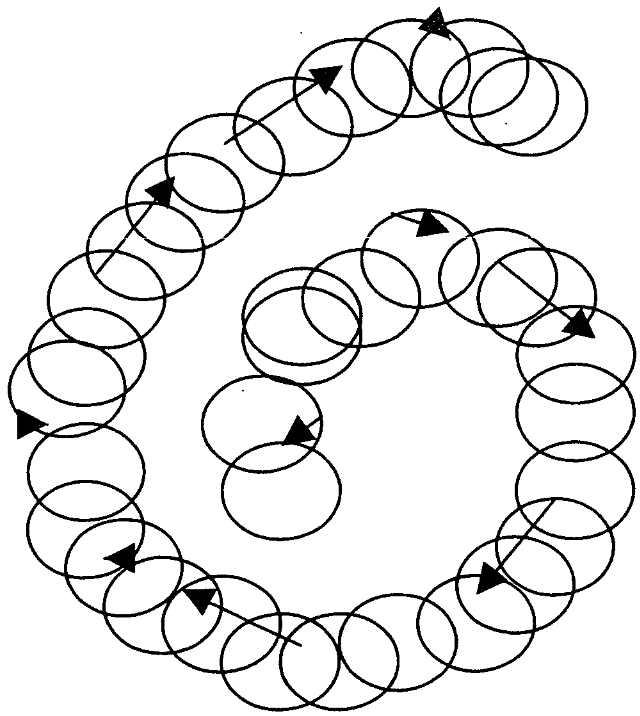

**Figure 2.** Coiled spring representation of student construction. While the teacher may have a broad cycle in mind, the teacher also recognized that the student is actually going through many multiple mini-cycles internally in order to reach a target concept. Each small circle in Figure 2 represents the one larger circle in Figure 1.

## Kinds of Questions

Discrepant questions are used as both "dissonance-producing strategies" and as "supporting strategies." By using questions as "dissonance-producing strategies," the teacher introduces alternative ideas or counter arguments to promote dissatisfaction within the students' models. Among the Questions that act like "dissonance-producing strategies" are "hint questions," "recalling-information questions," and "student questions." By using questions as "supporting strategies," the teacher detects the effect of the alternative ideas or counter arguments in the students' models and keeps the model construction process going. Among the Questions that act like "supporting strategies" the teacher might use "information-seeking questions," "prediction questions," and "assessment questions." After completing the construction of the intermediate model ($M_3$), the teacher employs "adjustment questions" that act like a "supporting strategy." "Adjustment questions" help the students to compare their final models ($M_3$) with their initial ($M_1$) models. In this paper we will attempt to provide evidence of the different types of questions that we believe can be grouped under the heading "discrepant questioning".

<u>How and When to use Discrepant Questioning</u>

Knowing when and what questions to use to stimulate model construction is essential. To do this the teacher must have in mind not only the ultimate target model but also recognize what the current mental model is that the student holds. That is, the teacher sees the end but also the student's beginning, as indicated in Figure 3. Once the teacher can visualize the student model, he/she then constructs an intermediate target model as a "stepping stone" for the student on the journey toward the target. Using discrepant questioning, and other strategies, the teacher helps the student construct, criticize, and revise their model until it comes more closely to the intermediate model. The teacher then assesses the student's $M_{1a}$ to see how closely it resembles the intermediate model envisioned by the teacher. If it is still not in the direction necessary to assist the student in building the ultimate target model, the teacher may have to use other analogies, discrepant questions, etc. to provide other opportunities for construction and dissatisfaction with the initial model.

This process occurs repeatedly with new intermediate models until the target is reached. An essential ingredient in the success of this model of pedagogy, is the teacher's willingness to take the time and effort to understand the student's model and to construct along with the student. That is, the teacher provides the students with successive counter-arguments and constraints that stimulate the students to review and modify their ideas (Nunez, et al 2002). The process is repeated over and over again with each individual concept involved in the topic of the lesson.

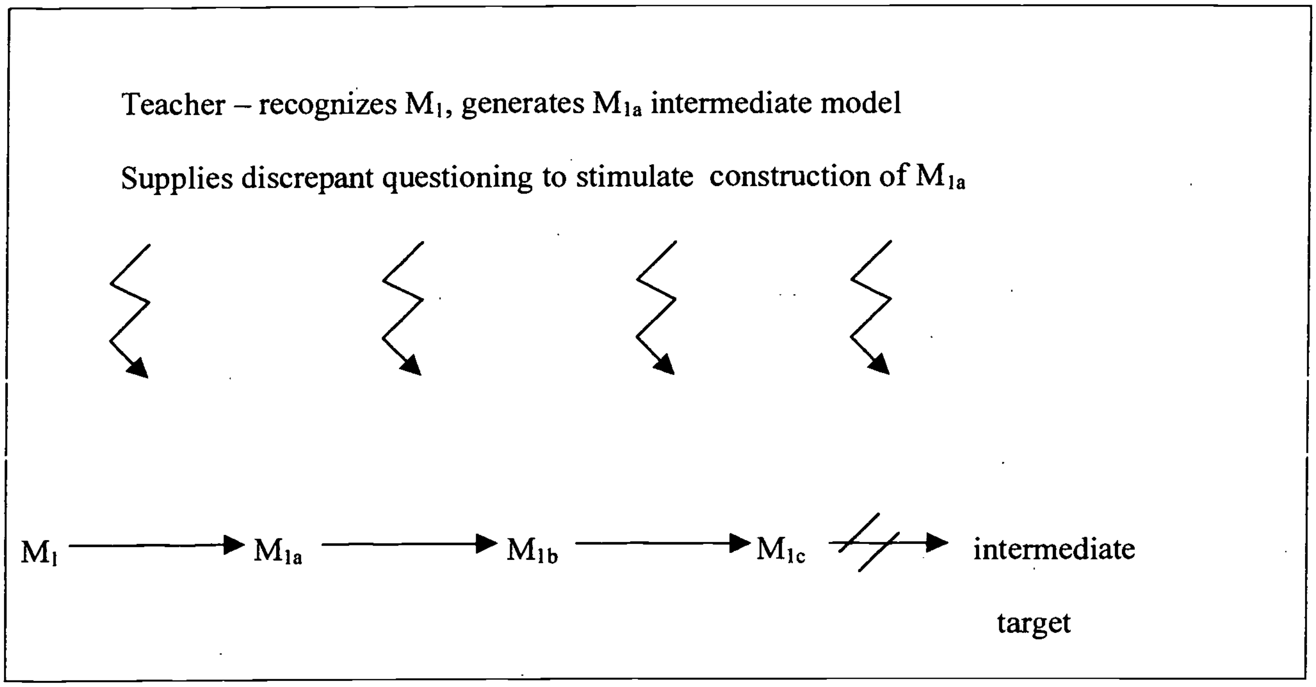


**Figure 3**. Cycle of model construction based on teacher generated new intermediate models that are optimally planned to step students through a construction process to the target model. Introduction of discrepant questions, analogies, discrepant events, hands on activities help students construct each new intermediate model. Intermediate models are designed by the teacher based on students' initial models and reactions throughout the construction process. The number of steps to the target is determined by the difficulty of the concept and the strength of the prior model.

"What if" questions are employed throughout the proposed curriculum to help students in constructing new mental models. This is perhaps the broadest sense of questioning that can activate students' existing knowledge, relate this knowledge to experiences, and intrinsically motivate students (Rea-Ramirez, 1998). When "what if" questions are asked during and after a lesson they could encourage students to evaluate, revise, generalize, and apply their knowledge (Glynn & Duit, 1991). Examples of "what if" questions that might be used by the teacher in the study of respiration are:

1. "What would happen if the capillaries were located a long distance from the cells?"
2. "What if the cell needed energy, what would it need to get this energy?"
3. "What if I asked you to go run up and down the steps - what would you feel?"
4. "What if I could take a very thin section of the heart tissue - what would you see?"
5. "What if blood vessels ended when they got to your finger, as you have suggested. What would happen to the blood?

In each instance the students are encouraged to think about their prior models and experiences to suggest explanations, as well as to evaluate these models along with emerging models. Students are often asked to look back at prior drawings to make comparisons and suggest new models through the "what if " questions. The following question was used with all of the participants to encourage model development through mapping between an analogy and the cell: "Look back at your drawing of the cell as if it were a school. In that model you said there would be chaos if you only had one big room where all the classes and gym and band took place. What if you only had a big open space in the cell where everything took place?" In this instance, students are not only encouraged to compare prior models to a newly emerging model, but are asked to apply that model to suggest causal relationships.

Deep questioning encourages students to make inferences, think logically, and extend their thinking about mental models. Questions in this curriculum rarely ask for factual information in the form of simple recall or memorized facts but rather encourage students to think deeper, to apply what they are envisioning. Students are prompted to apply the models they constructed and then to criticize them through questions such as, "Would any cells need more energy in the form of ATP than other cells in the body? Tell me about that" and "What if you removed one lung, what might happen?" and "If blood is only pumped out to the body one way and goes into the tissues, where do we get more blood to keep pumping out?" In one instance, when students showed tubes sending inhaled air directly to the heart but drew lungs as separate organs unconnected to the inhaled air, the teacher questioned, "I wonder why we have lungs then? What might their purpose be?" After having students take a deep breath of air, the students say the lungs get bigger, which is incompatible with their model. "I wonder why they do that if the air just goes directly into the heart?" When another student suggested that air goes from the mouth through the esophagus to the stomach and diffuses out of the intestines just like the glucose, the question was posed, "I wonder though, if your stomach was holding all that air, where would the food go?" This stimulated a criticism and building response in the student which could be co-constructed with the teacher through a series of discrepant questioning. This is not to say that the student immediately gave up this model, but that he began to suggest other intermediate models finally coming up with two hypotheses that could be tested.

In attempting to apply a mental model to a new situation, it is necessary for students to look critically at their mental model to see where it may be supported and where it may still need revision. In trying to investigate students' understanding or construction of understanding about diffusion, deep questioning was used to induce students to generate models and then to predict behavior. "If I have a glass of water and I put a few drops of dye into it, what will happen?" (various answers about spreading out or just turning a color) "I wonder how that happens, what it would look like if you could look at the water and dye very close up?" Finally, deeper understanding and explanation was often encouraged by statements such as, "Tell me what you mean by ____________" or, "Tell me more about that" and, "I wonder what that looks like?" Simple statements such as these told the students the teacher was listening, interested, and encouraging the student to continue talking.

Some questions required that the student use logical reasoning to build on what they already know and to make new connections. Example of this question include, "How could you figure out what glucose was primarily made of if you looked at the by-products" or, referring back to student's analogy of the cell to the federal government, "If it is winter what would the government buildings need?" (Student states, energy). "Now can you relate this need to the cell? Where in the government model would you produce energy? And how about in the cell?" At other times questions encourage students to use previously constructed explanatory needs to make predictions. "If all the cells in the body need glucose and oxygen, how do you suppose it gets to the cells, where does it come from?" After students suggest a variety of models of the lungs including just tubes to balloons and they have constructed that model with sugar cubes, they are asked, "Can you think of any other way that we could arrange the cubes so there would be more surfaces for air to come out?" In this instance, a hands-on activity is used in combination with discrepant questioning to encourage construction of a model.

There are times, however, that for clarification or reiteration necessary to stress a point, shallow questioning is necessary. This is often the case when students express ideas and the teacher wants to be sure that she is clear about what the student means. In these instances, shallow questions might include, "Where is that on your model or drawing" and "What in the animation might indicate a new product was made?" At other times shallow questioning can be used as part of a scaffolding strategy. Students are asked to give small pieces of information back to the teacher who then helps the student to begin integrating these pieces into a larger picture. “How do animal cells get glucose?” “What is the heart’s job?” “Is there anything in your model that acts like the nucleus?” “What kind of fuel might the cell use to produce energy?” These are all examples of shallow questioning that is intended to help build a larger concept, not to stimulate a deep explanation in itself. Often these questions trigger a connection within the student that then stimulates construction, speculation, and prediction.

## Evidence of Discrepant Questions

### Methodology

Evidence presented in this section is the result of an analysis of small group tutoring sessions on human respiration. Four two-hour classes were held with a group of four eighth-grade students. The group included two boys and two girls, and was ethnically diverse. Each session was audio- and videotaped. The instructor was the main researcher of the project. Subsequently, the curriculum has undergone extensive whole classroom trials in three schools over the past two years.

The students were instructed with a Standardized Teaching Sequence (STS) based on model construction and criticism theory that was developed by Rea-Ramirez (1998). The instruction was organized around five individual target models, which are related to the microscopic structure of the cell, internal structure of the cell, the digestive, the circulatory, and the respiratory systems.

### Results

Evidence suggests that students had a marked increase in comprehension of human respiration. Quantitative analysis showed that the small group had an overall significant mean difference of over three standard deviations on the pre to post test. (see Nunez, 2002).

Questioning Strategies Used in Methodology

Discrepant questions have been divided into dissonance-producing strategies and supporting strategies. [Quotes in this section come from research conducted on small group interaction and reported in Nunez (2001).]

Dissonance-producing Strategies

Supporting evidence of Questions that acted like "dissonance-producing strategies" is provided below. These can be further divided into "hint questions," "information-recalling questions," and "students' questions."

*Hint Questions:*

The teacher used "hint questions" to suggest alternative ideas to the students to promote review and modification of their models. Two examples of "hint questions" were taken from the circulatory system. The teacher asked:

Teacher: Ok, ok, so I'm still not clear. When the blood gets out to your toe what happens to it?

S1: It backs up.

S2: It is distributed to your foot and it goes back.

S3: It's like a truck.

Teacher: Tell me what that looks like. Let's draw a picture of when the blood reaches the big toe. [Drawing as she speaks] We go down to this toe level and I'm going to put a blood vessel here. Now, I'm going to call all of these things blood vessels, that is the name for all the different kinds…ok, is that all right with you? And I'm going to put one right here coming of down here. It's a pretty tiny one because remember how tiny the cells are? Now blood is coming through here. What happens when it gets to your toe?

In the first question, the teacher suggested that "something occurs when the blood arrives to the cell of the big toe." In the second question, the teacher enlarged her first question, and provided the students with a context such as a name for blood vessels and their relative size difference in respect to cells. The teacher also suggested that "something has to happen" in the toe when blood gets to it. By using the teacher's suggestions the students seemed to be able to examine and modify their ideas more concisely. The teacher also used other examples of "hint questions." Several of them were collected from the segment in which the teacher and the students Co-Constructed a more sophisticated model of the digestive system.

Teacher: ...beside just being a passage way, what may be happening in the intestine that might give you a hint about how glucose fits into your cells

Teacher: How do you think it [glucose] goes, how do you think it goes from there to there [the intestine to the blood vessels]

Teacher: I am going to draw a piece of intestine here, ok? [She draws] A piece that comes down like this and here is the food, food is all breaking up into little pieces, now we got some glucose. How does it [glucose] get from here out here [the intestine to the blood vessels]? Where does that blood vessels have to be? [She shows the drawing].

Teacher: can your body break down everything that you eat? Have you ever eaten corn?

The teacher used "hint questions" when the students' prior knowledge could not get them any further within the model construction process. The alternative ideas suggested by the teacher might be considered to be "possible avenues" that can be explored by the students while building a more sophisticated model of the Target Model.

*Information-Recalling Questions:*

The teacher presented the students with "information-recalling questions" to remind them of the information that had been previously discussed. These types of questions seemed to have worked in two ways: 1) to contradict an idea given by a student; and 2) act as an analogy to help the students to generate new ideas.

The teacher asked "information-recalling questions" that caused contradiction when she and the students were Co-Constructing the circulatory system. One student said that blood was able to cross the blood vessel walls to provide glucose and oxygen to the cells of the big toe. The students seemed to have been confusing the relative size of cells and molecules. To solve the confusion, the teacher asked the students to recall information regarding the relative size difference among atoms, molecules, and cells that had been discussed in the previous lesson. The recalled information appeared to have contradicted the student's ideas. After the teacher asked the students to recall that information, a student was observed modifying her initial statement:

> Teacher: Ok, remember when we talked the other day about molecules and atoms and how tiny they were and they were much tinier than cells, right? [Drawing] And if this is a cell, here is the oxygen molecule, see how much difference that is?
>
> S3: Oh yeah.
>
> Teacher: Ok, we can't even see a molecule with the microscope. So when we were...when I have these here what I'm really talking about is like this and here is

some oxygen on the blood cells [pointing at cells in the drawing]. Ok, so what do you think might happen?

S3: Ah, hah...

Teacher: So here is oxygen and glucose...[pointing the drawing]

S3: I am thinking it goes through the walls. Because I mean, like, even if the blood that goes into the actual cell it has go through the walls to get into the cell, so I am saying, that it makes any difference like floating around inside the blood cells.

The recalled information appeared to have produced dissonance within the student's ideas concerning the model she was discussing with the teacher. The recalled information helped her to review and modify her initial ideas but not in the direction the teacher had expected. The student, instead of saying that the blood cells do not cross the blood vessel walls, said that, "blood has to go into the actual cell ... like floating around inside the blood cells." The student appeared not to have had an understanding of a mechanism by which blood provides the cells with nutrients.

The teacher asked "information-recalling questions" that acted like analogies while the teacher and the students were Co-Constructing the respiratory system:

Teacher: remember when we talked about the intestine and how close the blood vessels had to be to the intestine to pick up the stuff

S4: very close

Teacher: very close, what do you think is happening here?

S4: it is seem that the blood cells are bumping into it, and then the oxygen has in there is... [He makes a noise with his mouth]

The teacher reminded the students of concepts that they had Co-Constructed while building models of the digestive, and the circulation system. The teacher asked the students to apply their prior knowledge to build a model of the respiratory system. The recalled information appeared to have acted as a conceptual core on which the teacher built the new idea.

Student Questions:

[The teacher used "student questions" to introduce alternative ideas to the discussion.] Some questions that the students asked were indirect questions, while others were direct questions. To detect the students' indirect questions, the teacher seemed to have been very aware of what the students were describing. When she detected an alternative idea, she initiated a discussion within the group about that idea. In the following piece of transcript, an example of the teacher and the students Co-Constructing a mechanism of blood transporting oxygen and glucose to the toe cells will be given:

S4: They're [glucose and oxygen are] smaller than the blood cells, and they are carried by the cells. I do not know if these cells go into walls because...

Teacher: Ok.

S4: Like little things.

Teacher: That's a really good question. Do the blood cells go through the walls?

S2: They have to be able to.

S1: There is a passageway

Teacher: And what goes through the passageway, tell L, convince L if you think you're right. L if you think you're right then convince her [B].

A student proposed that glucose and oxygen are smaller than cells and that they sink through the blood vessels walls. However, he was not sure if the red blood cells were also able to sink through the walls. The teacher detected uncertainty in the student statement, and transformed the student's doubt into a question to be discussed within the group. In the transcript analyses, it was also detected that two students agreed with the student's alternative idea with the teacher's support, and she encouraged them to provide evidence for their arguments.

The students also asked spontaneous questions as well as bringing up questions when there was a discrepancy or difference between what was being debated within the group with what they knew about the topic. For example:

Circulatory System

S3: So have the people, like, donated blood?

Lower Digestive System

S2: if the food comes out of the veins, when you go to the bathroom what is that?

Upper Digestive System

S3: yeah, why do people choke?

Respiratory System

S1: I have a question

Teacher: uh huh

S1: if the air goes to the heart does it mean it goes to the lungs too

Teacher: hummmm

S1: or do you have oxygen in the heart? That is my question.

Teacher: that is a good question, what does the heart do?

S1: just circulates the air

Teacher: what do you think? Turn around and ask your teammates.

The teacher was never observed answering questions directly, but was observed tossing the questions back to the students. The "students' indirect questions," and the "students' spontaneous questions" were observed throughout the major segments of the teaching session.

Supporting Strategy

Below, evidence for the Questions that acted like "supporting strategies" is presented. They were "prediction questions" and "information-seeking questions."

*Prediction Questions and Discrepant Questions*

While the teacher and the students were Co-Constructing a more sophisticated model of the digestive system, the teacher promoted a discussion regarding the possible connection between the lungs and stomach. Two students believed that the lungs and stomach are connected, causing the presence of air in the stomach. A student supported her ideas by saying that when there is no air, stomach cramps are caused. The other student supported his ideas by saying that the stomach might collapse if there is no air inside of it. Meanwhile, a third student did not agree with the idea that the lungs and stomach were connected. She supported her ideas by saying that stomach cramps come from muscular contractions in the walls of the stomach.

To explore other student ideas regarding the topic, the teacher introduced a situation and then asked a "prediction question:"

Teacher: hum, what happens to your stomach when you drink a lot of like Pepsi or something that has a lot of bubbles in it.

S1: You burp, you have gas in your stomach

Teacher: humm, you get gas in your stomach

S3: it comes back up your esophagus

Teacher: ok

S1: and it is released

Teacher: so if you have air in your stomach, all the time what would that be like?

St1: you'd burp all the time

S3: you would be a walking burp

S4: you would be airy

The students agreed that if a person constantly had air in the stomach, that person would be burping all of the time. The "prediction question" seemed to have helped the teacher to detect the students' ideas in respect the topic.

The teacher detected that the students held two contradictory ideas. The first idea was that if a person has air in his/her stomach he/she might be burping all of the time. The second idea was if a person does not have air in the stomach he/she may have stomach cramps or the stomach's walls might collapse. To help the students to review and modify their ideas, the teacher asked the students a "discrepant question:"

Teacher: so I wonder what do the rest of you think about that then there is natural air in your stomach?

The question generated a discussion among the students in respect to burping. The students realized that the source of a burp is the presence of air in the stomach. Therefore, it is not natural to have air in the stomach. As a consequence, the students realized that the lungs and stomach are not connected. The teacher seemed to have asked the "discrepant question" to help the students to reconcile the students' two opposite ideas.

*Information-Detecting Questions*

The teacher asked the students "information-detecting questions," such as "what do you think about that," to detect the impact of alternative ideas presented in the students' models. For example, while the students were discussing the location of blood vessels in respect to the intestine, a student suggested that blood vessels might be inside of the intestine. The teacher detected that the student may have been unsure of his suggestion, so she presented the student's idea to the group to be discussed:

Teacher: I wonder if there is blood in the intestine, what do you think about that?

S2: hum

S4: I am not saying that there is but (inaudible)

S1: Is there? I do not know

Teacher: Ok? What do you think?

St2: that would mean that blood would be coming out. I mean that every time that you go to the bathroom, you would bleed

(Group Laughs)

Because the teacher encouraged the students to present their ideas with her question "what do you think," one of them realized that the idea suggested by the other student was not worth further exploration. This might be seen as a point where the teacher led the students go to a blind alley to discourage continuing building incorrect ideas.

In addition to the "what do you think about that," the teacher frequently used other "detecting-information questions" styles such as,

Teacher: why might that be important?

Teacher: show us what you think about that.

## Conclusion

In the research described, discrepant questions were used as "dissonance-producing tactics" and as "supporting tactics." By using questions as "dissonance-producing tactics," the teacher introduced alternative ideas or counter arguments to promote dissatisfaction within the students' models. Among the Questions that acted like "dissonance-producing tactics" the tutor used "hint questions," "discrepant questions," "recalling-information questions," and "student questions." By using questions as "supporting tactics," the teacher detected the effect of the alternative ideas or counter arguments in the students' models and kept the model construction process going. Among the Questions that acted like "supporting tactics" the tutor used "information-seeking questions," "prediction questions," and "assessment questions."

Evidence suggests that these students had a marked increase in comprehension of human respiration at the end of instruction. Quantitative analysis showed that the small group had an overall significant mean difference of over three standard deviations between the pre and post scores. Examination of drawings showed a progression from naïve and incomplete models to detailed models much closer to the scientific view (learning pathway). In addition, over the course of the instruction the students reached high level of interactions among themselves and with the instructor.

While the tutor guided the students in constructing intermediate models, she used several different "dissonance-producing tactics" to promote dissatisfaction within the students. The "dissonance-producing tactics" (Analogies, Questions, Daily Life Experiences, Pictures, Hands-on Activities, and others) were like a "tool box" to be used by the tutor. Because there were multiple strategies used, it cannot be stated that discrepant questioning by itself caused the results but rather worked together with other strategies for success. It is important to note that instead of selecting and using a "dissonance-producing tactic" at random, the tutor appeared to have chosen the most appropriate tactic to promote dissonance within the students.

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