SELF-STUDY OF THE EVOLUTION OF A “DEFERRED JUDGMENT QUESTIONING” DISCUSSION MODE IN A MIDDLE SCHOOL SCIENCE TEACHER

This paper is a self-study of teacher thinking during the evolution of a “deferred judgment questioning” discussion mode which grew out of the author’s first experience with an innovative biology curriculum. The curriculum supports teachers to reach content goals, starting from ideas that are mostly student-generated. This approach, which has been called co-construction, challenged me to break my reliance on lecture and recitation (“fishing for the answer”) and develop new modes of interacting that were more open ended but that still converged on specific content goals. In this study, I articulate how I progressed from lecture and fishing to a discussion mode which I call “sounding”. I used this term by analogy to how ships use sonar to gain information about unseen features below the surface of the water and then use that information to navigate. Sounding developed gradually as I attempted to address the limitations of lecture and “fishing” as a means of generating and evaluating student ideas. The first stage of sounding is generative because it encourages students to generate models. It required me to develop a new set of skills associated with producing generative questions, deferring evaluation, and analyzing student models. The second stage of sounding is evaluative and required me to develop a new set of skills associated with encouraging and scaffolding student evaluation and modification. My analysis of class transcripts indicates that the change in my teaching did not happen all at once, but rather over a period of months, as I developed the skills needed to manage the new demands of each stage of sounding. It is my belief that this detailed account of my path toward a more constructivist mode of teaching will shed light on the evolutionary nature of teacher change.

Norman T. Price, University of Massachusetts, Amherst, MA USA

---

* This material is based upon work supported by the National Science Foundation under Grant REC-0231808, John J. Clement, PI. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Price, N. (2007). Self-study of the Evolution A “Deferred Judgment Questioning” Discussion Mode (Sounding) in a Middle School Science Teacher. Proceedings of the 2007 Annual Meeting of the National Association for Research in Science Teaching (NARST), New Orleans, Loiusiana

Objectives and Theoretical Perspective

National standards recommend the adoption of constructivist approaches while national and state policies have increased the pressures to reach comprehensive state standards efficiently. Using constructivist methods to meet content goals takes time and new skills, so many teachers turn to traditional and familiar lecture and recitation (Tharp and Gallimor, 1988) with the hopes of efficiently reaching standard based content goals. It is difficult for teachers to change their practice and reconcile constructivist theory of effective pedagogy with the practical realties of teaching in a standard based classroom. Teacher change may be facilitated by detailed accounts of how teachers meet the challenges of first implementing constructivist curricula and moving toward such reconciliation. (Hammer, 1995)

A central question for teachers new to constructivist methods is how to engage substantive student thinking, be responsive to student ideas, and still efficiently meet standard-based learning or content goals (Duckworth, 1987) (Clement, 2002) (Hogan and Pressley, 1997). How can teachers break their reliance on lecture and recitation as a means of reaching content goals and make room for more student thinking in class (van Zee and Minstrell, 1997) (Nassaji and Wells, 2000)? What is involved in changing long standing habits of a veteran teacher? This paper assumes there is a need for an inside (emic) perspective to offer a detailed description and analysis of change as experienced by a teacher. (Cochran-Smith and Lytle, 1993) (Lampert, 1999)

This paper is a self-study of teacher thinking during the evolution of a "deferred judgment questioning" discussion mode which grew out of the teacher's first experience with an innovative biology curriculum (Rea-Ramirez *et al*., 2004). It will offer a detailed account of how the teacher encouraged new patterns of discourse and modified "old skills" to meet new the challenges and dilemmas of constructivist teaching. It is hoped that this paper will contribute to the goal of understanding teacher change and the skills needed to make constructivist methods a viable part of standards based classrooms.

Design and Procedure

The teacher (the author) has 15 years of experience teaching in a middle school in a predominately middle class community in a small town in New England. He is experienced with traditional methods but new to constructivist modes of teaching. The new curriculum used was designed to reach content goals using constructivist methods. It aims for large group discussion where at least half of the ideas being discussed are student-generated rather than teacher-generated. This approach, which has been called co-construction, challenged the teacher to break a reliance on lecture and recitation as means of reaching content goals.

Data was collected during four 7^{th} grade science classes, each of about 23 students. The paper has its roots in the in-depth, out-of–class reflection and analysis of 20 hours of video tape of class discussions, artifacts of student work, transcripts of mentoring sessions with a teacher experienced with the EHB curriculum, and the teacher's reflective journals which were collected over a 10 week period during the teacher's first implementation of this curriculum. In an effort to develop viable descriptions of the teacher interaction modes from the data, the constant comparison method (Glaser and Strauss, 1967) was utilized. This involved a cycle of making observations from the classroom videotapes in order to hypothesize an interaction pattern that could explain the observations, consulting the video data to seek other confirming or disconfirming observations, and criticizing and modifying or extending the hypothesized pattern, in repeated cycles.

Analysis and Findings

Introduction

The Energy in the Human Body curriculum, (EHB curriculum), challenged me to try a model-based approach in my teaching (Rea-Ramirez *et al.*, 2004). No curriculum or teaching method works perfectly "right out of the box." I was expecting that like any new curriculum, this one would need to be modified to fit my situation, my students, and my personality.

Though a teacher for 15 years, I was a beginner when it came to using more constructivist modes of teaching. I still felt dependent on lecture and recitation as my primary mode of class "discussion" to meet the content goals of my curriculum. The EHB curriculum is unique, because it is carefully crafted to challenge and support teachers in reaching content goals while using ideas that are mostly student-generated.

I wanted to try co-construction, because I suspected that simply telling kids the correct model or answer was not the best or only way for them to learn science. The EHB curriculum asks students to generate, evaluate, and modify (GEM) mental models of how the body uses energy. Co-construction was offered as a way to stimulate GEM cycles, and thus was a real alternative to lecture and recitation. When I began this curriculum, I was full of questions such as: "What would co-construction look like in my class?" "Would it work?" and "Would I be able to do it?"

To anticipate the result, I believe my experience with the EHB curriculum permanently changed my practice: It helped me develop a constructivist method for reaching content goals by working with student models. By working through the challenges this curriculum posed to my old habits, I developed new skills and understandings which helped me to engage student model reasoning to reach content goals. By describing some of my struggles and the ways I overcame them, I hope to contribute to the pedagogical content knowledge of teachers who are trying constructivist and model based curricula for the first time. This paper describes the evolution of my teaching methods and understandings as I attempted to use co-construction to stimulate GEM cycles. My teaching changed incrementally over a period of months as I developed class discussion methods which moved me beyond lecture and met the co-construction goals of the EHB curriculum.

Lecture: A Familiar Mode to Reach Content Goals

I begin with a description of lecture since lecture mode was my starting point. During lecture, I direct class, determine the pace of instruction, and generate new ideas for the student to consider. A carefully crafted lecture can enlighten and efficiently "move through" a curriculum. But lecture, while it appears to move quickly, can leave many students behind. Student confusion or disengagement often goes undetected, because a lecture's purpose is not to gather information about student understanding. Its purpose is to explicate clearly and quickly the currently accepted understanding of scientists. However, it is hard to craft a lecture that engages, challenges, and permanently replaces the more robust and resilient misconceptions of students.

In the past, I resisted calling what I did lecture. Yet I was often the main speaker and explained science ideas and expected my students to remember them. As a middle school teacher, my "explanations" were between 5 and 20 minutes in length, and rarely seemed extended, at least from my perspective. Still these "explanations" were lectures and no matter how short or good they were, they did not always fit the learning style of my middle school students. Students craved more active learning that would engage them in the construction of knowledge. Yet I would frequently use lecture when I needed to explain a new concept. Lecture was my "default" teaching strategy to meet content goals. And yet, however comfortable I was with lecture, I wanted a good alternative. The EHB curriculum suggested an alternative.

A Model of Lecture

I will try to explain how my modes of teaching evolved through my work with the EHB curriculum. Diagrams or models of teaching modes will help to describe my modes of teaching and the modifications I made to them. For example, Figure 1 is a diagram or model of the lecture mode. In lecture, the teacher has scientifically accepted ideas and, by telling the ideas to the class, these ideas get moved into the approved category.

Fig. 1 Model of Lecture

Students see this set of approved ideas as the "correct", "best", or "right" ideas, and this collection of ideas, when woven together, becomes the scientifically accepted story or model. In the human body content area this model might be the structure and function of the circulatory system. I did not expect a student to generate any useful ideas in lecture, since that was my job. In this diagram I used an oval to indicate what was spoken in class and the smooth circle represents a place where the ideas were collected and displayed, for example on the board or in student notes. Lecture and recitation was my default mode for presenting and describing complex ideas, and I did not have a good alternative to it. The EHB curriculum invited me to develop an alternative approach.

What Does Co-Construction Look Like?

It was clear that co-construction would require me to step away from lecture. But what would the alternative look like? Below are descriptions of key elements of co-construction which helped me to visualize what my first step away from lecture might look like. Three key ideas or "rules of thumb" guided me as I tried to change my practice and develop a method of co-construction which would work for me: 1) the 40i-80i target, 2) the reversal rule, 3) take small steps.

The 40i-80a Target: Share Idea Generation and Agenda Setting

To begin to understand co-construction, it is useful to think about two facets of a class discussion: idea generation and agenda setting. To generate an idea means to add an idea to class discussion. The teacher and students can both add, or generate ideas, to be considered. This is different from directing class or setting the agenda, which relates to only the teacher choosing the activities, the pace, the topic, and the questions to be discussed by the class. Though I often thought idea generation and agenda setting to be solely the domain of the teacher, upon reflection, it is clear that students often attempt to influence the agenda and ideas in class through their questions and comments. The new curriculum suggested that instead of having this happen in a haphazard way, I could use student ideas more purposefully.

I began to understand the alternative presented by the EHB curriculum by first noticing who is generating the ideas and setting the agenda. My practice began to change when I realized that both teacher and student can do these activities. It was helpful to diagram these dimensions by setting each activity on a student–teacher continuum. For example, in a traditional lecture I often did almost 100% of the idea generation and agenda setting. This is shown in Figure 2.

Idea: Who is generating the ideas? [----------------------V-]
Student Generated — Teacher Generated

Agenda: Who is controlling the agenda? [----------------------V-]
Student Directed — Teacher Directed

Fig. 2 Lecture on the Idea-Agenda Continuums (The "V" represents lecture's position on the continuum)

The EHB curriculum describes a mode of teaching where the teacher generates about 40% of the ideas and sets 80% of the agenda. Therefore, the students generate about 60% of the ideas and direct about 20% of the agenda. This is shown in Figure 3 (Clement, in press).

Idea: Who is generating the ideas? [-------V----------------]
Student — Teacher

Agenda: Who is controlling the agenda? [-----------------V-----]
Student — Teacher

Fig. 3 The targets of co-construction on the idea-agenda continuums

The goal, the 40i-80a target, is to increase the student's role in idea generation and agenda setting. When I started the EHB curriculum, I couldn't visualize what this sharing would look like, but as I progressed, this target became an important guide in my attempts to develop this alternative approach. One of the target's most useful functions was to keep me from going too far to the student extreme of the continuum and thereby expecting the student to do all the idea generation. It offered a glimpse of what the EHB curriculum's alternative to lecture would look like by providing continuums that I could begin to move along and suggested the direction in which I needed to move.

The Reversal Rule: Ask Before You Tell

The EHB curriculum suggested a way to move my teaching along this continuum: Ask the students to explain before I explain. This simple suggestion challenged me to reverse my usual order of delivery: I explain and then ask questions. Using the EHB curriculum, I first needed to find out what the students thought before I explained what I thought. Instead of leading with an explanation, I needed to lead with a question. This reversal rule is fundamental to the EHB curriculum: the questions prompt students to take more responsibility for the generation of ideas and for the setting of the agenda.

The reversal rule began to change the fundamental habits of my practice. Instead of explaining, I would question. Beginning with questions shifted my focus from being understood to understanding students. My planning task moved from creating a sequence of demonstration activities, to composing a sequence of questions that would explore student thinking. I began to feel that my lessons worked when the students' ideas began to make sense, and I could understand the logic behind what I previously had thought of in terms of "right" and "wrong" ideas.

The EHB curriculum suggested that I use questions to introduce and construct a new idea or concept. Questioning was a familiar teaching technique, but I did not see how it could do the work of lecture to introduce and explain complex ideas. I worried that my questions and student answers would generate confusion and would not be complex enough to uncover the structures and functions of the body. Still I was willing to experiment, because I knew the EHB curriculum had been designed to support co-construction.

Take Small Steps: Trust that Models Will Evolve

My first step toward an alternative was based on my existing skills and on the level of risk and newness I could manage. I had used recitation questions in conjunction with a lecture mode to check for understanding, or for review. This pattern of teacher-student dialogue is often referred to as IRE, (Inquiry, Response, and Evaluation). When the function of the questioning is to draw out only the student ideas which match the scientifically accepted ideas, it is sometimes called "fishing for ideas". Based on the familiarity of this mode, my first step toward the alternative was to substitute fishing for lecture. "Fishing" alone was not suggested by the EHB curriculum nor did it feel like a co-constructive alternative. Yet, I gave myself permission to try fishing as a first step. Seeing my first steps as intermediate and provisional allowed my teaching to evolve as I developed the needed skills.

I found the EHB curriculum to support incremental teacher change, because it is based on conceptual change through model evolution. It encouraged students <u>and teachers</u> to see that models can be used provisionally as long as they are useful, and then modified or discarded when they are found not to work. Model evolution is hard but rewarding work. Patience and tenacity are required because models are rarely perfected in one step, and evolution is a long process. Faith and confidence are required because the final model is rarely visible when you begin. Courage is required because it is risky to try a model publicly that you know is only partially right. Yet, at the prompting of the EHB curriculum, I asked my middle school students to do this so that we might learn something by "trying out" their ideas. In this spirit of risk taking, it seemed fair that I should have to publicly risk new and "imperfect" teaching modes because I believed that we would learn something useful. By trying out imperfect modes that seemed to move in the right direction, I had faith that I would gain the information and skills needed to revise and improve my own model; that is, my model of teaching.

My First Step Away from Lecture: Fishing

An Example of Fishing

When I "fished" for an answer, I usually asked a question to find a certain (usually short) answer that would move the class toward my objective. I called on a series of students until one gave me the "right" answer and then I affirmed their answer as correct. Below is a transcript that illustrates the mode of student teacher interaction I used frequently before I worked with the EHB curriculum.

T: What are the things that plants need in order to live?
S1: One of the things that they need is sunlight.
T: Sunlight. Good.
S2: Water.
T: Good! Anything else?
S3: Uh, oxygen?
T: Oxygen. I don't think that's quite right. Does anybody else want to alter that a bit?
S4: Plants give oxygen up.
T: Right! Anything else that plants need?
S5: Plants need soil so they can eat.
T: No. Well almost. Plants do need soil but not for food. Can someone fix this?
S5: If you cut a flower and you put it in a vase it eventually dies because it doesn't get its food from its roots.
T: This is a bit more complex then we have time for now but plants mostly get water from their roots not food.

A Model of Fishing

This transcript can be modeled in Figure 4. It shows how my question initiates student ideas and how my immediate evaluation selects the approved ideas.

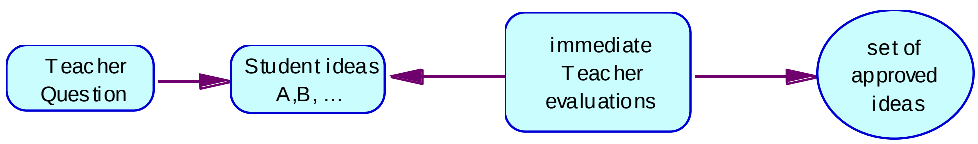


Fig. 4 A model of fishing

Some student ideas about plant needs (sunlight, water, carbon dioxide) were approved and some were rejected and then corrected (oxygen and soil for food) by my immediate evaluative feedback.

When I began the EHB curriculum I used this type of fishing as my first step away from lecture because it asked for students' ideas. This tactic helped me ask more questions and begin to reverse my normal pattern of telling and then asking. It maintained my control of the agenda, although not as absolutely as lecture did. Fishing provided some information about student thinking, and I was able to notice when I was leaving people behind or when they had misconceptions. When a student answered incorrectly, I could alter my agenda to address student misconceptions, as when the student above had the common misconception that soil provides food for the plant. In this way, fishing made progress toward content goals more dependent on student knowledge. My response to either wrong or divergent student ideas was to evaluate them immediately with the hopes of changing the misconception. (Plants don't need soil for food.)

Locating fishing on the idea and agenda continuums is useful because it shows that it was a step in the right direction. I realized that this method had limitations and problems, but on the whole it was a good first step. Fishing moved away from pure lecture, asked for students' ideas, and it offered me the opportunity to alter my agenda. In Figure 5, I indicate that the ideas from fishing were largely teacher generated, because my thin questions were often leading ones that pointed to an answer. Incorrect answers were evaluated immediately, with the teacher providing the answer if necessary.

Idea: Who is generating the ideas? [------------------- V-----]
Student Teacher

Agenda: Who is controlling the agenda? [--------------------V-----]
Student Teacher

Fig. 5 Fishing on the Idea –Agenda continuums

Building on this experience, I was able to evaluate and modify this mode into something more useful. Fishing represented a movement away from lecture because it gave me a chance to practice a new skill of reversing my order from "tell- ask" to "ask- tell". It influenced my agenda setting by giving me information about students' ideas and it encouraged me to change my agenda when the "fish" were not biting. Fishing was an improvement over pure lecture, but it needed to be evaluated and modified.

An Evaluation of Fishing

It quickly became clear that this kind of fishing was often not going to work because it constrained both questions and answers. Since my goal was to find the correct idea quickly, I tended to craft questions that would only elicit a narrow range of student ideas and then I would immediately evaluate the student responses. When I followed this type of question with immediate evaluation, I was fishing. The need to provide quick evaluation creates an incentive for crafting questions that are easy to judge in the moment. Just as in fishing, where the lure is placed on the line and is designed to capture one kind of fish, so too the questions asked by the teacher are often of the fill-in the blank type, designed quickly get the right answer and thus to maintain the pace and direction of class. The purpose of the lure is not to explore the population of ideas but to catch a certain answer.

I felt these constraints in the transcript above when the students offered "oxygen" and "soil for food" as needs of plants. Since my lesson goal was to generate my predetermined list of needs, I wasn't ready or willing to explain the more complex ideas, that plants do need oxygen to respire and do get inorganic mineral from their roots. Since these contributions were not helping me reach my lesson goal, I did not follow up to find out more about these ideas. I considered them to be off topic.

The environment created by this tactic wasn't effective in getting all students to generate useful ideas or in helping me to understand student thinking. If students' prior knowledge about a topic was high, such as during a review, these kinds of questions did yield ideas needed to move the discussion forward. However when I "fished for answers" in new topics where prior knowledge was low, either I did not get any bites, or I watched the discussion deteriorate into a competitive guessing game which often only disclosed and rewarded the thinking of the students who already knew the most.

When trying to elicit specific responses, I saw that often the students with the most prior knowledge got my attention. It was sometimes easier to call on the students who knew the answer than to evaluate tactfully the "wrong" ideas from students with less prior knowledge. I also worried that my immediate negative feedback rejected or ignored students' ideas and left students behind, leaving them feeling silenced, disengaged, and discouraged. This seemed to dampen student willingness to share their thinking, and it seemed most pronounced for students with the least academic confidence. Cooperative learning strategies did ameliorate this negative impact by giving students time during small group work to share correct ideas, but it did not fully overcome the limitations of my fishing strategy.

My use of fishing did not explore student thinking or encourage students to generate original or complex ideas. When questions target specific answers, risk taking and creative thinking are not nurtured. I sometimes felt the urge immediately to eradicate wrong ideas because I feared the "wrong ideas" would "infect" other students, even though I knew that others probably held the same belief and that simply telling them the correct answer would not be enough to change their idea. In this discussion environment, idea generation sometimes felt disingenuous. I questioned if the ideas which students generated were authentic and if they were revealing what students themselves really thought. It felt like I was trying to make students think they were coming up with ideas when, in fact, they were trying to guess what ideas were in my head.

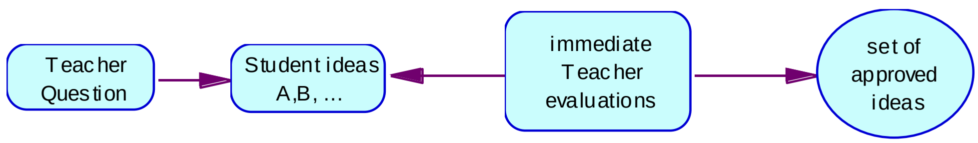
A Modification of Fishing

Exploration was not the goal of fishing. In order to understand student thinking I had to allow "wrong" ideas to get discussed. To achieve more authentic student generation of ideas, I had to develop a mode that was exploratory and that could help me understand why students had the "wrong" answers and what to do about it. To do this I changed the timing of my evaluation of student ideas. If I wanted to encourage more idea generation by students, I would need to *defer my evaluation* of the students' ideas. Normally I had evaluated student answers immediately in order to avoid tacitly approving "wrong" answers. It was hard to allow "wrong" answers to take a place on the board as equals with the right answer, because I worried that this would confuse students. However, since students were working on mental models which were evolving over a period of months, and since the EHB curriculum revisited and reviewed models, I realized that I could be more patient with student learning, and that I didn't need to rush to eradicate wrong ideas. The model concept used by the EHB curriculum helped me to alter my view of "wrong ideas." The mental models we were constructing were amalgams of correct and incorrect elements. I began to see misconceptions as "alternate models" that could be modified (van Zee and Minstrell, 1997).

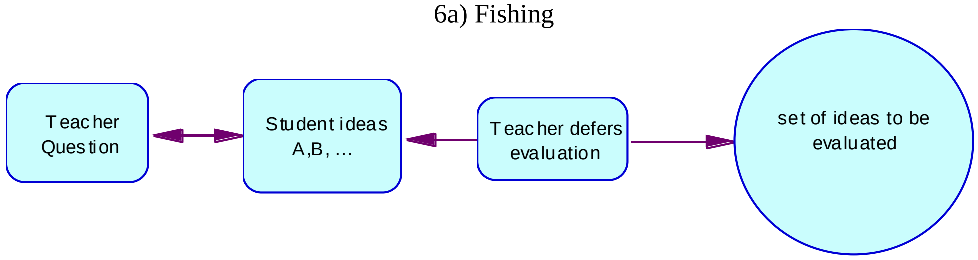
By modifying fishing with *deferred evaluation*, I began to see what co-construction would look like in my class. My model of co-construction was evolving into a discussion mode which I would eventually call "**sounding**". I used this term by analogy to how ships use sonar to gain information about unseen features below the surface of the water and then use that information to navigate. Thus the term, sounding, evokes the duel goal of co-construction: explore unseen student thinking and use this information to navigate to particular content goals. In what follows, I will trace my development in developing two stages of sounding: Generative sounding asks questions which are targeted to return rich information about otherwise unseen student thinking. Evaluative sounding replaces immediate teacher evaluation with scaffolded student evaluation and modification.

Generative Sounding

My first stage of sounding was generative, because I used questions to explore the range of student ideas. It was similar to brainstorming, in that student ideas were generated without being immediately evaluated. By asking questions that would return complex student ideas and by deferring evaluation of these ideas, I began to listen to student ideas in a new way. It is useful to compare this mode with fishing so in Figure 6 both models are included.



6a) Fishing



6b) Generative Sounding

Fig. 6 Comparing Models of Fishing and Generative Sounding

The goal of this stage of sounding was to encourage the generation of ideas by students and then to work to comprehend and analyze them. In both fishing and generative sounding, a discussion is started with teacher questions and student answers. But by deferring evaluation of student responses in sounding, ideas were not immediately approved or removed. This resulted in a larger set of ideas being collected and, more importantly, it created a space in class discussion which allowed me to listen carefully to student ideas and change the pattern of student-teacher discourse. I postponed work on the evaluation of the ideas and thus it is not shown in my model of generative sounding. The difficulty of transitioning into this mode caused me to focus on developing the skills I needed to foster a more generative pattern of teacher-student discourse.

Changing the Rules of Teacher-Student Discourse

Changing patterns with a class is difficult and this is especially true when the pattern involves middle school students sharing their original ideas in front of their peers during a whole class discussion. My students were not used to me asking questions about things we had not learned yet. They were also not used to me deferring evaluation of their ideas. I was asking them to change a comfortable and familiar classroom norm. My students needed to adjust to this new pattern of classroom discourse. They needed to learn to recognize when we were using this new pattern and had to come to trust that I would not suddenly switch back to immediate evaluation just after they had taken the risk of offering an original idea in front of all of their peers.

Changing the pattern of discourse was made more difficult because I was not skilled managing this type of discussion. If I was going to change the pattern of classroom discourse, I needed to find a way to maintain the pattern so that students would come to understand and trust the new rules of interaction. Since I was attempting to change my old habit, the immediate evaluation of student ideas, I needed to find discussion topics which would help me to produce questions which were easy to respond to without evaluation. Open-ended activities and student stories provided topics of discussion which helped us to begin to change the rules of classroom discourse.

Discussing the open-ended activities

An open-ended activity was my first source of open-ended questions. To introduce the EHB curriculum, I used a hands-on activity to show how sharing student ideas can create a better solution to a problem. I asked groups of students to build the tallest tower possible in five minutes, using only a piece of paper and a pair of scissors. I measured each group's result and calculated a class average. With the goal to improve the class average, students then shared their designs. Since there were many ways to design the tower, this open-ended activity encouraged everyone's participation. They then had a chance to build another tower. After a few repetitions, the class average did increase. I used this "tower challenge" as an example of how sharing student ideas help us improve our model, just as we would do in the EHB curriculum.

I hadn't responded at all to their ideas since their tower's success or failure provided its own evaluation. However, my students still expected me to evaluate their answers and when I did not, they took my neutrality as a negative evaluation or as a sign of disinterest. To counter this impression I learned to encourage their participation vigorously, while remaining neutral to the content of their ideas. One phrase I used often was "Thanks for your idea." Some students were uncomfortable not knowing if the were 'right", so when I did not evaluate student ideas explicitly, they tried to read my facial expressions, body language, and tone of voice for clues. I needed to practice deferring evaluation of right and wrong answers without giving any obvious prosodic clues of my opinion, or else student would be able to guess my opinion even if I never said a word. I began to fear that I needed perfect body and language neutrality to truly defer evaluation, but I was comforted by the fact that there is plenty of "noise" in teacher-student communications. All I needed to do to successfully defer evaluation was to make students uncertain enough of my opinion so that they couldn't be sure which response I liked the best.

Discussing student stories

Student stories provided topics of discussion which also helped us to continue to change the rules of classroom discourse. Student stories were a good source of open-ended questions. Open-ended questions are questions which have many "right" answers. By asking this type of question I was implicitly telling students that I wanted to hear many peoples' ideas. For example during our work on energy in the first chapter, everyone had a story about his or her arm falling "asleep" that they could contribute to the discussion. Each student story about their arm or leg falling asleep furthered my agenda by contributing an example of how the body used energy, even when inactive. However, student stories often led to discussions which were off topic, like "what is death?" , that did not advance my content goals. It was worthwhile to discuss these questions, since it was helping me to learn how to encourage curiosity and participation while deferring evaluation. In this way, open-ended questions were helpful in developing the norm that I expected active participation from everyone. It encouraged even shy students to take the risk of sharing their ideas. My students were naturally curious about the human body, and they came to class with many common experiences and questions. Inviting their stories and their questions about the topic allowed an opening for everyone to make a contribution to class.

Creating a generative environment

Discussions of activities and stories were not uncommon in my teaching prior to using the EHB curriculum, but this was the first time I had used activities and stories strategically to develop and nurture a more idea-generative discussion environment. Using these discussion topics, I slowly became more comfortable deferring my evaluation of student ideas. It was easier to curb my initial instinct to explain or correct student ideas.

Still, it was difficult to respond to students' ideas in ways that encouraged their contribution but were neutral about their content.

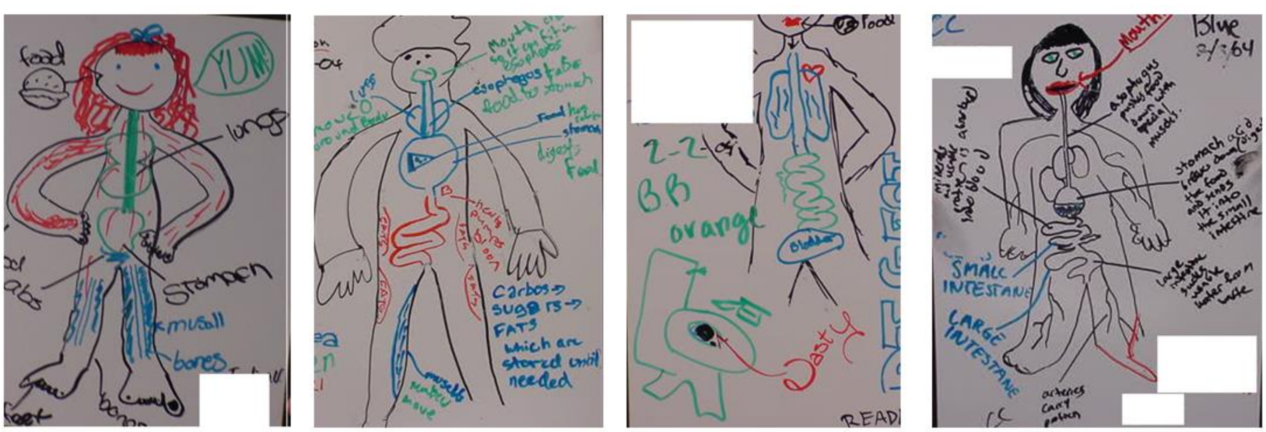
There are many ways to be neutral and it took time for students to come to understand my intentions. I began to ask follow up questions encouraging students to give reasons for their answers: "Why do you think that?" Or "Can you say more about that?" I wanted my follow up moves to invite students to say more about their ideas. Some researchers have referred to this type of move as a reflective toss (van Zee and Minstrell, 1997). It took time for students to learn that these follow up moves were not implicit negative evaluations but were honest invitations for them to share more of their thinking.
My students and I slowly became used to these new norms of classroom discourse. I vigorously praised students who contributed thoughtful, honest, and unique ideas and questions and who listened carefully and responded respectfully to the ideas of others. Enthusiasm and positive attention for these behaviors supported new class norms that encouraged fruitful and good spirited idea generation. The few students who tried to use the "wrong" ideas of others to demean them were explicitly told they were not contributing positively. By discussing open-ended activities and student stories, I developed the skill and confidence I needed to encourage participation and defer evaluation about the content of ideas. It took weeks, but I began to see an increase in student participation and comfort with the new pattern of student-teacher discourse. I had confidence that this new pattern was firmly established in my class, and I was ready to use EHB curriculum to ask more difficult questions.

Understanding Student Models

Open ended questions had helped me to change class norms, but they had not helped me to use student ideas to meet the content goals of the EHB curriculum. I needed to ask questions which would stimulate the process of model evolution. The EHB curriculum offered questions about models and analogies, and these questions generated rich information about student thinking. At first, the complexity of student thinking was difficult to comprehend and organize, but with some practice, I learned to see student ideas as models and to use these models to help me meet my content goals.

What is a model?

The concept of a model was unfamiliar to the students and to me. Our understanding of modeling improved most after we worked on some of the EHB curriculum's model-based questions about the digestive system. One such question asked students to draw and to explain their initial model of what happens to food after they chew it. Each student or group of students generated a labeled drawing and shared with each other their explanation of how digestion worked. These drawing and explanations were complex sets of ideas, and the students and I began to refer to these sets of ideas as models. I have included 4 examples of student work in Figure 7 to illustrate the complexity and diversity of students' initial models.



Example a Example b Example c Example d

Fig 7 a-d Examples of student groups' initial models of the digestive system

New modes of action required new modes of thinking

I found these drawings and explanations (models) hard to understand. My confusion with these models made it hard to run a whole class discussion meant to help students evaluate them. I felt a bit discouraged at this point but I began to be more hopeful when I realized that my habit of action, fishing, was connected to a habit of thinking. Because I was asking content questions about the digestive system, I had engaged a kind of evaluative thinking that I had used in fishing. I had abandoned the action of fishing but I had not abandoned the thinking and expectations associated with fishing. I was still trying to understand student answers quickly in order to evaluate them immediately. Since I was unfamiliar with student models, my ability to understand them immediately was overwhelmed by their complexity and diversity. Model based questions had returned rich results and helped to reveal the logic behind student answers. Student models were complex sets of ideas and reasoning and could not be comprehended as easily as the simpler answer a fishing question might return. In addition these sets of ideas were diverse, and each student model had different strengths and weaknesses.

Brainstorming models of digestion had generated a "conceptual splatter" (Easley, 1990) that would take some time and patience to untangle. These student models represented good and honest thinking that students had risked sharing with their peers. I had to be careful that my response to them did not reverse the progress we had made in developing generative class norms. I was able to collect and display these model drawings but I wasn't sure how to make sense of them or to use them productively in class discussion. So in order to preserve the generative environment, I was still avoiding evaluation. I would simply listen to their description of their models and not evaluate their content. Simply collecting and describing ideas without evaluation had caused the agenda setting and idea generating to shift too much toward the student as can be seen in Figure 8.

Idea: Who is generating the ideas? [-V------------------]
Student Teacher

Agenda: Who is controlling the agenda? [----V---------------]
Student Teacher

Fig. 8 Pure deferred evaluation on the Idea-Agenda Continuums

Without any teacher evaluation, I did not make quick enough progress toward my content goals. The Idea-Agenda continuums suggested the direction in which I needed to move. I needed to add more ideas and regain control of the agenda. At this point, the only way I knew how to do this was to shift back to the other side of the continuum, and use fishing and lecture modes. Doing this helped me to progress toward my content goals, but I knew I had not reached the 40i-80a target. The path toward co-construction was not straight, and being flexible with my strategies kept me from getting discouraged.

Reasoning with Analogies: Strategies to Analyze Student Ideas

I needed to comprehend student ideas before I could help students interpret and evaluate them. I needed to practice analyzing models. Fortunately the next part of the EHB curriculum offered an array of questions about analogies. My challenge at that point was to use these questions to practice the skill of comprehending and organizing student ideas so that I could begin to use them as resources in meeting my content goals.

Analogies Isolated model elements

Part of the difficulty of comprehending student models was that the models represented interrelated sets of prior knowledge and logical reasoning. Questions about analogies served as practice for questions about models, and evaluating how students mapped individual analogy elements served as practice for evaluating model elements. The middle section of the EHB curriculum used a variety of structural and functional analogies. When these analogies were mapped, individual ideas or <u>model elements</u> could be isolated, and the student reasoning about them could be explored. For example, the "cell as school" analogy was developed and mapped. Key parts of the cell were linked with parts of the school that had analogous functions. Students developed an understanding that the nucleus of the cell was like the school office. By asking students to justify why the nucleus of a cell is or is not like the office of the school, I could begin to isolated individual ideas, access prior knowledge, and begin to see their reasoning. Asking them to complete the simple sentence, "The nucleus of a cell is like the office of a school because…" gave me very useful information. Analogy mapping helped me to "untangle" the conceptual spatter and isolate ideas from the sets of ideas which students generated.

Analogies allowed reasoning with shared prior knowledge

Analogies helped me develop "why" questions to which most students had an answer from prior knowledge. These questions helped expose the prior knowledge and the associated logic behind student ideas. Since analogies start with a base that is well known by most students, such as the office in the "office as nucleus" analogy, the associated reasoning rests on more solid prior knowledge and can be used more fluently by more students. For example, when I was introducing "the cell as school" analogy, we walked around the school and found various parts of the school that were similar to parts of the cell. I asked students to take me to the nucleus. Many students wanted to take me to the space in the center of the building, which happened to be the library, because structurally, they thought that the library is where the nucleus should be. Others liked the office better because, functionally the nucleus housed the "boss" of the cell, as the office housed the principal.

This disagreement about which was a better nucleus, the library or the office, was important because both groups could and did engage in a productive discussion and used reasonable arguments to make their case. I had given them enough information about the cell so that they could take off and productively reason on their own about this question. In addition, this reasoning was comprehendible to me. I could see when they were using the logic of structure or function. I could see what factual knowledge they could not generate on their own, (for example, all nuclei are in the center of the cell), but that might be needed to help them reason. I could see which questions were too hard and which too easy.

The comparison of analogies started many animated discussions. How is a cell like or not like a building block? How is a cell like or not like school? Which is more analogous to a cell, the school or the block? In the course of these discussions, a norm of scientific argumentation began to emerge: your answer needed to be backed up by reasons. The students engaged in these discussions because they had the knowledge they needed to reason with confidence. They could engage productively in the evaluation of ideas, and I could help them by adding ideas they needed when their prior knowledge fell short.

Analogies allowed for judiciously timed teacher input

Using the analogies in the EHB curriculum, I began to see a way that I could allow myself to contribute the addition of my ideas and the evaluation of ideas as in fishing. But the way I added and evaluated ideas was very different from the lecture and fishing modes. This new mode added ideas and engaged in the evaluation of ideas, but it did not dampen the generative environment. In fact, it seemed as though analogies had given me a way to start the "fire" of a scientific dialogue and helped me to analyze it, so that I could keep it alive by "fueling" it with the well-timed addition of a question or fact useful for reasoning. This is a very different metaphor for teacher input than the pipeline metaphor of the teacher as the only legitimate source of information, information that is being transmitted directly to the passive student.

Evaluative Sounding

Reasoning with Models

With these new skills, I could begin to shift from encouraging students to generate models and begin to ask them to evaluate them. My next task was to get students to reason with their models the way they had been reasoning with analogies. Analogies had helped me avoid conceptual splatter by breaking down a set of ideas into smaller units or elements and then to asking tractable "why" questions about them. I needed to comprehend student models so that I could add ideas and questions to keep the scientific argument "burning" while also moving it toward resolution.

Finding model elements

In order to better comprehend and then build from student models, I had to analyze them so that I could see their constituent parts, or model elements. I was first able to do this with initial student models of circulation. When discussing circulation, students were given an empty drawing of a body and given the following set of instructions:

On the drawing of the girl, show the path followed by oxygen and sugar to the big toe. Show how carbon dioxide gets out of the big toe. Be as detailed as possible. Label your drawing.

At the time of this assignment, students had already studied the circulatory and digestive systems, and had understood that blood is pumped from the heart to the big toe. Initial student models of the larger circulatory system were collections of four model elements: heart, vessels, digestive system and tissue in the big toe. Figure 9 shows the model elements that were most common in initial student models. I came to see initial student models as groups of model elements.

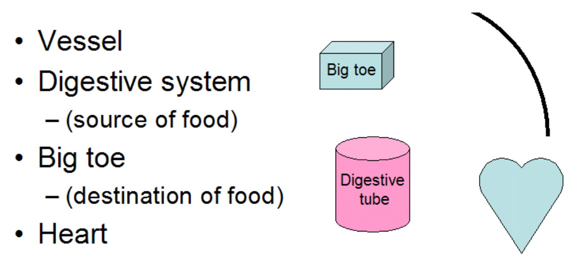


Fig. 9 Early model elements of the circulatory system

Once I identified these elements, I was able to look more diagnostically at student drawings of the circulatory system. I could see what they contained and what they were missing. Certain student drawings that, at first glance, appeared to show very little understanding, with more careful examination, revealed many correct elements that could serve as useful starting points for class discussion. Once I had identified these model elements, I could categorize student work based on which elements their models contained and how they arranged these elements.

Figures 10-13 show representative samples of student work completed in their first response to this prompt. In these figures, I represent the model elements that they include with my diagram of the how they were connected model.

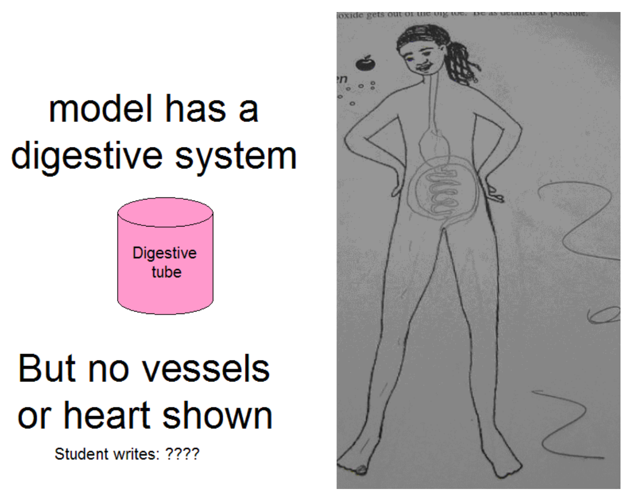


Fig. 10 An initial student model with only a digestive system

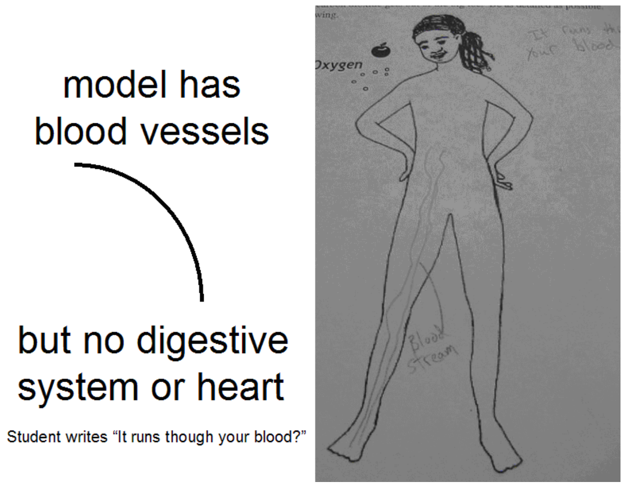


Fig. 11 An initial student model with only a blood vessel

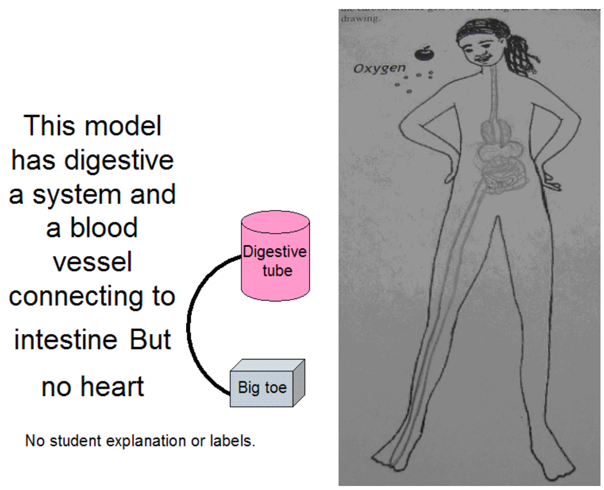


Fig. 12 An initial student model with a blood vessel connecting the digestive system to the big toe

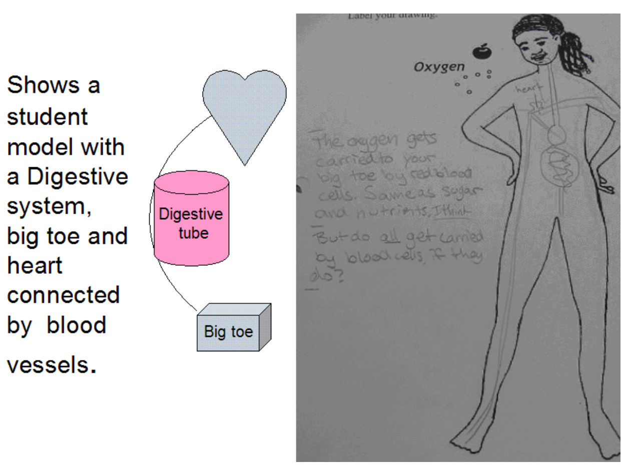


Fig. 13 An initial student model of a blood vessel connecting the digestive system heart, and the big toe

Deferring evaluation

One key difference between evaluation used in fishing, and evaluation used in sounding was its timing. In sounding, my goal was to evaluate ideas after I had neutrally collected and analyzed a variety of student ideas. Shifting from neutral collector into the role of evaluator was hard, because it was easy to fall back into my earlier habit of immediate feedback. To help make shift from collector to evaluator easier, I began to collect ideas at the end of class, analyze them after class, and work on evaluating and modifying them with students the next day. This delay served many useful purposes. First, a delay gave me more time to make sense of their work and to think about what modifications were needed and I could think about what evaluation tasks might start a discussion and move it toward resolution. Second, it allowed me to make the idea's source more anonymous. Anonymity diminished the personal link between the idea and the student contributors and allowed more honest discussion. Students could argue an idea's merits and not worry about how their comments about a friend's idea would affect their personal friendships and loyalties. This timing allowed the simple binary, right/wrong evaluation of fishing to evolve into the multifaceted and diagnostic evaluation and modification of sounding.

Reasoning with model elements

By deferring evaluation of their ideas, I was able to maintain the class norms needed to encourage honest and thoughtful student generation of ideas. It also gave me the time to analyze their models and to see the various elements that together make up the target concept. When I broke the student drawings down into their constituent model elements, I began to understand why one model with its array of structures would function better than another. Just like my students, I had to develop my understanding of how unique combinations of body structures would function together. It was no longer a simple question of which student model structurally matches the scientific model. It became a more interesting and complex reasoning question of how each model would function.

The search for common elements in their drawings gave me a way to organize their ideas and to avoid the confusion of conceptual splatter. As I became more aware of the reasons for each part of the model, I could categorize the student drawings into groups of models with common strengths or weaknesses. This in turn made it easier to select the student model to discuss in class. I set my agenda based on which part would be the easiest to work on next. I noticed that lungs and capillaries did not make it into most student drawings, but the EHB curriculum suggested that I deal with these important but complex omissions later in the curriculum.

My simplest task was to get all the basic model elements into all student drawings. Since some students had all the elements in their initial model, I found that the students could generate a list of the needed elements and begin to evaluate models for the presence or absence of these structures. The student models that were closer to the scientifically accepted model functioned better, and this made it possible to evaluate student models based on functionality. If comparisons were made between partially correct models, students were able to make thoughtful evaluations of them and were able to justify inclusion of needed parts. For example, they could give reasons why models with a heart were better than models without it. For questions at this level, evaluation of function "made sense" to students and had the power to force students to make modifications to their models.

My analysis of student models helped me to diagnose what modifications were needed and to select the right evaluation task. An evaluation task I often used, called model competition, asked students to compare and evaluate the functionality of two student models. Using student models in this ways helped me to see misconceptions as "alternate models" (van Zee and Minstrell, 1997) since they were useful launching points for evaluations, and since they often become the foundation of deeper understanding. A tractable evaluation task engaged students in the search for answers by raising questions that they felt they could answer and wanted to answer. It catalyzed a scientific dialogue that engaged students in the evaluation and modification of their models.

Scaffolding Student Evaluation with Model Modifications

Evaluative sounding replaces immediate teacher evaluation with scaffolded student evaluation and modification. The goal of evaluative sounding is to use an understanding of student models to select an evaluation task and teacher modifications that will engage students in the evaluation and modification of their own models. It was often too difficult for students to run their own evaluation completely independent of the teacher. I found that in practice this process needed to be scaffolded by making modifications to the model which made the evaluation task easier. In the course of student evaluation, I was able to make model modifications to give students the information they needed to make better judgments. This modification improved the condition of the initial student model without ending the student search for an answer.

Evaluative sounding offers a useful and informative focus of student reasoning. By remaining neutral and resisting the urge to do the evaluation for them, I attempted to keep students in the reasoning zone as long as possible. When evaluation tasks were pitched correctly to student reasoning zones, the tasks were tractable and were completed efficiently by the students. Under these conditions, GEM cycles were stimulated and the model evolved quickly. However, it was difficult to create an appropriately pitched evaluation task or make the appropriate modification before class. The diversity and creativity of student thinking often exceeded my ability to predict or plan what would be tractable to student reasoning. Because of this complexity, I came to see that each evaluation task was also exploratory and I began to expect that during the discussion that I would need to scaffold flexibly with teacher modifications when students became stuck.

Generative and Evaluative Sounding

An Model of Generative and Evaluative Sounding

In the previous sections, I have traced my progress in developing two stages of sounding: Generative sounding asks questions which are targeted to return rich information about otherwise unseen student thinking. Evaluative sounding replaces immediate teacher evaluation with scaffolded student evaluation and modification. The generative and evaluative phases of sounding are shown in Figure 14. In the diagram, students take a large role in evaluation, but as the models are evaluated, I scaffold the process by contributed model modifications which make the evaluation task more tractable to student reasoning. Well-measured and timed modifications did not give away too much information too soon.

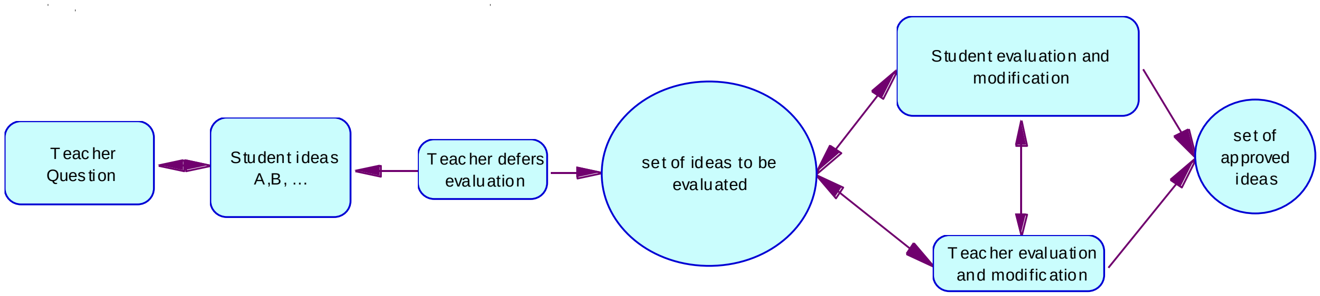


Fig. 14 A model of Generative and Evaluative Sounding

An Example of Generative and Evaluative Sounding

This model of sounding can be seen in the transcript below. I had asked this class to add the lung to their model of the circulatory system. A few students had generated a model with a blood vessel containing blue oxygen poor blood traveling to the lung, gaining oxygen and turning red and then traveling to the heart. Representations of chalk board drawings are shown in Figure 15 and where relevant, the colors of the lines are indicated.

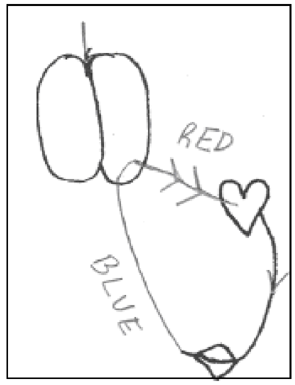


Fig. 15 Representations of teacher chalk board drawings showing model of lungs, heart, and blood vessels

I thought the model in Figure 15 would appeal to students and quickly win approval. Remaining neutral, I did not to reveal my position when I asked students to evaluate the model and explain their reasons. To my surprise many student did not like this model.

> T: Do you like this model?
> S8: No... the vessels don't make a continuous circle.
> T: And you think that is necessary?
> S8: Yeah, because that is what have been learning.
> T: S9, do you want to say something about that?
> S9: Well, it's wrong because the veins go to the lungs, but the arteries go to the lungs, and the veins go back to the heart, and you can't have arteries going into the heart they have to go out.
> T: So you're talking about this being an artery.
> *(Teacher points to red line representing a vessel linking heart to lung)*
> S9: Yeah.
> T: Why do you call that an artery?
> S9: Because it is red.
> T: So in the model we had been using veins to go back to the heart…. This new model shows the veins going to the lung instead of the heart. So is that a problem or are we going to have to shift our model now? That is the question for us.…
> S6: Neither of those are right are they?
> T: No, they are not right. We are closer, but we are not there. We just started the lungs, we can't expect to figure out the lungs in one period. The trick for us is to figure out which model makes the most sense and for what reasons they make sense. It is not about memorizing a picture. Okay? It is trying to reason why one would work better than the other. That is what I am curious about.

By asking students to evaluate the model, I had diagnosed how they were reasoning with or "running" their model. Students were reasoning with elements from an earlier model that showed a circulatory system with blood flowing in it like a circle, with red arteries going away from the heart and blue veins going toward the heart. The new model violated some ideas of previous models: namely that veins need to go the heart, and all veins are blue. When S6 revealed her surprise that neither the old nor the new model was right, I realized how students' habit of memorizing "the answer" or expert model can interfere with reasoning flexibly and modifying transitional and imperfect models. Students believed our early simple model of the circulatory system to be immutable, because it was approved and used to explain how that system functioned.

I decided to scaffold the evaluation by adding model modifications which would simplify the evaluation task. Selecting the most useful modifications was aided by the information I had received from observing their attempts to evaluate a model. In this situation, I clarified that vessels are named artery or vein based on direction of flow, not based on "color" of the blood. This gave us permission to breaks some old rules (blue veins only go the heart).

I decided also to sketch in 4 chambers to the heart in our model, in order to provide the places to connect all of the blood vessels containing different types of blood. These changes allowed us to erase part of the drawing (Figure 16a) and start again. With this help, students were able to make productive model evaluations and modifications with minimal interventions from me.

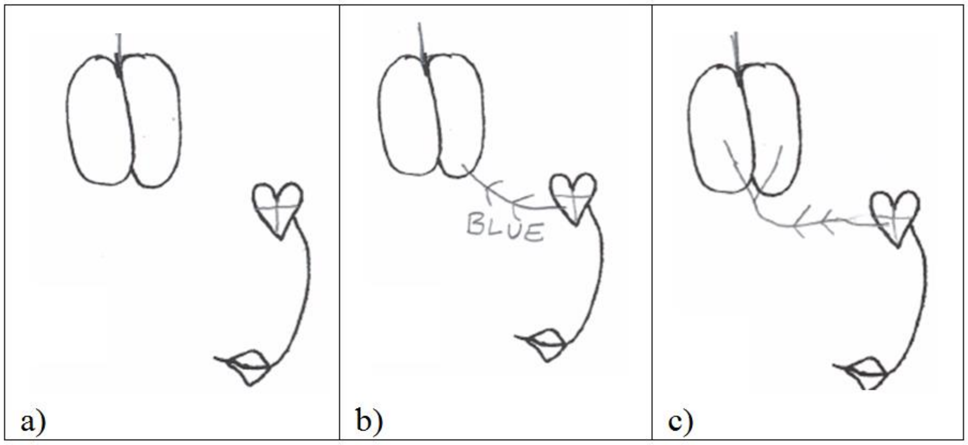


Fig. 16 Representations of teacher chalk board drawings showing initial model modifications

T: Now does someone want to take a stab at (redrawing) this? S4?
S4: Instead of a vein going through the lungs, it should be an artery going through the lungs and a vein coming back. Because it would be a vein going all the way through the lungs, and they kept picking up oxygen, because it doesn't have cells to drop off to, because the blood has already been to the cells. So shouldn't an artery be going to the lungs?
T: So we need an artery going to the lungs.
(In Figure 16b, I draw a white vessel going from heart to lung.)
T: Now, question: what color would it be?
S4: Red?
T: Red. Why would it be red?
S4: I mean wait, no, it wouldn't have oxygen in the blood.
T: So if we had a blue, lets just say, going from the heart to the lung, would that make sense?
(In Figure 16b, I draw over the white line and make it blue.)
S4: Yeah, cause it won't have oxygen in it.

One of my strongest students did not like this modification in Figure D and to my surprise quickly became stuck. Another student, not as academically strong, offered a flexible solution of allowing the vessel to branch and offered a modification (Figure 16c) to solve the problem.

S1: Well, I was going to say according to those, then, there would be no reason to have two lungs because everything is connected to one lung and other one is just there, we wouldn't have two lungs if there wasn't a reason for them.
T: So what do you think we should do about that?
S1: I have no clue.
T: No idea?
S1: No idea.
S5: It just doesn't make sense.
S4: There could be two arteries going off, one to each lung.
T: You mean something like this going in here like this?
(In Figure 16c, I draw in the branching suggested by S4)

Another student used an idea we had studied earlier, a closed system, to evaluate the model (Figure 16c) and because of time, I offered a modification (Figure 17 a) to solve the problem.

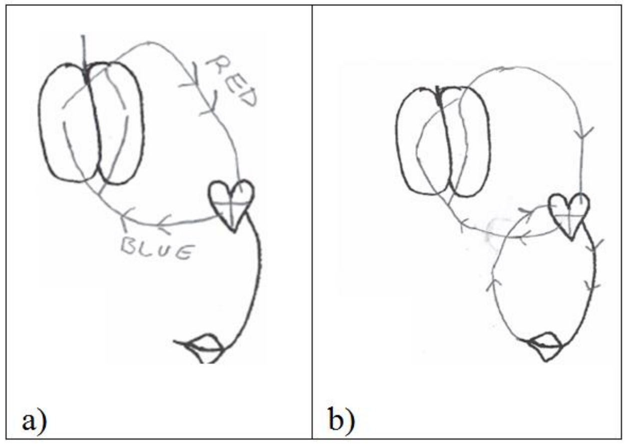


Fig. 17 Representations of teacher chalk board drawings showing final model modifications

> S5: But if there are both arteries coming up from the heart, then how does it get back because it is not a closed system if it goes away and never gets back.
> T: Alright, so it has to go back to the heart.
> *(In Figure 17a I draw a vessel going from the lungs to the left auricle.)*
> All right, that is very good. So now we have got arteries going towards the lung which are blue. They get into the lungs, fill up with CO2, oh sorry, fill up with what?
> S: all (oxygen)
> T: Oxygen. And then they leave the lung and this is our, what do we call this vessel then?
> S: (choral response) Vein!
> T: It is a vein. So these are exceptions to our rules aren't they? We have a red vein and a blue artery.

At this point another student was able to add the final modification to the model by completing the linkage to the heart (Figure 17b)

> T: Now, we just need one last little piece. And that is what S8?
> S8: Which is connecting up to the chamber just above where the artery is.
> *(In Figure 17b I draw in vena cava connecting the toe to the heart.)*
> T: … Ok? Now we have a reason for four chambers all of a sudden!

The evaluative phase provided useful insights about how students were using their model. I could use these insights to guide my intuition about new information they might be ready to use. With this perspective, I could make a judgment about what new information they might need and be ready for. It was helpful when I decided what information to add, based on how my students were running their model vs. how I was running my model. My understanding of the expert model sometimes made it hard to put myself in to my "students' shoes", and to know how they were thinking about their model. The information I offered them in the above transcript, was useful and it helped them cut their way out of confusion. The ideas which I added in this way were accepted and assimilated into the student model, and were used immediately to solve a problem students were having with the model.

Conclusion

This paper is a self-study of teacher thinking during the evolution of a "deferred judgment questioning" discussion mode. It grew out of my first experience with an innovative biology curriculum, the "Energy in Human Body" (EHB) curriculum. The EHB curriculum is unique because it is carefully crafted to challenge and support teachers to reach content goals, using ideas that were mostly student-generated. This approach, which has been called co-construction, challenged me to break my reliance on lecture and "fishing for the answer" discussion modes, as means of reaching content goals.

Above, I articulate the elements and characteristics of lecture, fishing, and the alternative discussion mode that I call “sounding”. Sounding is primarily a response to the limitations of “fishing” as a means of encouraging and evaluating student generated ideas. Like fishing, sounding is, in a sense, the reverse of lecture because it asks a question before revealing the answer. By deferring teacher evaluation of student ideas, sounding invites and encourages students to take a larger, less passive role in the generation and evaluation of their models. However, this is not just an academic analysis of “sounding”, because each step away from lecture required skills which were a real challenge for me to develop. I needed weeks to develop proficiency at each stage of sounding before I could productively manage and direct the classroom consequences of beginning with questions and deferring the evaluation of student answers.

The first stage of sounding is generative and required me to develop a new set of skills associated with deferring evaluation, producing generative questions, and analyzing student ideas. This stage seeks to explore and comprehend a wide variety of student ideas and reasoning and replaces the fill-in-the-blank type questions often employed in fishing. This stage provided me with useful and complex knowledge about student thinking, and helped me to determine the questions and ideas needed to help the students construct meaningful, accurate, and useful scientific models.

The second stage of sounding is evaluative and required me to develop a new set of skills associated with encouraging student evaluation and model modification, and scaffolding this process with teacher ideas. This diagnostic evaluation and treatment of student models replaces the typical binary (right or wrong) evaluation of student ideas in fishing. The overall goal of sounding is to get students with all levels of prior knowledge to articulate and reason with their best understanding, and then evaluate and modify this understanding as they are stimulated by ideas from the teacher and their peers.

Sounding involves a method of formative assessment and scaffolding. My attempts at sounding created a richer context of understandings about student models, and helped me to add information (teach content) in ways that did not collapse zones of active student reasoning. It was hard for me to do this using lecture and recitation. When I planned a lecture, I would choose new information which was the next logical piece I thought was needed, based on my expert model and my understanding of the typical student models. In a lecture, however, my understanding of student models is limited, so often my beliefs about student models were little more than guesses. Yet even when I made a good guess about the state of the student model, and added a piece of information which matched the need of the student model, I still was putting the student in a passive position. If this idea I offered was not used by the student to answer some student question, then the student remained a passive recipient of expert knowledge.

Sounding involves another way of questioning and listening to students. It can create an inviting space for student thinking in whole class discussions. Its goal is to get students with all levels of prior knowledge to articulate and reason with their best current understanding, and then to evaluate and modify this understanding based on questions or ideas from the teacher and their peers. One of the goals of sounding is to listen to students and learn a how students are running their models. When I listened to their ideas in this way, I gained information but I also changed my relationship with them and changed the environment in the class. I switched from being the primary knower of the expert model, to being the secondary knower (Nassaji and Wells, 2000) of how they were using their models to reason. From this position, I could use my intuitions to generate authentic questions which were not designed to lead them to guess my idea but rather were designed to help me to understand their models and how they were evaluating them. When I took the stance of secondary knower and genuinely pursued an understanding of their models, students felt respected as primary knowers and were encouraged to articulate their model in a context that was unfettered by worries about whether their model matched my expert model. This respect created a safe space for their ideas and encouraged them to engage actively in the model construction process. (Duckworth, 1987)

Sounding involves another way of delivering ideas to students which differs from lecture in many ways. If the goal of the lecture mode is to get the student to use the clarity of the lecture to position each element of the model carefully in its proper place, then the goal of the sounding mode is to get students to engage in evaluation of ideas, to reach out and grab the ideas they need in order to evaluate and modify their own ideas. By getting the student to ask the question before the teacher answers it, sounding supports the process of co-construction. Sounding provides a rich context of information about what the student knows and needs to know. This rich context prompted me to offer ideas, because students needed them to make a good evaluation of the model. In addition, student assimilation of the ideas is immediately visible by whether and how they use the ideas to explain their choice between competing models. The stages of sounding lead to an understanding of what knowledge is needed to help students make meaningful, lasting, and "correct" modifications to their model. Sounding attempts to keep students in an active reasoning zone of generating, evaluation, and modifying models. Sounding gave me a map of the current state of student models, and this map helped me to stimulate and guide the active process of student model evolution.

Sounding fostered co-construction and helped me to reach content goals, starting from ideas that were mostly student-generated. I hope that this detailed account of my path toward a more constructivist mode of teaching will contribute to the understanding of the evolutionary nature of teacher change and how it can be catalyzed outside of formal professional development by the implementation of innovative curricula. I was expecting that like any new curriculum, this one would need to be modified to fit my situation, my students, and my personality. I did not expect the lasting way it changed my practice and the way I think about teaching. My evolution toward a constructivist mode of teaching suggests that teacher change is not a quick process. The change in my teaching style did not happen all at once but rather over a period of months, because the skills I needed were difficult to learn and develop. It wasn't until these skills were developed that sounding became a viable, comfortable, and dependable alternative to lecture and recitation.

References

Clement, J. (2002). Managing student/ teacher co-construction of visualizable models in large group discussion. *Proceedings of the AETS, 2002*.

Clement, J. (in press). Student/teacher co- construction of visualizable models in large group discussion. In John Clement and Mary Anne Rea-Ramirez, Eds. *Model based learning and instruction in science*. Springer.

Cochran-Smith, M., & Lytle, S. (1993). *Inside/outside: Teacher research and knowledge.* New York, NY: Teachers College Press.

Duckworth, E. (1987). *The having of wonderful ideas.* New York, NY: Teachers College Press.

Easley, J. (1990). Conceptual splatter in peer dialogues in selected Japanese and U.S. first grade mathematics classes. In W. L. Steffe (Ed.), *Transforming childrens' mathematics education* (pp. 216-226). Hillsdale, NJ: Erlbaum.

Glaser, B. G. & Strauss, A. L. (1967). *The Discovery of grounded theory: Strategies for qualitative research*. New York: Aldine Publishing.

Hammer, D. (1995). Student inquiry in a physics class discussion. *Cognition and Instruction*, 13, 401-430.

Hogan, K. & Pressley, M. (1997). Scaffolding scientific competencies within classroom communities of inquiry. In Hogan, K. & Pressley, M. (Eds.) *Scaffolding student learning : instructional approaches and issues.* Cambridge, MA : Brookline Books.

Lampert, M. (1999). Knowing teaching from the inside out: implications of inquiry in practice for teacher education. In G. Griffin (Ed.), *The education of teachers* (pp. 167–184).Chicago, IL: The National Society for the Study of Education.

Nassaji, H. & Wells, G. (2000). What's the use of 'triadic dialogue'?: An investigation of teacher-student interaction. *Applied Linguistics.* 21 (3), 376-406.

Rea-Ramirez, M., Nunez-Oviedo, M., Clement, J. (2004). *Energy in the Human Body: A Middle School Life Science Curriculum*

Tharp, R., & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning, and schooling in social context.* New York: Cambridge University Press.

van Zee, E. and Minstrell, J. (1997). Using questioning to guide student thinking. The *Journal of the Learning Sciences*, 6(2), pp. 227-269.