Model Competition: A Strategy Based on Model Based Teaching and Learning Theory

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Abstract

The purpose of this study is to develop a theoretical framework for describing different teaching strategies that can foster student model construction in large group discussions. Such a framework is necessary for developing new instructional principles about how to build mental models in large classroom settings. This particular paper focuses on a mode of interaction call model competition as one possible strategy. The teacher has an opportunity to promote model competition when the students contribute to a discussion with ideas that are contradictory to each other. The presence of these different kinds of ideas fosters dissatisfaction in the students' minds that can be productive. We follow the strategies a teacher uses to support this and other important modes of learning, such as model evolution, in a case study of classroom learning in the area of respiration.

We believe that the teacher played a key role during the teacher/student co-construction process described in the present study. The teacher participated by constantly diagnosing the students' ideas and attempting to introduce dissatisfaction by suggesting constraints that led the students to evaluate and modify their ideas, producing cycles of model construction and criticism. In this way she was able to guide students toward targeted content goals. The learning model we develop includes nested teacher-student interaction organization patterns that the teacher used in order to encourage the students to disconfirm, recombine, restructure, or tune their ideas and to generate successive intermediate mental models. These patterns have been analyzed from the perspective of a theoretical framework of model construction theory. We believe that this framework can provide a set of lenses that complements other cognitive and sociological frameworks for analyzing classroom discussions.

Introduction

In the last decade there has been an increasing recognition of role of models and modeling in describing how scientists and students reason (Gobert & Buckley, 2000; Gilbert & Boulter, 1998). Some articles have discussed differences in the mental models held by experts and students (Borges, 1999; Snyder, 2000), models in the history and philosophy of science (Justi & Gilbert, 2000), theoretical aspects of model based instruction (Hestenes, 1987; Gobert & Buckley, 2000; Clement, 2000b), reports of model based instruction conducted with large amount of students (Hafner & Stewart, 1995; Raghavan & Glaser, 1995; Hmelo, Holton, & Kolodner, 2000), and reports of model based instruction conducted with single students (Buckley, 2000; Rea-Ramirez, 1999; Clement & Steinberg, 2002).

Although some of these studies have used cycles of model construction and criticism, we still lack a clear set of mechanisms to explain how students build mental models. In addition, very few of these studies have examined how to deal with multiple alternative conceptions in large classroom settings. In short we still lack of detailed theory of model-based learning and teaching (MBTL) (Gobert & Buckley, 2000; Clement 2000b).

In this study we attempt to contribute elements of a model of the learning processes involved in student model construction by examining the teacher-students interactions that occur while students are learning human respiration.

Rea-Ramirez (1998) emphasized the key role of the teacher during mental model construction by saying that the teacher is "a co-constructor of knowledge with the students" (Rea-Ramirez, 1998, p. 174). She described the teacher's role as being constantly aware of the students' mental models so as to foster criticism and revision cycles.

Nunez-Oviedo (2001), Nunez-Oviedo, Rea-Ramirez, Clement, & Else (2002), and Nunez-Oviedo & Clement (2002) defined the teacher/student co-construction as the process by which the teacher and the students both contribute ideas to building a model and evaluating it. Co-construction is a highly complex process that may be considered a middle road between purely teacher generated and purely student generated ideas in the classroom.

These findings enabled the development of a curriculum based on MBTL theory for middle school students called Energy in the Human Body (Rea-Ramirez, Nunez-Oviedo, Clement, & Else, in preparation). The curriculum has been field tested for almost three years in normal sized classes of urban, suburban and rural areas of Western Massachusetts.

The field-testing of the curriculum has yielded through the years a huge amount of videotaped data, drawings and other sources of evidence. It was a challenge for the research team to sort through this database and to identify concepts that describe repeated discussion patterns at different time scales that lead to conceptual change.

Purposes

In a paper derived from field observations during the first year of the curriculum testing, Clement (2002) identified three other teacher-students interactions patterns that could be promoted in large group discussions: selective confirmation of correct pieces, model competition, and model evolution.

Throughout this study we have dual purposes. The first purpose is to describe the strategies used by a successful middle school science teacher to build mental models of human respiration in her classroom. The second purpose is to enlarge and revise Clement's theoretical framework based on protocols gathered during the second year of the curriculum testing. Essentially the problem is to work from patterns in transcripts to develop concepts needed to model learning and teaching processes by examining teacher-students discussion patterns that appear to produce different types of conceptual change.

Overview of the Present Study

The data for this paper comes from videotaped lessons conducted with normal sized middle school classes located in a suburban area. Students' understanding of human respiration was assessed before and after instruction. Quantitative and qualitative data analyses were conducted.

In the quantitative analysis, statistical results indicated that students had a significant gain in their understanding of human respiration. In the qualitative analysis, the teacher-students interaction identified by Clement (2002) were modified, expanded, and described as medium sized co-construction modes. These modes were integrated into a hypothesized model of the process of learning that takes place during mental model construction in large group discussions and normal sized classes.

The learning model hypothesizes the existence of nested teacher-students interactions organization patterns through each unit of instruction. The large pattern was termed Macro Cycles, the medium patterns were called co-construction modes and included "collection with feedback," "collection with repair," "model competition," and "model evolution." The smallest pattern was termed Micro Cycles.

The learning model also hypothesizes that the teacher combined these discussion patterns to build successive intermediate mental models of a target. The teacher participated in the co-construction process by constantly diagnosing the students' ideas and providing constraints that aimed at fostering dissatisfaction and that led the students to evaluate and modify their ideas.

In this study we will provide evidence for model competition in large group discussions. Because of their close connection with model competition, the study will also discuss a second medium sized teacher-student discussion pattern called model evolution and smaller interaction pattern called Micro Cycles. The study will describe as well the ways in which this teacher combined these discussion patterns to repair students' preconceptions.

Related Research

The theory of mental models opposed to the rules of inferential reasoning and emerged from a research tradition called "informal reasoning" (Voss, Perkins, & Segal, 1991) that searches for an alternative to formal logic to describe thinking. In this theory, people build mental models from the world that can be considered "structural analogs of real-world or imagined situations, such as a cat being on a mat or a unicorn being in the forest" (Nersessian, 1992, p. 9). Nersessian (1995) points to Philip Johnson-Laird's theory as foundational.

Johnson-Laird argued that people build mental models by using "the semantic of connectives rather than on rules of inference (Johnson-Laird, 1986, p. 34). He proposed that when an individual generates a model s/he checks the accuracy through a process called "recursion" that consists of investigating alternative models that could contradict the initial one (Johnson-Laird, 1983).

On the other hand, Collins & Gentner (1987) claimed that people generate mental models by using analogies. These authors argued that people, when reasoning about simple unfamiliar domains, use analogical mapping "to create new mental models that they can then run to generate predictions about what should happen in various situations in the real world" (Collins & Gentner, 1987, p. 243). The known domain is called the "base" and the unknown domain is called the "target." But when the unfamiliar situation is complex "people partition the target system into a set of components models, each mapped analogically from a different base system"

(Collins & Gentner, 1987, p. 248). In other words, they hypothesized that the subject needs more than one analogy to generate a complete mental model of an unknown situation.

In recent literature there is the idea that scientists and experts generate mental models about a topic by engaging in a domain-independent practice called "constructive modeling" (Nersessian, 1995) or "cycles of model generation, evaluation, and modification" (Clement, 1989).

Constructive modeling "is a process of abstracting and integrating constraints into successive models of the target problem" (Nersessian, 1995, p. 222). Cycles of generation, evaluation, and modification are rounds of successive refinements through which an initial model is criticized and then revised originating a series of more and more complex and sophisticated models (Clement, 1989). Supporting evidence for these iterative processes comes from historical cases examined by Nersessian (1992, 1995), Gruber (1974), Schweber (1977), Darden (1991), Gould (1980), and from protocol analyses examined by Clement (1989).

Nersessian (1992, 1995) and Clement (1989) both claimed that the thinking practices in which scientists and experts engage during the generation of scientific models are directly relevant to learning. Nersessian (1995) pointed out that "we will be more successful in training students to think scientifically if they are taught, explicitly, how to engage in the modeling practices of those with expertise in physics" (Nersessian, 1995, p. 204-205). She argued that students have the cognitive abilities employed in constructive modeling but they require knowledge about the subject to introduce adequate constraints. So in order to have success with this approach in learning science, the teacher would need to develop in the students expertise in the content and in constructive modeling at the same time.

On the other hand, Clement argued that generation, evaluation and modification cycles are useful to describe the processes "that need to take place in students who are learning to comprehend scientific models" (Clement, 1989, p. 376). He considered that the modeling process might be also relevant for understanding established scientific models, to solve ill structured problems, and for conducting inquiry.

Even though Clement (1989) and Nersessian (1992, 1995) both encouraged the use of these iterative processes for fostering learning in science, none of them provided guidelines for teachers and curriculum developers about how to guide instruction.

More recently Clement & Rea-Ramirez (1998) converged with Nersessian in that the learning process about model construction involve the emergence of successive intermediate mental models. The authors explained the emergence of these intermediate mental models by using the "Festinger's theory of cognitive dissonance (Harmon-Jones & Mills, 1999) instead of the Piaget's equilibration theory.

Clement & Rea-Ramirez proposed that the students' ideas, rather than being replaced or eliminated through disequilibrium, might be transformed through the introduction of successive "cognitive dissonance." Dissonance was defined as "an internal sense of disparity between an existing conception and some other entity. This can occur at a mild as well as strong levels, as

opposed to the concept of 'conflict,' which suggests only a strong disparity" (Clement & Rea-Ramirez, 1998, p. 2). The existing conception may be compared with external sources such as discrepant events, analogies, and counterexamples and with internal sources such as incoherence between two conceptions, a model suggested by a teacher or peer, and criticism of a conception. The authors suggested that a source of dissonance should be recognized and internalized by the students before the actual internal dissonance may take place.

However Clement & Rea-Ramirez (1998) also recognized that there are events that produce episodes of dissonance that is " too mild to be called conflictual…in which the person feels and interesting sense of mild unease, and from which the person may experience a need to pursue some form of change" (Rea-Ramirez & Clement, 1998, p. 10.) So the authors instead propose the term dissatisfaction to include mild and strong forms of dissonance. In the remainder of the paper, the concept of dissatisfaction will be used to describe the mild or strong discomfort that the students may experience when the teacher introduces a discrepant event.

Clement (2000b) presented a linear framework for thinking about cognitive factors involved in model construction during instruction. He postulated that the "instructional efforts will be directed at moving at student from model M_n to model M_{n+1}" (Clement, 2000b, p. 1043). The emergence of successive intermediate mental models is also called a "learning pathway" (Scott, 1992).

Background and our Previous Studies on this Topic

The study about teacher-students interactions that occur during co-construction in large group discussions emerged from a project whose main goal was to develop a curriculum based on MBTL theory for middle school students on human respiration. Rea-Ramirez (1998) conducted pilot studies that contributed to the construction of the curriculum. The idea of generating a curriculum on human respiration emerged from studies that indicate that middle schools students do not know how their bodies work and therefore they are not aware of reasons for the danger of practices such as smoking.

Rea-Ramirez first studied students' preconceptions on this area through extensive student interviews. She then conducted a small number of individual pilot tutoring interviews to identify the most efficient teaching tactics.

The most successful teaching tactics were then organized in a teaching sequence. Eight-eighth grade students were taught with the sequence through individual tutoring interviews (Rea-Ramirez, 1998). Rea-Ramirez reported that throughout the instruction the teacher fostered many small cycles of model construction and criticism. She also described the teacher as a "co-constructor of knowledge" with the student.

The teaching sequence was used next to teach a small group throughout four tutoring sessions that were videotaped and lasted approximately 8 hours. Student's understanding was determined before and after instruction (Rea-Ramirez, 1998).

Nunez-Oviedo (2001), Nunez-Oviedo, Rea-Ramirez, Clement, & Else (2002), and Nunez-Oviedo & Clement (2002) also analyzed the videotaped lessons and reported a significant gain between pre and post assessment scores. These authors also reported different levels of teacher-student discussion patterns. These patterns were explained through a model of learning that contained two patterns of nested teacher-students interactions. The large pattern was called Macro Cycle and many smaller patterns of discussions were called Micro Cycles.

The Macro Cycle contains several phases that were inferred from the teacher and the students' conversations and behavior: *Introducing the Topic, Detecting Student Ideas, Building on Student Ideas, Comparing the Student and the Scientific Models,* and *Adjusting the Student Model*.

Throughout the phases of the Macro Cycle, the teacher introduced the topic of the unit of instruction and detected the students' initial ideas. The teacher used different kinds of teaching tactics to foster dissatisfaction and modification until their ideas were more compatible with the target. The teacher then showed the students an animation that contained the target model and asked them to compare their final understanding with their initial ideas. Therefore, through each unit of instruction, the teacher adopts different modes. The Macro Cycle developed for each individual target model lasted between 45 minutes and one and a half-hour in the small group studies. However, it could last up to two weeks in a regular classroom as a unit sized pattern.

The general aspects of the Macro Cycle have some similarities to the teaching sequence developed by Driver (1989) and the general structure of the learning cycles in Lawson, et al (1989). However, the learning model developed also described shorter teacher-students interactions patterns that were called Micro Cycles.

Micro Cycles constitute a finer level of cycling occurring mostly during the *Building on Student Ideas* phase of the Macro Cycle. A Micro Cycle can be described in general as a process in which the teacher acts with the intention of introducing dissatisfaction and stimulating them to examine and modify an element inside of their models.

In a more detailed description, a Micro Cycle contains three phases in which the teacher and students interactions are closely intertwined: *Focusing on a Preconception in the Student Model (M_1'), Producing Dissatisfaction in the Model Element,* and *Fostering Student Review and Modification of the Model Element (M_1'')*. Throughout these phases, the teacher first asks for students' ideas, detects a preconception and asks the students to describe the idea. Secondly, the teacher introduces a teaching tactic (such as a discrepant question or event) that generates mild or strong dissatisfaction. Lastly, the teacher uses another teacher tactic to foster modification by encouraging them to restructure, tune or adjust their ideas (such as having them draw a revised model). (See Figure 1.)
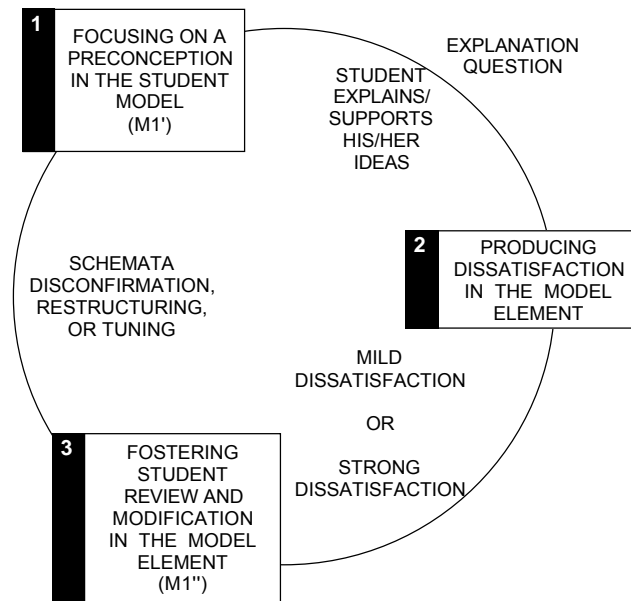
Figure 1. Micro Cycle

Through the three phases of the Micro Cycles, the students' misconceptions and "gaps" detected by the teacher in the students' initial models (M_1) can be repaired. The length of each individual Micro Cycle varied depending on the kind of teaching tactic used by the teacher, but most of them lasted approximately 5 minutes. These Micro Cycles driven for a small episode of dissatisfaction appeared to have been responsible for the student learning through the evaluation and modification of increasingly complex intermediate mental models of the target concept. A simplified diagram of a Micro Cycle is shown in Figure 2. This diagram shows time going from left to right, as model M_1 is challenged by an action by the teacher or a student (T/S), and then modified to concept M_2. The arrow from T/S to M_2 indicates that such an action will probably constrain and motivate the modification.
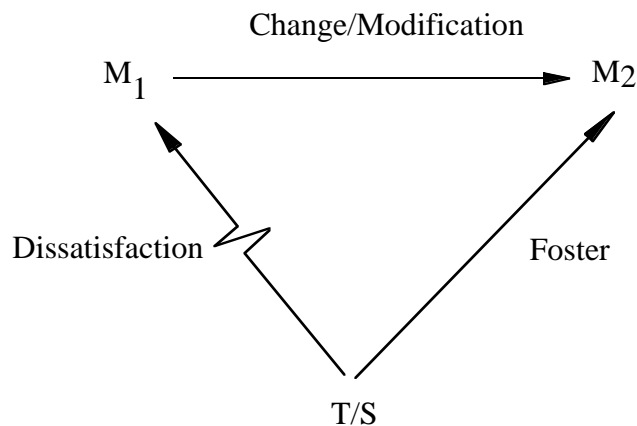

Figure 2. Simplified Diagram of a Micro Cycle

Micro Cycles could be considered a piece-wise procedure for dealing with students' multiple misconceptions and in the hands of a skilled teacher appears to be an important process for at least three reasons. First, a Micro Cycle criticizes and modifies one preconception at a time. Secondly, the teacher introduces only a small discrepant event to avoid overwhelming the students. Lastly, the discrepant event is only presented to the students when they are ready to receive it.

Based on the understanding gained with the process of learning that occurred in the small group experiment, a curriculum based on MBTL theory about human respiration suitable for seventh grade students was developed (Rea-Ramirez, Nunez-Oviedo, Clement, & Else, in preparation). The curriculum has been field tested by conducting three rounds in normal sized classrooms located in urban, suburban, and rural settings.

Three teachers participated in the first round of testing by piloting the first half of the curriculum during the 2000-2001 school year. Three teachers also participated in the second round of testing by piloting the full curriculum during the 2001-2002 school year. The third round of testing in which participate five teachers piloting the full curriculum is still in progress. This study examines data obtained from the suburban setting during the second year of testing.

The Curriculum

For instructional purposes, the content of the curriculum was organized around five individual target models (Rea-Ramirez, 1998) that are related to the digestive system, the microscopic structure of the cells, internal structure of the cell, the circulatory, and the pulmonary system. The curriculum includes the teacher's manual, the students' workbook, an assessment book, and a folder with transparencies that contain the scientific models.

To organize the instruction, the curriculum includes eight units or chapters that were developed from the target models. Within each unit, the instruction is organized by using the teacher-students interactions described in the Macro Cycle. The content of each unit was broken down into smaller segments to foster the teacher-students interactions described as Micro Cycles. The chapter or units are connected by a question that emerges from the previous chapter that is answered throughout the upcoming chapter.

The Setting and Participants

The study was conducted at suburban public middle school of a college town with mixed cultural, economic, and racial population. The teacher. Ms. R. taught her four-seventh grade classes, more than 80 students, with the second edition of a pilot version of the Energy in the Human Body Curriculum. Ms. R. is an experienced middle school science teacher with more than 15 years of practice with good content domain knowledge as well as classroom management. Prior to participating in the research, she was trained in cooperative learning and she had some experience conducting her teaching by using small and large group discussions, and hands on activities. She was trained in the curriculum by attending to workshops that lasted one week during two summers.

The teacher met each individual class four times a week. Two of the lessons lasted 45 minutes and the other two lasted 1 hour. The classes were gender mixed and ethnically diverse including a decreasing proportion of white, Asian, Latino, and African American students. The four classes also contained mixed ability students some of whom needed special accommodations and other who were special education students. The teacher named her classes by using a number and a color (G1 green, G2 red, G3 blue, and G4 yellow).

Each class had 20-22 students and they were organized into five or six groups. The teacher used numbers to name the groups or tables inside of each class (1, 2, 3, 4, 5, and 6). There was an attempt to have each group or table have gender, ability, and ethnically mixed organization. The students were asked to participate in the study by signing a permit letter along with their parents or tutor.

Data Collection and Methods of Inquiry

Three questions guided this study. Is there evidence of student learning on human respiration? How does the teacher help the students to modify ideas that are partially compatible or incompatible with the target model? What are the cognitive mechanisms involved in the process?

A micro-analysis was conducted to identify and describe different teacher-student interactions that took place while Ms. R. was using the second trial version of the curriculum. The main data source for the concepts developed in the study was the examination of videotaped lessons recorded in G3 and G4. These classes included students with mixed abilities but not special education students. For scheduling reasons, G4 also included students that were taking a course in advance math and several of them also participated in the school orchestra.

The lessons were recorded with a digital 8 video camera. Seven microphones were used to capture the small and large group conversations.

Seventy hours of videotaped lessons were examined and twenty-six hours were selected and transcribed in full for further analysis. The protocol examined in this paper comes from group G4 and was selected because it clearly illustrates the use of a model competition strategy.

The data used in this study were obtained from these transcripts as well as observations, drawings, and an identical pre- and posttest. The test contained two parts. The first part included a transfer problem and the second part included 35 multiple-choice questions.

Data Analyses

Two kinds of data analyses were conducted: quantitative and qualitative. In the quantitative analysis, the pre- and post-test scores were examined and a paired mean comparison (t-test) for each part of the test was conducted. The goal of the quantitative analysis was to determine the effect of the instruction on the students' understanding of human respiration.

In the qualitative analysis, a generative analysis to develop a model for explaining the learning process that occurred in normal sized classroom was conducted (Clement, 2000a). The model contains a description of the various co-construction modes and how they work together to produce learning.

Results

Results from the transfer problem and the multiple-choice questions showed a significant mean difference (t-test) (p< .001) of more than one and half standard deviations between pre and posttest scores.

Nunez-Oviedo (2001), Nunez-Oviedo et al (2002) and Nunez-Oviedo & Clement (2002) provided evidence for Macro and Micro Cycles in the small group experiment. In this study we will examine evidence for the presence of model competition, model evolution, and Micro Cycles in large group discussions in normal sized classes by examining the teaching-students interactions of a successful middle school science teacher and her students.

The evidence was obtained from examining a lesson about the structure of the throat that lasted 35 minutes. This study will mostly focus on model competition but model evolution and Micro Cycles will be also included because these interaction patterns are closely interconnected.

Definitions and Background

Although the following definitions are actually one of the main results of this generative exploratory study, we place them here as an advanced organizer. Model competition was defined as the process by which the students display or express to the class two or more competing ideas at a time providing an opportunity for comparisons (and therefore dissatisfaction) before closure is reached on an idea. (See Figure 3.)
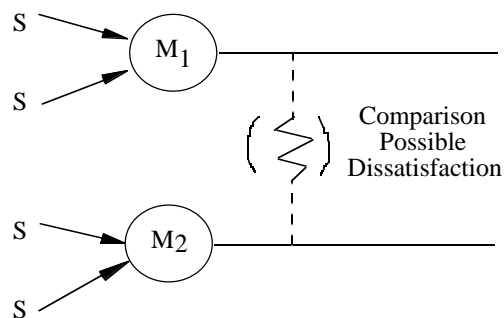

Figure 3. Model Competition

The episode of dissatisfaction during model competition generates a Micro Cycle through which one of the competing ideas can be disconfirmed. (See Figure 4.) The X in the diagram indicates that the preconception has been discounted or removed permanently from consideration

in the present context. Even though it is not possible to speak with certainty about its removal from consideration for all of the students, it was at least observed that the students did not reintroduce that conception in the remainder of the episode.
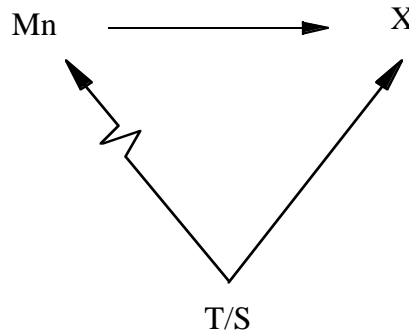
$$Mn \longrightarrow X$$

Figure 4. Model Disconfirmation

Model evolution was defined as the process by which the students conduct two or more rounds of modifications in their notions until they reach closure on an idea. A simplified diagram also illustrates the process. (See Figure 5.) The modifications may involve restructuring or tuning of students' ideas and are the result of two or more contiguous Micro Cycles.

$$S \qquad S \qquad S$$
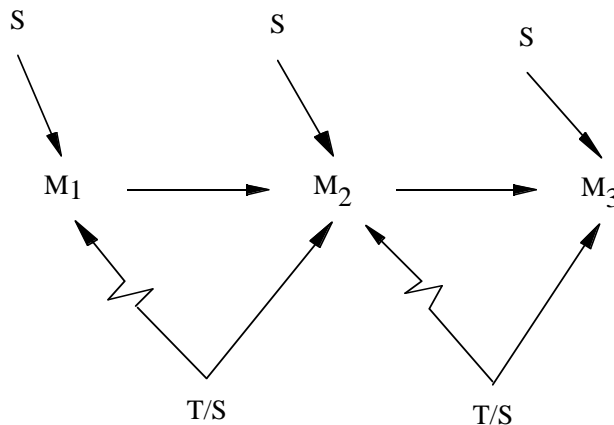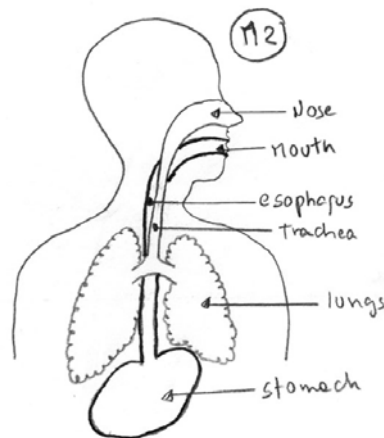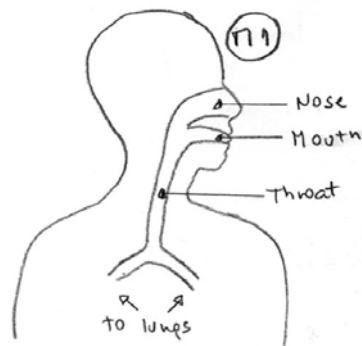$$M_1 \longrightarrow M_2 \longrightarrow M_3$$
$$T/S \qquad T/S$$

Figure 5. Model Evolution

Micro Cycles are teacher-students interactions nested within model competition and model evolution modes. In a Micro Cycle, the teacher encourages the students to evaluate and modify their ideas. The organization of a Micro Cycles was described in a previous section of this report. (See Figures 1 and 2.)

In the following paragraphs, two episodes of model competition, one episode of model evolution, four Micro Cycles will be described. They come from a lesson recorded on 12/17/2001 at G4 that lasted approximately 35 minutes. The topic of the lesson was the structure of the throat and it was included in the unit of digestion located the beginning of the curriculum.

The teacher was observed combining model competition, model evolution, and Micro Cycles to support her students in repairing their preconceptions by disconfirming, restructuring, or tuning their ideas until they were compatible with the target. (See Figure 6 and 7.) The repairing process originated several intermediate explanatory mental models of the target that were depicted through a learning pathway.

Figure 6 shows a learning pathway that includes drawings that were taken from the classroom. While models 1, 2 and 3 were actual drawings drawn by the students at the beginning of the lesson, models 4 and 5 were inferred from the teacher-students interactions. Figure 7 represents the same learning pathway but with words. Figures 6 and 7 will act as advanced organizers to support the reader in following the progress of the lesson.

M3

Nose
mouth
throat

M4

Nose
mouth
Throat
Trachea
esophagus
to stomach   to lungs

M5
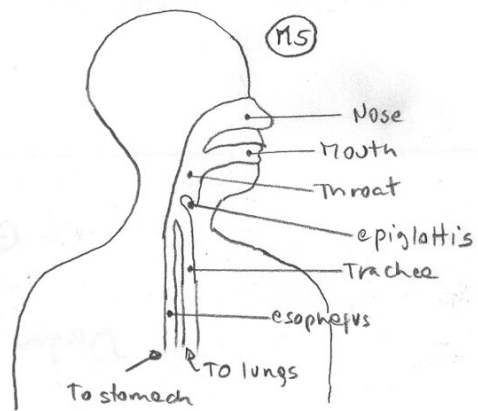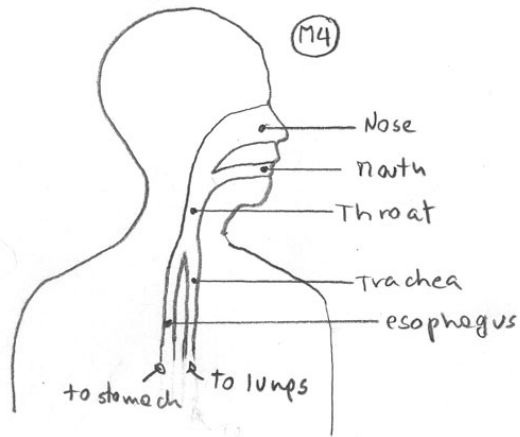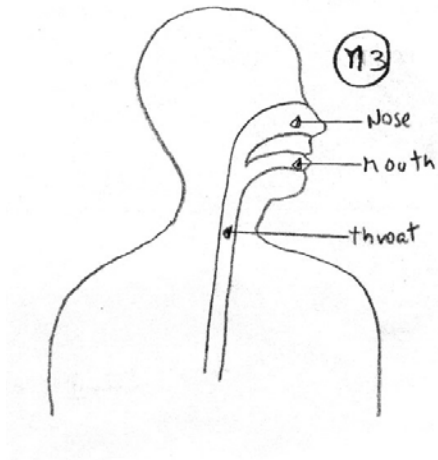
Nose
Mouth
Throat
epiglottis
Trachea
esophagus
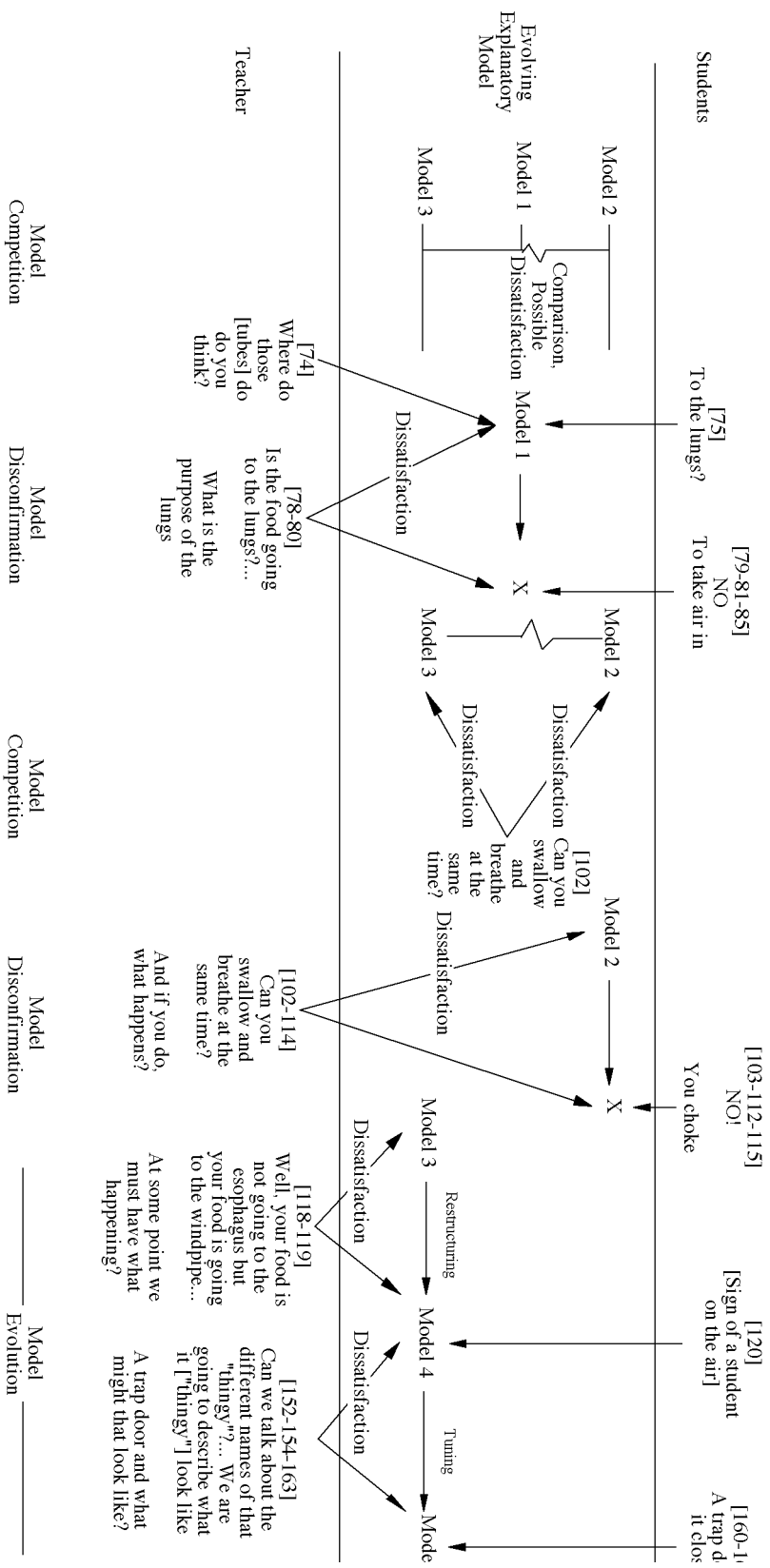TO lungs
To stomach

Figure 6. Learning Pathway Of The Structure Of The Throat

Figure 7. Learning Pathway of the Structure of the Throat

Evolving Explanatory Model

Students

Teacher

Model 2   Model 1   Model 3

Comparison, Possible Dissatisfaction   Model 1

[75] To the lungs?

[79-81-85] NO To take air in

Dissatisfaction   Model 1 → X

[74] Where do those [tubes] do you think?

[78-80] Is the food going to the lungs?...

What is the purpose of the lungs

Model 2   Model 3

Dissatisfaction   Dissatisfaction   Can you swallow and breathe at the same time?

[102] Can you swallow and breathe at the same time? Dissatisfaction

Model 2 → X

[102-114] Can you swallow and breathe at the same time?

And if you do, what happens?

At some point we must have what happening?

[103-112-115] NO! You choke

Dissatisfaction   Model 3   Restructuring   Model 4   Tuning   Mode

[118-119] Well, your food is not going to the esophagus but your food is going to the windpipe...

[152-154-163] Can we talk about the different names of that "thingy"?... We are going to describe what it ["thingy"] look like

A trap door and what might that look like?

[120] [Sign of a student on the air]

[160-1...] A trap d... it clos...

Model Competition   Model Disconfirmation   Model Competition   Model Disconfirmation   Model Evolution

The Target Model of The lesson

The structure of the throat is a complex topic for students. (See Figure 8.) The scientific model proposes that the throat is an intricate place located between the mouth and the esophagus that leads the food into the stomach. On the other hand, the trachea is a tube located in front of the esophagus that emerges from the larynx and allows air to travel to the lungs. This passage is usually open and it only closes when a person swallows. Several structures converge at the throat or pharynx including the mouth, nose opening, and the entrances of the esophagus and larynx. The ears are also connected to this place through the Eustachian tubes that lead into the throat from the middle ear.

A flap of skin called the epiglottis is situated above the larynx. It covers entrance and directs the food back to the esophagus when a person swallows.
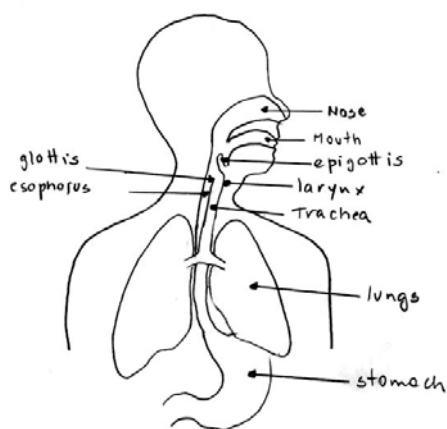

Figure 8. Structure of the Throat

Preconceptions

Two kinds of students' preconceptions about the throat were detected throughout the research. In the first kind, the students believed that there was only one tube where food and air go together. In the second kind, students believed that there was one tube for the air and another completely independent tube for the food. A few students also believed that a tube connected lungs and stomach. The majority of the students did not indicate the flap of skin above the larynx.

Detecting Students' Preconceptions

Most of the activities for determining the students' preconceptions were conducted in the prior lesson. In that lesson, students were asked to draw individually their ideas about the throat and to share them in order to reach consensus within the small group. In this lesson, the teacher completed the detection of students' ideas by asking them to create a team drawing on a small whiteboard to illustrate the structure of the throat.

<u>Model Competition</u>

The teacher conducted an extended period of model competition in which she asked the students to compare and evaluate three models.

<u>First Episode of Model Competition</u>

Once each team completed their whiteboard drawing, the teacher gave the students the role of examining each other's drawings and determining similarities and differences among them. The teacher organized this activity in such a way that one member of each small group stayed at the table to explain the group's drawing to the incoming students while the other three members of the group went to examine other groups' drawings ("three stray, one stays.") We hypothesized that while students were examining each other drawings they experienced model competition and possibly dissatisfaction when they realized that there were drawings that were markedly different from their own group picture. (See Figure 3.)

This first episode of model competition could be described as active, open, and unshared. It is considered "active" because the teacher encouraged the students to find the differences between the groups' drawings. It is considered "open" because the teacher did not provide the students with guidelines about what they had to look for in each other drawings. Finally, this first episode of model competition is considered "unshared" because the students did not report their findings immediately to the class.

<u>Description of Students' Preconceptions</u>

The teacher then asked the students to point out those drawings that they believed were strikingly different from each other and they selected three drawings. These three drawings or models will be called respectively model 1, model 2, and model 3. (See Figure 9, 10 and 11.)
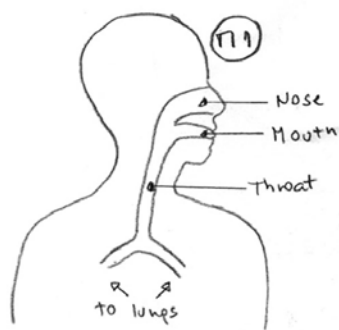

Figure 9. Model 1

In model 1, the students drew a tube going from the mouth and another tube going from the nose that joined together in the back of mouth and showed one tube that split off down into two tubes.
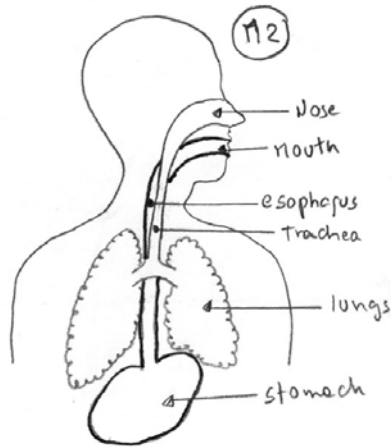
Figure 10. Model 2

In model 2, the students drew one tube going from the nose down to the lungs and another tube going from the mouth down to the stomach.
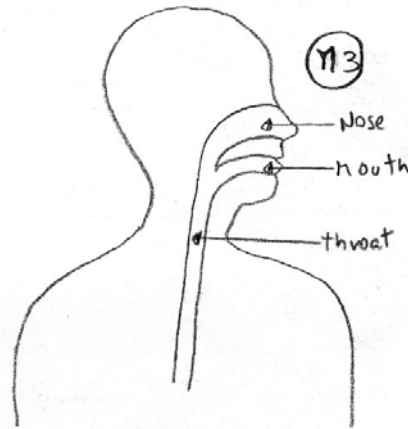

Figure 11. Model 3

In model 3, the students drew a tube going from the mouth and another tube going from the nose that joined together in the back of the mouth and drew only one tube that was going down from the mouth. The three models each had characteristics that made them incompatible with the target model.

Once the students detected these three different models, the teacher encouraged them to disconfirm those models that were too far from the target and to restructure the model that was easier to repair. The teacher supported the students in disconfirm and restructure their ideas by promoting four Micro Cycles that were nested within model competition and model evolution.

First Micro Cycle

The teacher supported the students in evaluating and disconfirming model 1 through the three phases of the Micro Cycle. (See Figure 1 and 2.)

In the first phase of the Micro Cycle, the teacher focused on a preconception and detected the students' ideas. As stated earlier, the teacher asked the students to report in large group whether they had found strikingly differences between groups' drawings. A student from table 1 reported that the drawing from table 3 was different from her own group's drawing. (Figure 9.) The teacher took the whiteboard in her hands and described it aloud. She said that the drawing showed only one tube that split off down into two tubes but the drawing did not show any other structure. So the teacher asked the owners of the drawing where these two tubes were going. A student said that these two tubes were going to the lungs. They said:

72. T: OK, if you noticed something strikingly different from your drawing and the table that you're at raise your hand.
73. S: [Inaudible]
74. T: OK, in this drawing, [student name] noticed that it essentially starts as one tube and splits off down here as two and where do those go do you think?
75. S: To the lungs?

The student answer was incompatible with the target. It meant that the air and the food were going through the tubes down to the lungs. Based on the student's answer, the teacher went to the next phase of the Micro Cycle.

In the second phase of the Micro Cycle, the teacher attempted to introduce dissatisfaction. The teacher repeated the answer provided by the student and asked the class to generate a question to evaluate model 1. She encouraged the class to ask the question by saying, "What would be my next question?" A student made a comment inaudible to the observers that was paraphrased by the teacher by asking, "Is the food going to the lungs?" Another student answered "no" to the teacher's inquiry. They said:

76. T: To the lungs. Okay, so the question is […] what might be my question for this group? They have one tube leaving the mouth area veering out, splitting off into two tubes and those two tubes are going down to the two lungs. What might be the question I might have for this group?
77. S: Like there has to be different…(inaudible)
78. T: How, so does that mean is the food going to the lungs?
79. S: No
80. T: That might be my question for this group. Is the food then going to the lungs?
81. S: No!

Based on the transcript, it is hypothesized that the teacher's question, "Is the food going to the lungs?" introduced fairly strong dissatisfaction and encouraged them to evaluate the viability of the model proposed by the group.

In the third phase of the Micro Cycle, the teacher supported the students in modifying their ideas. The teacher persuaded the students to question the model by asking the class about the purpose of the lungs. A student answered that the lungs allowed the air to go into the body. The teacher agreed with the student's answer and said that, however, the group's model only explained what happened with the air but it did not explain what occurred with the food. Therefore that group had to reexamine their ideas again. They said:

82. T: Alright, so, we see something in this model then that somebody didn't have and that is they're taking care of what? They take care of the what?
83. S: The lungs?
84. T: And what is the purpose of the lungs?
85. S: To take in air.
86. T: They are taking care of the air that's being inhaled but they haven't accounted for what's happening to the food. So this would be something that they want to go back and look at.

Based on the transcript, it is hypothesized that the teacher encouraged the students to cast doubt on model 1 as a complete model.

Second Micro Cycle

In the second Micro Cycle, the teacher asked the students to compare models 2 and 3 and encouraged them to criticize one of the models through the phases of the Micro Cycle. (See Figure 1 and 2.)

In the first phase of the Micro Cycle, the teacher focused on a preconception and detected students' understanding. The teacher showed model 2 and 3 to the class and described them aloud. (See Figure 10 and 11.) The teacher encouraged the students to find evidence to support either model 2 or 3. A student pointed out that according to model 2 a person could breathe and swallow at the same time because the drawing showed two tubes. They said:

93. S: Well umm, according to this thing, you can only eat and breathe at the same time.
94. T: So, according to this model you could eat and breathe at the same time. Because why? That's a good observation. Because why?
95. S: Because you have two tubes.
96. T: This is portraying you as having two separate tubes so that you could be breathing simultaneously as you're eating because neither one will interfere

Based on the transcript, the teacher detected the students' understanding with regard to model 2. (The teacher later used the idea suggested by the student as a criterion to compare the two models.)

In the second phase of the Micro Cycle, the teacher attempted to introduce further dissatisfaction. The teacher encouraged the students to evaluate model 2 and 3 by promoting model competition through and using two procedures. In the first procedure, the teacher asked the students to vote to select model 2 or model 3. They said:

97. T: OK, instinctively which model do you feel more comfortable with, model 2 or
       model 3? Instinctively, that is which do you think is the best, more correct model.
98. S: I can't really see them.
99. T: All those who think it's model 2 raise your hand. We got 1, 2, 3, 4 5
100. S: Put 'em up, put 'em up
101. T: Well we have a tie here …

The teacher requested the students to use their "instinct" to vote for model 2 or model 3 but she got a tie. It appeared that the strategy did not work as the teacher expected. Two outcomes seem to have emerged from encouraging the students to vote in this way. On one hand, the strategy failed to prompt the students to articulate new criticisms or repairs to the models. On the other hand, the strategy was successful in maintaining an extended period of model competition.

Second Episode of Model Competition

The teacher promoted model competition between models 2 and 3 by using a student's question of whether a person could breathe and swallow at the same time. Based on video observations, several students answered negatively to the question and the teacher thought that she had found an important criterion for evaluating the models. But the evaluation of the models was not a smooth process.

A student strongly cast doubt on the line of argument by saying that one tube shuts off when a person is eating in Figure 10. The teacher responded to the student's comment by repeating the question and emphasizing the swallowing part instead of the eating or the chewing part. In addition, the teacher supported her point by saying that a person can breathe when chewing but not when swallowing. Finally, the students agreed that a person could not breathe and swallow at the same time. They said:

102. T: … Okay, lets think for a second can you swallow food and breathe at the same
        time.
103. S: NO!
104. T: No, OK so we solved that.
105. S: Because one tube shuts off when you're eating
106. T: Well when you're swallowing right? Because can you breathe when you're
        chewing?
107. S: Yeah
108. S: No
109. S: Well you can but it's not very good
110. [Teacher and a student talking at the same time] food in your mouth…like when you
        have a cold or something.
111. T: So we have that you can breathe and chew at the same time but you go to the act
        of swallowing, can you breathe?
112. S: NO!!
113. T: No, so you can't …

Based on the transcript, it is hypothesized that the question, "can you breath and swallow at the same time" introduced strong dissatisfaction and was an effective criterion to initiate criticism of model 2. (See Figure 3.) The teacher strong dissatisfaction appeared to persuade the students to find fault with model 2 in the next phase of the Micro Cycle.

In the third phase of the Micro Cycle, the teacher supported the students in modifying their ideas. She asked the students, "What's happening when a person swallow and breathe at the same time," and they answered that the person will choke because the food is going into the esophagus. She corrected the student statement by saying that the food was not going to the esophagus but into the windpipe that goes down to the lungs. They said:

114. T: … And if you do, what happens?
115. S: You choke
116. T: You choke because what's happening?
117. S: Your food is going to the esophagus?
118. T: Well, your food is not going to the esophagus but your food is going to the windpipe whatever that pipe is called that is going down to you lungs …

Based on the transcript, it is hypothesized that the teacher used choking as an empirical evidence to support the students in disconfirming model 2. (See Figure 10.) Model 2 suggested that a person could breathe and swallow at the same time idea that was contrary to the students' empirical evidence.

In summary, in the second Micro Cycle, the students evaluated and modified their ideas with regard to model 2. The teacher encouraged the students to evaluate their ideas by asking a question that introduced strong dissatisfaction and stimulated them to disconfirm model 2 because it contradicted the students' experience. (See Figures 6 and 7.)

Thus far, model 1 and 2 were disconfirmed because both contradicted students' previous understanding. Model 1 held that food was going to the lungs contradicting students' previous knowledge on the topic. Model 2 held that a person could breathe and swallow at the same time contradicting students' empirical experience about the topic.

On the other hand, model 3 had not been carefully examined yet. (See Figure 11.) Even though this model was also incompatible with the target, it had some features that could be more easily repaired than in model 1 and 2. For that reason, model 3 is also called partially compatible with the target. The repairing process of model 3 initiated an episode of model evolution.

Model Evolution

Model evolution was defined as the process by which the students conduct two or more rounds of modifications in their ideas until they reach closure on an idea. A simplified diagram illustrates the process. (See Figure 5.) The modifications may involve restructuring or tuning of students' ideas and are the result of two or more Micro Cycles.

The teacher repaired model 3 by fostering model evolution in which there were two Micro Cycles that generated two successive intermediate mental models of the target.

Third Micro Cycle

In the third Micro Cycle in this protocol, the teacher supported the students in modifying model 3. (See Figure 11.) The modification consisted in generating the idea of a second tube at the throat. It built on the idea that you choke when food goes into the windpipe that goes down to the lungs. The third Micro Cycle began at this point and its phases occurred very quickly and only the second and third phases were more evident. (See Figure 1 and 2.)

In the second phase of the Micro Cycle, the teacher made a request for additional explanation. The teacher asked the class what must be happening at the throat. A student made a gesture with her hands in the air indicating the splitting off of the tube. They said:

119. T: … Now the question is … at some point we must have what happening?
120. [A student made a sign in the air with her hands showing a tube splitting off into two tubes]
121. T: The splitting off of a tube that's going to go down to towards the, a tube that's going to go down towards the lungs and a tube that's going to go down to the stomach …

Here the teacher's very minimal question was sufficient to prompt this student to generate the idea that the initial tube split off into two tubes to carry down the food and the air to the stomach and lungs respectively.

In the third phase of the Micro Cycle, the teacher supported the students in modifying model 3 by agreeing with the student's sign and adding information with regard to where the tubes were going inside of the body. So the teacher supported the students in restructuring their conceptions by transforming one tube drawn in model 3 into two tubes that were drawn on model 4. (See Figure 12.)
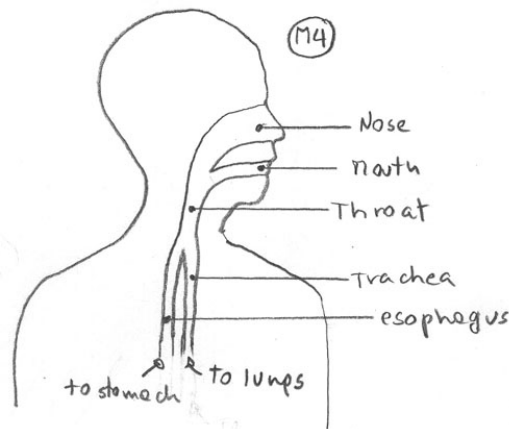

Figure 12. Model 4

<u>Fourth Micro Cycle</u>

In the fourth Micro Cycle the teacher helped the students to modify model 4. (See Figure 12.) The teacher supported the students to incorporate into model 4 the flap of skin called epiglottis located above of the larynx and originating model 5 throughout the phases of the Micro Cycle. (See Figure 1 and 2.)

In the first phase of the Micro Cycle, the teacher detects a preconception and students' understanding with regard to the topic. The teacher asked the students about what was preventing the food from going into the wrong tube. A student answered that it was the "thingy." The teacher asked the students about other names used for this structure but the students did not know this information. They said:

148. T: … And what is going to prevent the food from going down to your lungs?
149. S: The thingy
150. T: The little thingy? What's the little thingy?
151. S: The thingy in the back of your throat
152. T: Can we talk about the different names of that "thingy?"
153. S: I don't know what it's called

It is hypothesized that the teacher suspected that the students did not know what was the exact nature of the structure that avoided the food going into the wrong way.

In the second phase of the Micro Cycle, the teacher attempted to introduce dissatisfaction. The teacher asked the students to create an example to illustrate what the "thingy" was. The teacher asked the students to generate ideas to help the students to continue reasoning about the flap of skin. Several students proposed ideas such as muscle, sliding door or even a trap door. They said:

154. T: That's alright, we are going to describe what it looks like.
155. S: A tube
156. S: A muscle
157. S: a sliding door
158. T: maybe a sliding door so the sliding door would be something that slides, any other possibilities?
159. S: A one door…
160. S: A trap door

Based on the transcript, it is hypothesized that the teacher's question generated in the students mild dissatisfaction that encouraged them to look for an example to illustrate the "thingy."

In the third phase of the Micro Cycle, the teacher encourages the students to modify their ideas. The teacher asked the students to examine the idea of a trap door. She asked the students how a trap door might look like and a student suggested that it closes. The teacher agreed with the student's answer and completed it by saying that the trap door opens and closes. She also encouraged them to recall the scientific name of this flap of skin. They said:

163. T: A trap door and what might that look like?
164. S: It closes
165. T: So something that opens and closes
166. S: It looks like a (inaudible)
167. T: Does anybody know what the part is?
168. S: A valve.
169. T: Well like a valve, some valves open this way [hand movement]… Does anybody know what we call this flap of skin?
170. (Silence)
171. T: Starts with an E?
172. S: Epidermis.
173. S: Esophagus.
174. T: Close. Epiglottis is…(inaudible)

Based on the transcript, it is hypothesized that the teacher supported the students in modifying model 4. The students tuned or adjusted their mental models of the structure of the throat by incorporating the idea of the presence of a flap of skin that works by opening and closing to direct the food and air in the right direction. The addition of the flap of skin modified model 4 into model 5. (See Figure 13.)
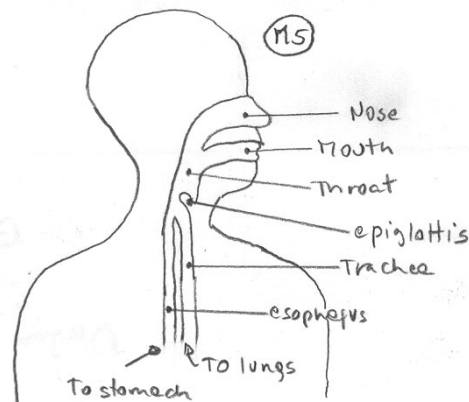

Figure 13. Model 5

In summary, in the fourth Micro Cycle, the teacher encouraged the students to evaluate their ideas by asking a question that introduced mild dissatisfaction that guided them to modify 4 by tuning or adjusting their previous ideas and producing model 5, which was compatible with the target. (See Figure 6 and 7.)

At this time the teacher asked the class to draw their new ideas about the structure of the throat on the small group whiteboard. In addition, the teacher asked the students to draw also their ideas on paper in order to continue the discussion in the following class. These final drawings captured students' new ideas with regard to the topic and constitute a more advanced intermediate mental model of the target.

In the following lesson, the teacher showed the students a transparency with the structure of the throat and asked them to compare their own group drawings with the transparency originating an even more advanced intermediate mental model of the target. At the end of the unit about digestion, the teacher asked the students to compare their final ideas with those that the students had at the beginning of the unit.

Summary and Discussion

The study examined a videotaped lesson that lasted 35 minutes about the structure of the throat from the Energy in the Human Body Curriculum (Rea-Ramirez, Nunez-Oviedo, Clement, & Else, in preparation). Quantitative and qualitative data analyses were conducted.

In the quantitative analysis, we gathered evidence about the increase in understanding of the students that participated in the study. In the qualitative analysis, a model of the learning process during model construction in large group discussions and normal sized class was hypothesized.

The learning model postulated the existence of nested teacher-students interaction patterns. The large pattern was called a Macro Cycle, the medium sized patterns were called "collection with feedback," "collection with repair," "model competition," and "model evolution." The small pattern was called Micro Cycles. The learning model also proposed that the teacher combined these discussion patterns to build successive intermediate mental models of a target. The teacher participated in the co-construction process by constantly diagnosing the students' ideas and providing constraints intended to foster dissatisfaction that would lead the students to evaluate and modify their ideas.

In this study supporting evidence was provided for an extended period of model competition, one episode of model evolution, and four Micro Cycles. Even though the focus of the study was model competition, the other teacher-students interactions were also included because they were closely connected.

The teacher conducted an extended period of model competition in which she asked the students to compare and evaluate three models. (See Figures 9, 10 and 11.) The extended period of model competition was divided into two by an episode of model disconfirmation.

In the first episode of model competition, the teacher asked the students to examine each other group's drawings and detect differences with their own group's drawing. This period of model competition was described as an active, open, and unshared. It was considered active because the teacher encouraged the students to find out the differences between the groups' drawings. It was considered open because the teacher did not provide the students with guidelines about what they had to look for in each other drawings. Finally, this was an unshared episode of model competition because the students did not report immediately their findings to the class.

The extended period of model competition contained two episodes of active competition divided by an episode of model criticism and disconfirmation. We hypothesized that the effect of

this middle episode was that the process of active model competition was deferred reducing the students' cognitive load during the process. The teacher promoted a Micro Cycle to call model 1 into question. We call this an episode of deferred model competition.

In the second episode of active model competition, the teacher asked the students to compare models 2 and 3. This episode of model competition could be described as an active criterion based, and shared comparison. This episode was considered an active process because two contradictory models were again under active consideration. It was considered a criterion based process because the focal point of this part of the lesson was the comparison of these two models by using a criterion suggested by one of the students about the possibility of swallowing and breathing at the same time. Finally, the second episode was considered a shared comparison because the students had the opportunity of presenting their ideas with regard to the two models. The second episode of active model competition ended when the teacher began to focus only on model 2 in the second Micro Cycle.

The extended period of model comparison described in the episodes above was followed by an episode of model evolution. During the episode of model evolution, the teacher encouraged the students to examine and modify model 3 by fostering two Micro Cycles that produced models 4 and 5. (See Figure 6 and 7.)

Within each individual Micro Cycle, the teacher encouraged the students to evaluate and modify their ideas by attempting to introduce dissatisfaction. Most of the time, the teacher used discrepant questions and identified gaps in the students' understanding to promote dissatisfaction. Discrepant questions also contributed with constraints to promote the change in the students' ideas.

Finally, it was observed that the students were also able to suggest ideas within the course of the lesson that could be considered as model contributions criticisms, or constraints. Thus the episode is one of teacher-student co-construction, since both contributed ideas to the final model.

Alternative Possibilities for Interpreting the Transcript

The teacher's use of discrepant questioning and other tactics to promote dissatisfaction with current models leads one to interpret the present episode in terms of strategies like model competition and model disconfirmation. Another possible interpretation of the last active competition process, however, could be that model 4 contained ideas from not only model 3 but also from model 2 as shown in Figure 14. This suggests another mode of construction that we call model combination.
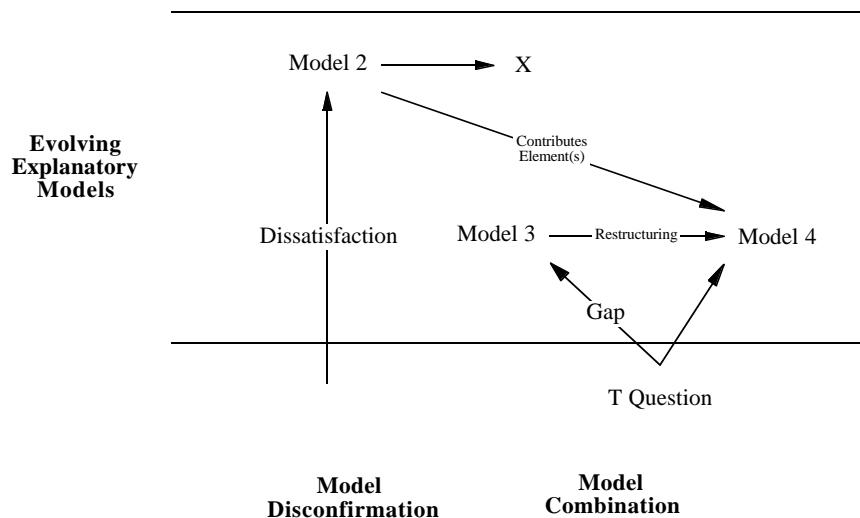
Figure 14. Model Combination

Figure 14 represents this as arrows leading to model 4 from both models 2 and 3. Model combination occurs when elements from two previous models are combined to produce a new model. We do not really have enough data in the present transcript to judge whether this view is more accurate than the one presented earlier. However, we believe the transcript has served an important purpose in fostering the articulation of these different possible modes of model construction.

Conclusions

Throughout this study we had dual purposes. The first purpose was to enlarge our theoretical framework for teacher-students interactions in large group discussions and improve it based on protocols gathered during the second year of curriculum testing. The second purpose was to describe the strategies used by a successful middle school science teacher to support the process of building mental models in her class.

The learning model included nested teacher-students interaction organization patterns that the teacher combined in order to encourage the students to disconfirm, recombine, restructure or tune their ideas and to generate successive intermediate mental models of the target.

Model Construction Cycles and Dissatisfaction

The process of introducing successive episodes of dissatisfaction that lead to the evaluation and modification of students' preconceptions resemble Nerssesian (1995) and Clement (1989) ideas to explain the ways used by scientists and experts to reason about a domain. Nersessian argued that experts reason by introducing successive constraints into their ideas that make them to change. She also argued that students and scientists appear to share the some similar cognitive mechanisms that lead to the construction of internal representations (Nersessian, 1995).

However, students may differ from experts in their level of preparedness for evaluating models. This ability appears to be closely connected with the widely different amount of domain-specific knowledge that students and experts possess.

Students may lack the knowledge to introduce sufficient constraints and criticisms with respect to their initial models in order to construct target models on their own that meet content goals. On this view the teacher has a fundamental role in examining students' ideas and providing them with small constraints or requests that produce dissatisfaction and that encourage them to examine their ideas and modify them accordingly. In other words, the teacher appears to play a key role in engaging the students "in the active construction of their own representations of extant scientific knowledge" (Nerssessian, 1995, p. 203).

We believed that the teacher played a key role during the co-construction process described in the present study. The teacher participated by constantly diagnosing the students' ideas and attempting to introduce dissatisfaction by suggesting constraints that lead the students to evaluate and modify their ideas originating cycles of model construction and criticism or Micro Cycles. In this way, she was able to guide the students toward target models.

Model Evolution vs Model Competition

It is interesting to compare the modes of model evolution and model competition. One way that a skilled teacher can use model evolution to advantage is to try to minimize the size of dissatisfaction episodes (Steinberg & Clement, 2001). The teacher designs probes which produce only small successive episodes of dissatisfaction and that foster small, easy model identifications in Micro Cycles. In this way the student is not discouraged by dissatisfaction problems that are too complicated to deal with, and is able to participate in repairing the models.

In model competition however, if the models come from the students, some of the models may represent more radical alternatives. Small modifications may not be possible for some, and the teacher may have a more complicated agenda. On the other hand, competition may foster motivation and/or model criticism on the part of the students. Model comparisons may highlight key issues. We are currently uncertain as to when and how each mode should be used, and this issue has a high priority for future study.

Complementary Frameworks

The section of tape we analyzed in this paper was selected because it appeared to contain a fairly complex set of model construction processes that were well beyond our ability to decipher at the time. It has forced us to define several basic processes that reflect different teacher-students interaction modes of model construction. We are therefore more optimistic that discussions at this level of complexity can be analyzed. They have been analyzed from the perspective of a theoretical framework of model construction theory. We believe that this framework provides a set of lenses that complements other cognitive and sociological frameworks for analyzing classroom discussions.

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