Facilitating Discourse in the Physics Classroom

A Compilation of Quotes from Experienced Modelers

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"If I invite friends to my house for dinner I will go to the grocery store and buy several ingredients. I will pick up vegetables, meats, and spices, along with several other items. Then, I will bring these items home and lay them out on my kitchen counter. Even if I buy the best of ingredients, I still am not ready for my guests. To get that meal ready requires the skills of a chef; skills that require an understanding of what ingredients go together, and how to adapt the use of those ingredients to produce a masterpiece of a meal. This is what it takes to be a great teacher. While we can supply teachers with all of the greatest of curricular materials, supplies and equipment, it still requires that the teacher knows how to be a chef in the classroom to create a masterpiece for his or her students."

Carol Ann Tomlinson
NCREL Annual Conference, March 11, 2004

Introduction

The Modeling Method of Physics Instruction has been honored twice by the United States Department of Education as an exemplary program for preparing teachers for the physics classroom. In the Modeling Method, students work in small groups to explore and uncover physical relationships on their own with guidance from the teacher. Typically, data are collected and analyzed using a computer. Results are summarized on dry-erase whiteboards using multiple representations (e.g. system schemas, graphs, and diagrams). Whiteboards are shared in a large-group format for teacher and peer feedback. During *whiteboard discussions*, students develop important questioning skills.

This manual is a compilation of quotes, from experienced modelers, on how to elevate quality of classroom discourse through whiteboard discussions. Keep in mind that the whiteboard technique is just a tool – one possible "ingredient" in good teaching (as per the Tomlinson quote above). Adapting whiteboard discussions to your own unique strengths has proven to be an enduring challenge for Modelers.

Two Modeling Programs

The Modeling Method emerged in the late 1980s. However, it has evolved considerably from its initial foundation. In this paper, we describe two Modeling programs: *Socratic Modeling* (the original program), and *Modeling Discourse* (a more recent, and more "radical" implementation of the Modeling Method). Both these programs have Arizona State University roots. We do not propose that one program is better than another. Instead, the reader is encouraged to compare and contrast these programs, and use their skills as a "chef" to make intelligent decisions in their own classroom.

The Modeling Method is supported by years of research on how students learn and how teachers effectively facilitate their classrooms. The philosophical basis, and basic research foundation, for the Modeling Method is described in (see Appendix H):

- *How People Learn, Inquiry*
- *National Science Education Standards*
- *In Search of Understanding: The Case for Constructivist Classrooms*

Below, we compare *Socratic Modeling* and *Modeling Discourse* in eight different areas (see *Table*.) In the following section (*Whiteboarding Issues and Tips*), we cite conversations on the Arizona State University listserve by experienced modelers. This section highlights ongoing debate on the use of whiteboard discussion and tips on how to use whiteboard effectively. This material will help you decide how to use whiteboards in your own classroom!

Table. Eight areas of comparison

1. Theory behind each approach
2. Facilitating discourse – the role of the teacher
3. The purpose of whiteboarding
4. Using whiteboarding to develop models (pre-lab, post-lab, and worksheets; closure)
5. Promoting discourse between students
6. Classroom climate: Creating a safe place for learning
7. Assessment and evaluation

Socratic Modeling

1. Theory: The promotion of student discourse through Socratic dialog*

As a high school teacher and doctorate student in physics education at Arizona State University in the early 1980s, Malcolm Wells pioneered the Modeling Method. A reviewer wrote:

> (Wells) concentrated on developing techniques for improving the *quality of student discourse* about scientific subjects. Modeling theory supplied a clear goal: *scientific discourse* featuring the formulation, elaboration, evaluation and application of well-defined models; discourse exhibiting a suitable mixture of qualitative and quantitative elements. In pursuit of this goal, Malcolm expanded the class time allotted to oral presentations by students. The time for *student postmortems* of laboratory activities was increased to a third of the total activity. The postmortem is devoted to analyzing and consolidating what the students have learned from the experiment. It seems likely that the most significant learning occurs in this period — at least, when the activity is guided with the skill of a teacher like Malcolm Wells. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

The quality of discourse in Wells' physics classroom was evident. After observing Wells, a colleague wrote:

> The class was discussing a problem about the motion of an object subject to several forces. One student was holding up a "whiteboard" with a solution sketched on it. The board displayed clearly drawn diagrams with a few algebraic equations and some numbers. The class was gathered round as he explained his solution. An occasional question from another student was answered crisply. Relations between the diagrams and the algebraic statements were explained clearly. Substitution of the numbers into the algebraic statements was explicit. But Malcolm challenged the student further.
>
> Malcolm: Why did you do that?
>
> The student replied that he had identified and added all the forces along one dimension.
>
> Malcolm: Why did you do that?
> Student: So I could find the net force.
> Malcolm: Why did you do that?
> Student: Because a = F/m.
> Malcolm: How do you know that?
> Student: Because that's Newton's Second Law.
>
> It was the first time that I had heard a student account for *everything* he had done in solving a problem, explaining why he had done it, and ultimately appealing to theory developed on the basis of experiments that had been done by the students. These students were explicit in their

* In Ancient Greece, Socrates was often seen in mall areas leading others, through persistent questioning (not by telling!), to a deeper understanding of philosophy.

> understanding. Malcolm did not take correct statements for granted. He always pressed for explicit articulation of understanding.
>
> The students in Malcolm's class explained their solutions to problems publicly, and he made sure that they could justify them. He was uncanny in his ability to expose deficiencies in student explanations with questions. Many times I would have joyfully accepted a student's correct answer as sufficient. But Malcolm would again ask one more question, and, much to my surprise, the student would falter. This ability, as I gradually came to understand it, arose from his mastery of modeling in Newtonian physics. His understanding extended beyond the content of Newton's Laws to an acute awareness of the techniques for applying the laws in practice. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

Malcolm's colleagues elaborate on the Socratic dialog discourse expectations in his classroom.

> His deep understanding of scientific explanation and justification enabled Malcolm to be a remarkable Socratic guide. He had clear knowledge of what students had to make explicit to be assured that their understanding is adequate. His line of questioning was unfailingly purposeful. Students were required to present an explicit model to account for the physical situation in question and explain how the model had been obtained from overarching theory and/or experimental data. His students became accustomed to supplying not just answers and clear explanations of how they got them, but also full justification for their approach. The students' solutions to physics problems were superior. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

A summary of the Socratic Modeling is shown in the box that follows.

BOX 2: MODELING METHOD Synopsis

The Modeling Method aims to correct many weaknesses of the traditional lecture-demonstration method, including the fragmentation of knowledge, student passivity, and the persistence of naive beliefs about the physical world.

Coherent instructional objectives

• To engage students in understanding the physical world by ***constructing and using scientific models*** to describe, to explain, to predict, to design and control physical phenomena.

• To provide students with ***basic conceptual tools*** for modeling physical objects and processes, especially mathematical, graphical and diagrammatic representations.

• To familiarize students with a small set of basic models as the ***content core*** of physics.

• To develop insight into the ***structure*** of scientific knowledge by examining how ***models*** fit into *theories.*

• To show how scientific knowledge is ***validated*** by engaging students in *evaluating* scientific models through comparison with empirical data.

• To develop skill in all aspects of modeling as the ***procedural core*** of scientific knowledge.

Student-centered instructional design

• Instruction is organized into ***modeling cycles*** which engage students in all phases of model development, evaluation and application in concrete situations — thus promoting an integrated understanding of modeling processes and acquisition of coordinated modeling skills.

• The teacher sets the stage for student activities, typically with a demonstration and class discussion to establish common understanding of a question to be asked of nature. Then, in small groups, students ***collaborate*** in planning and conducting experiments to answer or clarify the question.

• Students are required to present and justify their conclusions in oral and/or written form, including a ***formulation*** of models for the phenomena in question and ***evaluation*** of the models by comparison with data.

• Technical terms and representational tools are introduced by the teacher as they are needed to sharpen models, facilitate modeling activities and improve the quality of discourse.

• The teacher is prepared with a definite ***agenda*** for student progress and ***guides*** student inquiry and discussion in that direction with "Socratic" questioning and remarks.

• The teacher is equipped with a ***taxonomy*** of typical student misconceptions to be addressed as students are induced to articulate, analyze and justify their personal beliefs.

(M. Wells, D. Hestenes, G. Swackhamer, 1995)

2. Facilitating discourse – the role of the teacher

Malcolm's colleagues continue to describe his classroom.

> Whiteboards were new to me. Student groups prepared them with care and pride. With colorful dry markers they dressed the whiteboard with diagrammatic, graphical and mathematical representations of physical situations from problems or lab activities. By the time I visited the class, students were consistently referring to these representations as *models.* They were using these models to solve problems or interpret experiments, and they could explain how the various representations cohere in their interpretations. The dialog during oral presentations was potent, whether the presentation was consistent with Newtonian physics or not. Students found holes in their understanding and honed their arguments, both by questioning one another and providing answers. Malcolm served as Socratic guide to keep the dialog moving in a profitable direction. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

Thus, the teacher's role in whiteboarding is to facilitate student discourse through Socratic dialogue.

> The teacher continues to ask probing questions until the students articulate a satisfactory quantitative characterization of the concept. The teacher strives to remain unobtrusively in control of the agenda throughout the discussion, never acting as an authority or a source of knowledge. (Taken from http://modeling.asu.edu/modeling/mod_cycle.html)

> The teacher is prepared with a definite ***agenda*** for student progress and ***guides*** student inquiry and discussion in that direction with "Socratic" questioning and remarks. (Taken from http://modeling.asu.edu/modeling/synopsis.html.)

Malcolm Wells' colleagues described this role concretely upon their reflection of his teaching.

> I was struck by Malcolm's responses to student questions. He invariably sought to elicit the answer from the students themselves, and to induce them to assume responsibility for their own explanations. Sometimes, when students were thoroughly nonplused, he would suggest that they find out what other students were doing. Malcolm assiduously avoided the role of authority — this was a matter of principle with him. The belief that learning science is acceptance of what the text or teacher declares was regarded by Malcolm as an obstacle to valid understanding by the students. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

The teacher's role reflects a philosophy of how students learn.

> He (Malcolm Wells) sought to change their view of learning from collectors of information to expectant creators of this coherent understanding. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

The teacher's role also needs to adapt to misconceptions that students possess.

> The teacher is equipped with a *taxonomy* of typical student misconceptions to be addressed as students are induced to articulate, analyze and justify their personal beliefs. (Taken from http://modeling.asu.edu/modeling/synopsis.html. Emphasis is from the website.)

> Rather than dismiss these beliefs as incorrect, Malcolm learned to encourage students to elaborate them and evaluate their relevance to the issue at hand in collaborative discourse with other students. *In the context of modeling activities students have a framework for testing and correcting their own ideas,* especially in regard to relevance and coherence with other ideas. (M. Wells, D. Hestenes, G. Swackhamer, 1995)

Finally, Dave Braunschweig, former physics instructor from Madison West High School (Wisconsin) discusses the importance of keeping students engaged in whiteboard sessions.

> We don't cover all the material that people want you to cover. You have to come to terms with that for yourself. You can't do everything. You need to find a way to make sure the students stay engaged during whiteboarding, and that can be difficult. You have to work on good questioning techniques. I think teaching in modeling is much harder than teaching in lecture. With lectures, I could go on autopilot. I didn't have to think about what I was doing after the first class. Here, every class is different - different things happen. There is no set result that you can expect. You have to deal with the people; you have to keep good track of what's happening in the class so that you make sure you have all of the key points covered. Pacing is hard; you have to figure out how to pace things. (Braunschweig, 1997)

3. The purpose of whiteboards

For "postmortems":

> To facilitate postmortems and other student presentations, Malcolm experimented with a variety of techniques. For example, he tried having students outline their presentations on "butcher paper" to be hung up for other students to see, but that proved to be awkward. Finally, he hit on a brilliant idea. He equipped student groups with "white boards"…kitchen and bath paneling…The whiteboard soon became an integral part of Malcolm's method. (M. Wells, D. Hestenes, G. Swackhamer, 1995)*

On the topic of what NOT to put on whiteboards, David Hestenes writes:

> The whiteboard externalizes are conceptual representations. I do not think that a verbal representation should BE on the whiteboard. The whiteboard then forms a focus for discussion; and the students' understanding of what's up on the whiteboard can be explored by asking questions. (Taken from http://modeling.asu.edu/modeling-HS.html.)

* It should be noted that physical characteristics and maintenance of whiteboards can be found in *Appendix A*.

To provide focus for students Hestenes recommends that,

> Exemplary whiteboards (should be) put on the chalkboard, and that exemplary lab reports (should) be handout out to the students. (Taken from http://modeling.asu.edu/modeling-HS.html.)

4. Using whiteboards to develop models

(a) Pre-lab discourse

Dave Braunschweig describes how to facilitate discourse prior to an experiment.

> In modeling, the instructor has set the context for the experiment; you've illustrated something and you now ask the students to talk about what they see happening, identifying things of interest that we see happening. In the case of the pendulum, they observe that it swings back and forth and has some kind of regular motion. Then we start to ask what they think they could measure about this system, and obviously the length and how far you can pull it to the side come up. We start listing things on the board; all these things are listed from the student response. I can't think of a time when I haven't written down something that they told me; I make no judgments about what they say. What they think might affect what they see happening goes in the list.
>
> When we did this first at the Arizona State University workshop, there were 24 teachers who gave all the standard answers -- the length, gravity, the amplitude, and the mass (which wouldn't really affect it much). When I got to class the very first day with modeling I wasn't sure how this was going to work. Would my students even come up with these four ideas? I shouldn't have worried. My first class came up with 25 things which they thought might affect how the pendulum would behave. Some of the ideas were bizarre, I wouldn't have thought of them. It was the start of the school year, and in Wisconsin that can be deadly because there are no air conditioners in our schools and it can be very hot and humid. One of the things they said might affect the pendulum was humidity, so it was included in the list. It is important to include all the students' ideas because sometimes they lead to other experiments you haven't thought of. With our narrow focus we sometimes forget about the things that students are thinking about. (Braunschweig, 1997)

(b) Post lab whiteboarding

> Every lab activity is concluded by each lab team preparing, on a whiteboard, a detailed post-lab analysis of the activity and reasoning that led to the proposed model(s). The teacher then selects one or more of the lab groups to make presentations before the class, explaining and defending their experimental design, analysis of data and proposed model. For a post-lab presentation to the class, the instructor selects a group which is likely to raise significant issues for class discussion and often a group that has taken an inappropriate approach. At that time, the group members are expected to present a detailed explanation and defense of their experimental design and conclusions. (Taken from http://modeling.asu.edu/modeling/mod_cycle.html)

The colleagues of Malcolm Wells describe what this looked like in his classroom.

> The apparatus would be around for several days should they need it. After allowing time to prepare whiteboards, Malcolm would select one person to present an oral account of his group's experimental procedure and interpretation. Typically, the interpretation consisted of graphical and mathematical models for the system investigated. For Malcolm, the class's interpretation of experimental data was the origin of principle and the end of argument.
> (M. Wells, D. Hestenes, G. Swackhamer, 1995)

The following is Dave Braunshweig's interpretation of post-lab whiteboarding.

> The next step was really new to me: the postlab part. In most labs before, they'd hand in their lab report, I'd grade it and give it back, and we'd go on to the next topic. Here, the first thing the students do after analyzing their data is make a whiteboard presentation of their findings to the class. *Here is where I found a new task for the teacher.* While they were preparing the whiteboards, I'd walk around the lab to see what they were doing and try to decide on the order of presentations. I determine what I would like to have happen in the presentations, how I hope the discussions proceed. That is a skill I think teachers will keep working on as long as they are teaching. On the whiteboard, the students make multiple representations of the model they have developed. Traditionally we've encouraged students to go right to the algebraic expression. But here they must have a verbal description of the relationship they've found, as well as a diagram - and every time, a graphical representation. Graphs are our starting point. And then, finally, the algebraic relationship, the justification, and the conclusions.
> (Braunschweig, 1997)*

(c) Worksheet whiteboarding

> Each study group develops solutions for each problem in the study set. Each group is then assigned one of the problems in the set to prepare, on the white boards, for class presentation. One member of the group is then selected to make the presentation. (Taken from http://modeling.asu.edu/modeling/mod_cycle.html)

Dave Brauschweig offers a step-by-step approach to preparing and presenting whiteboards of homework problems.

> With the modeling approach I don't see students coming into class with their worksheets and writing down answers at the last minute, because a numerical answer isn't sufficient. My students have learned that they have three chances to understand the problems. The first time is when they try themselves, as homework. When they walk into class the next day they go right to their lab stations with their group, because on the board is the assignment problem that they have to whiteboard for class. I go around and stamp their worksheets if they have made a reasonable effort at their worksheet. The big benefit of this comes now as they are preparing their whiteboard; they are discussing the results of their problem, trying to agree on an answer. A lot of learning goes on there. If they finish their whiteboard before the rest of the class is

* It should be noted that sample instructions for student preparation of their whiteboards are available in ***Appendix B***.

> ready, they then talk about the other problems, and the discussions that they have are incredible. Then they present the whiteboards to the class, so there's the third time that everybody sees the problem. They really understand the problems better. Of course the worksheets are constructed beautifully, very well thought out. (Braunschweig, 1997)

5. Promoting discourse between students

In a lecture by David Hestenes, he reflects on a significant goal for students in Modeling.

> What I want to promote is much richer discourse, not just direct interchange between teacher and student. The discourse will go on in different modes at different times, so there are different objectives. One is to improve the quality of interchange among students. We want the students to use terms correctly; to present coherent arguments. We know that in some of your classrooms students stand up and give wonderfully coherent accounts on their whiteboards. So the discourse includes the presentations of the students; not just questions and answers by the teacher; that's only one mode of discourse. The overall quality in the way things are talked about is our main concern. What we want to see in the classroom is a general improvement at that level, however it's achieved. (Taken from http://modeling.asu.edu/modeling-HS.html)

Dave Braunschweig adds concrete expectations for student-student exchanges during whiteboarding.

> It is hard for some of the students not to want to blurt out, "You're wrong! I think I'm right." I have a ground rule that they can't do that. If they are going to talk to the people making a presentation, they have to ask a question; they can't give their opinion about what's right. In their question, they may give away some clues on what they're thinking, but they can't just attack the other group as wrong; they have to ask good questions. The presenting group may be wrong, but the questioners have to draw that out of the other group. (Braunschweig, 1997)

6. Classroom climate: creating a safe place for learning

Hestenes feels that the climate in the classroom is critical for promoting the discourse in the physics classroom.

> The first thing the teacher must do is to establish a climate of openness, one where students feel free to make mistakes; where it's IMPORTANT to make mistakes, in fact! …. In opening the discussion to understand what's going on, Malcolm engages the entire class. He doesn't make an evaluation of whether the student has it right or wrong but tries to engage the students in doing the evaluation themselves, insofar as they have the tools to do that! (Taken from http://modeling.asu.edu/modeling-HS.html)

When asked during a lecture how a physics teacher establishes and manages discourse in the context of creating a safe classroom climate, Hestenes offered the following insights (taken from http://modeling.asu.edu/modeling-HS.html):

- The teacher (should start) by setting….classroom climate [of openness, where students feel free to make mistakes] and establishing the subject of discourse. This is often done by demonstrating a phenomenon and posing a problem. The teacher is responsible for leading the discourse so that issues and questions are raised and claims can be made that are WORTHY of investigation. This doesn't need to be something that students go into the lab to do; the investigation could be something that you go on the Internet to find out information about.

- Communication requires shared meaning…when you use the word "force", the student must ascribe the same meaning to the word as you do. Results of the Force Concept Inventory say that this is not happening in traditional instruction. The teacher is rambling on about forces and the students have a totally different idea of what those words mean. Consequently, the students are systematically misunderstanding. How do you get to a common understanding? You get students to use the term to find out what it means to them. You don't condemn their usage, but you say, "Do you really mean this? or do you mean that?" You are adjusting the students' conceptual framework to the external frame. So a big initial part is setting up a framework in which everyone has a common understanding of the use of terms. As the students master the basic vocabulary, the basic ideas, things get better!

- Scientific discourse is not just a matter of vocabulary; it also involves models, which are conceptual structures. The meaning of words, equations, and diagrams is constructed from situated use! This is a big emphasis in current research, not only in science education but also in linguistics and other fields. How is a common meaning of words constructed? From SITUATED USE: you see how so and so uses that term in a SITUATION. And these meanings must be negotiated.

Further, Hestenes notes that (taken from http://modeling.asu.edu/modeling-HS.html)::

> The quality of the discourse depends on (and this is a crucial point, where the Modeling Method differs very significantly from other approaches!):
>
> - the representational TOOLS at the students' disposal, and how they are used,
> - the structure of the arguments, and
> - the standards of the argumentation (which are set by the teacher).

Dave Braunschweig has also describes the importance of classroom climate. The following excerpt refers to post-lab whiteboarding, but may apply to any part of the course.

> During the student presentations, the teacher is asking questions - Why did you do this? How do you know that? The class is encouraged to ask questions as well. In fact, one of the things you need to do is establish an atmosphere in the classroom that has everybody as equals, including the teacher; you are all part of a team trying to learn something. You try to take the

teacher out of being the authority and have the students rely on themselves. (Braunschweig, 1997)

7. Assessment and Evaluation

How to assess student participation is often a large debate with either approach to modeling. Here is one interpretation of how to assess and evaluate students, taken from the Modeling website.

> The same recitation grade is given to the entire group, and it depends on the quality of the presentation. During the presentation, if questions are asked by fellow students that the selected presenter can not answer, other members of the group may offer assistance. If however any assistance from other members of the group is required to satisfy the questioner, the recitation grade awarded the group may be reduced. The recitation scores of the groups are enhanced if the members ask valid, well thought out questions during the presentations (shared responsibility). (Taken from http://modeling.asu.edu/modeling/mod_cycle.html)

On facilitating homework whiteboards and qualitatively assessing student presentation performance, Braunschweig offers a different approach.*

> During this, I'm sitting in the back of the room, probably at a desk with another student. They are running the class. It is very difficult at first for the teacher. You want to hop in and correct something. But what you will see happen if you are patient is that they will often correct their own mistakes when presenting the whiteboard. You also get a much better idea of what they are thinking by letting them proceed. With five classes, I have often seen five different solutions to the same problem, all of them correct. They have much different thinking. They have not done my way of doing the problem. I have a comment from one student that I'd like to share. This student identified herself to me when she wrote this. She said, "I, who am not a science/math person, have found physics more understandable than other sciences in high school. The whiteboarding helps a lot. It lets you understand the reasoning behind all the formulas." This was a young lady who struggled. She worked very hard. But she felt she had a much greater success in physics than in the other classes. (Braunschweig, 1997)

* It should be noted that sample checklists and rubrics for assessing and evaluating students during whiteboarding are in Appendices D-G.

Modeling Discourse

1. Theory: The promotion of student discourse through seeding and a “learning community”

As part of his doctor of philosophy degree at ASU, Dwain Desbien used Modeling Discourse as the focus for his dissertation.

> Key features of modeling discourse such as seeding, questioning, and a learning community are demonstrated in *Figure 1*. Seeding/questioning is a common technique for motivating students to bring their ideas to the classroom community rather than to the instructor. The instructor is outside the community but interacts to provide activities, materials (tools), terminology, and guidance. The instructor extracts information from student discussions for use in formative evaluation of class progress and understanding.

Desbien reflects on the motivation for developing modeling discourse.

> Therefore, the problem solution was not to change the class activities, but rather change how the class was managed. Students needed to develop the models themselves. The epistemology of science needed to be explicit. Use of shared representational tools needed to be developed collaboratively. The class needed to be a community working together like scientists through peer-peer interaction. Modeling discourse management was developed to meet these goals. (D. Desbien, 2002)

Figure 1. (D. Desbien, 2002)

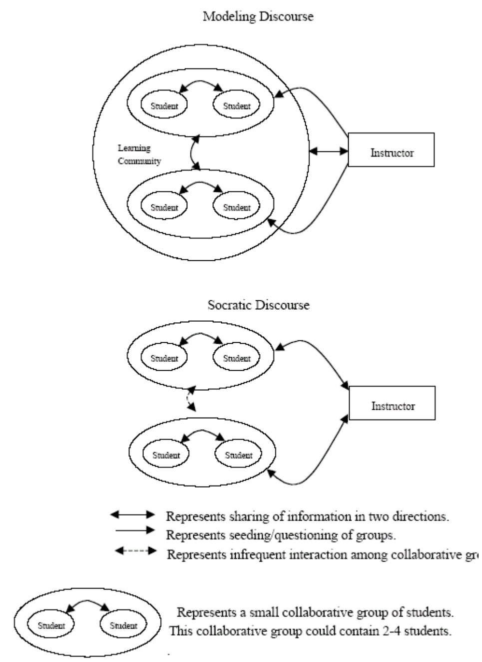

Figure 1. Modeling Discourse vs. Socratic Management Styles.

Components of the Modeling Discourse program include:

- Deliberate creation of a “learning community”
- Explicit need for the creation of models in science
- Creation of shared inter-individual meaning
- Seeding
- Intentional lack of closure
- Inter-student discussion
- Formative evaluation”

Desbien boasts of MD’s effectiveness:

> The five smaller research questions all indicate that modeling discourse management is a successful enhancement of a modeling course. Inclusion of modeling discourse management improved FCI post-test scores and gains. Evidence was presented that modeling discourse improved student understanding of science as measured by the VASS. (D. Desbien, 2002)

The Philosophical Impetus—Social Constructivism

The radical philosophical roots of MD are seen in the following quotes [bold emphasis mine]:

> **Science should be understood as being subject to human perspectives and as such it is socially constructed by scientists**. However, the creation of a classroom where such ideas are understood would require a radical change from the traditional course. Lecturing as an authority on what science is and its tentativeness is inconsistent with the notion that science is socially constructed.
>
> **Scientific models do not explain reality** – they only represent reproducible patterns that anyone can observe.
>
> Social constructivism places the process of learning squarely in a dynamic social context. **A consensus on scientific knowledge is socially constructed through journals and conferences.** The community shares ideas and results, modifies the results based on feedback and experimentation, and continues the process of modeling the world. (D. Desbien, 2002)

2. Facilitating discourse

Goals of Discourse

For discourse to be effective it must be allowed to reach a conclusion, which may mean that the discourse needs to be quite long and uninterrupted**.** Extended discourse is required if students are going to be able to work out differences and reach consensus on an idea or concept. Extended discussions will often require more time than is allotted in a standard class time frame. (D. Desbien, 2002)

Arranging the layout of the discussion environment is straightforward. However, getting the students to actually discuss in a productive manner requires careful management of the classroom. Classroom discussion should be designed with these three questions in mind:

- How do students negotiate meaning?
- What is involved in shared meaning?
- What is involved in consensus building? (D. Desbien, 2002)

What is Seeding?

Seeding involves two interrelated activities: planting and questioning. The first activity is to plant an idea or concept with a small collaborative group of students so the students can bring that idea to the larger learning community. The second activity is for the instructor to question a small collaborative group to guide the group's thinking. The collaborative group can then bring its answer to the instructor-supplied question to the learning community. Both of these techniques to introduce concepts or questions enhance classroom discussions and the level of student involvement. Students guided in this manner often find the course material more interesting, and they feel greater ownership of the ideas. (D. Desbien, 2002)

Seeding is the primary technique for introducing new ideas into modeling discourse. The instructor seeds a small collaborative group with a question or a hint. This group may be struggling and need some extra help or be further along and need a challenge. (By seeding questions, concepts, and ideas the instructor need not introduce an idea to the whole class because the small collaborative group introduces the seeded idea into the class discussion. Seeding is done during small collaborative group time so the group has time to work out details and gain ownership of the seeded idea. Thus, peers, instead of an authority figure, introduce the ideas to the whole class. (D. Desbien, 2002)

The teacher is the guide but not the leader of the discussions. The instructor keeps the discussion focused and on task but should avoid being the leader. When the discussion gets off task the instructor should intervene and redirect the discussion with an appropriate question. (D. Desbien, 2002)

What is a Board Meeting?

To facilitate modeling discourse a classroom should have two major components. First, it should have tables on which students can perform experiments, have small group discussions and create white boards. Second, the room should have an area for whole class discussions that is free from obstructions. When in the circle for whole class discussion, there should be no tables or chairs between the students. Having the students in this arrangement allows for students to see all white boards at the same time.

Then, similar items on the white boards are quickly noted and attention can turn to differences. Since common items are not repeated, the discussion moves more quickly and deeper issues can be addressed. Also, the avoidance of unnecessary repetition keeps the students from becoming bored and allows for more questions to be addressed…

During the all class discussions, the instructor's actions are critical. First, the instructor should not be central to the discussion if involved at all. If the instructor is the focus, student-student interactions are unlikely to occur. Therefore, the instructor should observe discussions from an unobtrusive position. The instructor should be able to easily hear the discussion, but in a location that is difficult for students to see. Major ideas that the instructor wants addressed in discussion should be seeded during the small group work. A modeling instructor should expect silent time during the discussion and should not talk during the dead time. (D. Desbien, 2002)

Though the instructor should appear passive to the students, the instructor is actively evaluating the student discussion for understanding, misconceptions, and conceptual holes. The instructor should pay careful attention and take copious notes on the discussion. However, the students should not be aware of the amount of notes the instructor is writing. The notes serve two purposes. First the notes serve as a reminder of agreed upon concepts or ideas and of questions to ask the class at the end of the discussion. Second the notes serve as information for the instructor to use in post-class reflection. (D. Desbien, 2002)

3. The purpose of whiteboarding: Building shared meaning.

No term can be used until a definition has been agreed upon. (An) important aspect of shared meaning is to understanding the role of communication tools. The whiteboards used is a physical tool to aid the discussion. (D. Desbien, 2002)

4. Using whiteboarding to develop models (closure)

The science classroom should make students aware that science is tentative and always evolving—that the development and revision of scientific models is a continuous process

(Following each session) the instructor…reminds…the class of what had been agreed upon and unresolved observations or problems. The instructor does not resolve the issues, but merely keeps them alive. Without closure, students continue to wrestle with the issues outside class and return with new ideas to share. Thus, lack of closure can foster student thinking about the class activity between classes and keep the discussion lively. An unexpected benefit of not resolving issues before the end of class is an increase in office hour attendance. Adequate follow-up is essential to reap benefits from lack of closure.

There is a one possible negative to this lack of closure. Some students use this kind of problem as an excuse for not putting sufficient effort into homework. Some students assume that any problem that requires extra effort will be discussed in class. Therefore it is important that the follow up problems to an impossible problem require thought and work. The follow up problems cannot be simple problems. (D. Desbien, 2002)

5. Promoting discourse among students (an emphasis on learning communities)

Research has shown that unless the students see the need for a learning community, no amount of effort by the instructor will continue classroom growth. Students need to understand the importance of building a consensus. They must understand the need for an open and supportive environment to make progress. Students therefore must see the explicit need for an agreement on the conduct of social interactions. Within this setting they can learn to see science as tentative and evolving. Students' views of the classroom learning community determine its success. Unless the students recognize the need for a community, its benefits are lost.

(As) students' views of the nature and need for the community evolve, so does their understanding of the course content. A well-formed classroom atmosphere helps develop student understanding of science. Inherent in this type of environment is the notion that knowledge is constructed and shared through dialogue. Students must recognize this idea for this type of classroom environment to be successful. In addition, students must understand the process by which they are to learn science to optimize its success.

> For an effective learning community, students must come to share the view that truth requires coherence. Students must negotiate a common understanding of what is observed and on how to interpret what they observe. The community needs to resolve differences in opinions and ideas to make a coherent picture of the content of the course. Only through sharing and seeing a need for that sharing will development of a coherent consensus occur. As the course evolves, student views of a particular situation will change along with the community view. A more in depth look at an activity may lead to a greater coherence and a deeper understanding for the students. However, without the explicit understanding by the students of the need for consensus, incompatible views of the activity will remain unresolved. (D. Desbien, 2002)

Desbien adds,

> For a learning community to be successful everyone must feel comfortable about participating. That does not mean that everyone must participate in every discussion. A classroom atmosphere that is conducive to participation requires an environment that is supportive and empathetic rather than competitive. The instructor should try to correct problems in a manner that does not embarrass individuals or impair the overall tenor of classroom discussions.
> (D. Desbien, 2002)

Desbien comments on student behavior as a function of the development of a learning community.

> This research found that in the classroom where the learning community exists, behavior is better. (D. Desbien, 2002)

Desbien provides a step-by-step procedure for how he initiates a learning community in his classroom.

> At the beginning of the semester, the instructor must organize the class into a learning community. Before physics content is addressed, the classroom community must exist to foster student learning. The community is shaped by activities designed to encourage students to interact in a noncompetitive manner. To create this atmosphere without the pressure of "learning physics" at the same time is critical to encouraging the greatest number of students to be both involved in the discourse and prepared to be contributing members of the class (Beane, 1995). Student-student interaction is continually encouraged throughout the semester with an emphasis on cooperation.

Making Airplanes

> The course begins with a community building activity. One such activity is to have small groups of students create instructions on how to make a paper airplane. The activity begins with organizing students into groups of three or four. Each group is told to create instructions on how to make a paper airplane on the paper provided. Immediately questions arise, such as:

- Can we use pictures?
- Does the plane have to fly?
- Does create mean write?

All questions are answered the same way, by repeating the charge to create instructions on how to make a paper airplane. Students are also told to decide themselves what that means and act accordingly. After the groups complete the activity, the instructions are collected and redistributed to other groups who are told to use them to construct an airplane. As the papers are being passed out to other groups, the class is told to follow the instructions exactly. Where the instructions are unclear the group must interpret as best they can. Typically students do not give this last comment much credence. As the groups begin to work the instructor passes among them asking questions. The instructor is looking for certain words or phrases in the instructions. As an example, students will often write "fold the paper lengthwise." The instructor might ask the group following that instruction what edge of the paper is the length and which is the width? Students typically respond that the long side is the length and the narrow the width. The instructor responds, "Why? What if you print on a printer in landscape mode?" The students soon see that every term on the page can be interpreted many ways. Then they gleefully create paper "airplanes" that in no way resemble what was intended by the creator of the instructions. Finally the class is then brought together for a discussion of the activity. Discussion is best in groups of 20-30 students

The instructor occasionally interjects a question but typically remains outside the discussion. To join the discussion the instructor must take a position in the circle. This way the instructor is seen as part of the circle and not the leader of the discussion.

Students quickly comment that terms need to be defined and agreed upon by the class and that pictures are often better than words. The students reach agreement on these questions quickly and without much conflict. When the discussion is winding down the instructor steps in and reviews what has been agreed upon. The instructor emphasizes the shared definition of terms and the positive tone of the discussion.

A critical component of the modeling discourse management style is to *lay the foundation of a learning community early and continue to build the community throughout the semester*. Students are reminded of basic rules throughout the semester. The most common reminders are that only one person should talk at a time and that evaluation of other student work must be done in a positive manner. (D. Desbien, 2002)

6. Classroom climate: Creating a safe place for learning

Students must be immersed in a classroom atmosphere that facilitates the development of scientific thinking. Students need to recognize changes in their beliefs and convince others of the merits of their new ideas. These new ideas should be shared and agreed upon as a foundation for future development. (D. Desbien, 2002)

Studies have found that students must place emphasis on empathy and understanding for peer interaction to occur and be constructive. Interviews and surveys with students consistently found that for students to participate in peer interaction, the addressee must be empathic and understanding of the ideas being presented. Disagreements about ideas can be resolved, but the feeling of ideas not being considered by peers will destroy the learning community and effectively end discussion. Students must feel that their peers are interested in their contributions and that differences can be resolved in a constructive manner. These studies investigated how students viewed student-student interactions. Therefore, to have successful student-student interactions, the classroom atmosphere must address the issues that the students consider important for participation in discussions. (D. Desbien, 2002)

Desbien also provides a snapshot of how to create classroom climate by establishing norms for scientific discovery. “Before beginning physics instruction, the instructor establishes a need for the creation of scientific models. At the end of the first day the students are given the following questions to ponder and answer with their own ideas:

- What is reality?
- What is science (or physics)?
- Is science reality?

The second-class period begins with students working in small collaborative groups to create a white board summarizing their answers to the homework questions. Each student brings different background, experiences, and views of the world to the discussion. While the students work on the white boards the instructor seeds ideas. These ideas include the notion that science is both incomplete and in a constant state of change and evolution. Once the small groups are done, the class comes together for a discussion…in a circle. Students are reminded to hold their white boards so that other groups can see them at all times…The instructor emphasizes to the students that a goal of discussion is to reach consensus. One group is asked to present their ideas on the first question and let the discussion flow from that point.

During this discussion the instructor will often have to intercede and refocus it. The discussion is often intense and many different points of view are presented. In the end, the instructor’s goal for the discussion is to have the students come to the conclusion that no explanation is complete. A secondary goal is to have students realize that how they describe something depends on their own experiences. The description of an event will be dependent on the observer and what aspects the observer focuses on. At the end of the discussion, the instructor summarizes the agreed upon ideas and introduces the idea of a model. The instructor discusses how a model has similarities to the object it represents but certain details are missing. The discussion ends with the idea that science continuously creates models because no one model is ever complete. Scientific models do not explain reality – they only represent reproducible patterns that anyone can observe. (D. Desbien, 2002)

7. Assessment and evaluation

Creation of a learning community as described requires the instructor to continually evaluate the classroom and modify the atmosphere as needed. Formative evaluation of the class must not only consider student understanding of the material but also the classroom environment. Forming the class into an effective social learning community must begin immediately in the course, and evolution of this community must continue throughout the course. Without continued evolution the atmosphere will become stagnate and discourse management will become more difficult. The instructor cannot neglect either the content or the learning environment. Continued development of each by formative evaluation is required for a class to grow and learn. Formative evaluation involves reflection by the instructor after each class. This reflection is facilitated by taking notes during classroom discussions, evaluating understanding by listening to the quality of argumentation, and evaluating class responses to seeded questions. (D. Desbien, 2002)

The question of grading whiteboards often comes up. Whiteboarding is much like any process of learning a skill. There has been some misunderstanding in the role of the teacher in whiteboarding. If students are whiteboarding a pendulum lab, there is little need for teacher directed inquiry. Student directed questions are appropriate since the only surprise is the independence of mass on period, and that is easily observed. At this stage, we are not explaining it, just observing. On the other hand, when we are whiteboarding Newton's first or third law or the idea that an object can push back, the teacher's role is critical in organizing the dialogue in a way to provide the necessary bridges for the student. I, as an experienced teacher, already know that most students will not understand these concepts. They will give the correct answer, easily accepted by their peers, so that it will require careful inquiry by the teacher to actually probe their alternate conceptions. This will not occur with only peers asking questions because they share the same alternate conceptions. (D. Desbien, 2002)

Whiteboarding Issues and Tips

1. The degree of teacher/student control during discourse in the physics classroom

A. Don Yost comments:

"Whiteboarding: a tool; a learning experience; a path plotted by a professional
I have grown concerned lately when reading comments about whiteboarding (not board meetings). I fear that I have inadvertently contributed to some misconceptions about whiteboarding. During training, we stress audience participation during white board sessions. The purpose for this is to provide practice for a group of professionals who will be using this technique later in their own classrooms, and the best way to learn to do something is to do it. The situation is artificial because the audience is made of teachers skilled in the content material needing to hone questioning skills, not novice content learners, as are your classes. The impression we instructors gave, unfortunately, was that the whiteboarding should be mainly student driven. This is unfortunate, because *in attempting to make the WB sessions student centered, you lose much of its power and bring in irrelevant issues such as grading the white boards*. The conditions under which you learned whiteboarding are necessarily artificial and should not resemble your classroom whiteboarding. The two have entirely different goals: learning a skill vs. learning content.

The power of whiteboarding lies in its ability to allow the instructor to follow the learning process as it is happening, and to control that learning process in a way that optimizes learning. Whiteboarding should not become a report about the learning process to be scrutinized and evaluated by a group of peers. It is a process designed to let the professional guide and evaluate the learning process as it takes place. This is what makes grading a white board irrelevant. If you are teaching a skill like driving, you do not grade the student as he is learning: how well did he make the first right turn he ever made? how well did he stop for the first time? how well did he start the car for the first time? You grade the student after he has learned and then you do it by having them demonstrate that skill in a totally different environment than the learning environment. Certainly, you can assess the student's progress, but not for the purpose of evaluation, but for the purpose of designing further learning activities.

The whiteboarding process should be as free from stress as possible, for the same reason that learning should be a reduced stress environment. Learning is more effective when mistakes are accepted as part of the process of learning. This means that *instead of standing in front of the group, a round table presentation showing everyone's work together is preferred.* It means that *mistakes should be correctable during the process;* no one should have to parade their mistakes to the group after they realize that they are mistakes.

If done correctly, whiteboarding is an exhausting process for the teacher leaving no time for evaluating the art work. You must interpret exactly what the student is saying, and understand the alternate concepts so well that you can anticipate any direction he may be going so that you can construct a question which will direct his learning. This process of listening, interpreting, and constructing a strategy all at the same time is a highly demanding skill for the teacher. (The questioning about the solar system from the last part of the "Private Universe" provides an excellent example of this process).

Whiteboarding is a teacher tool, and should be used by the teacher. I do not mean to imply that the audience should not be involved, just to stress that the questions asked during a WB session are not the type of questions a novice learner will normally employ. *The skillful teacher will often reflect questions back to the audience: do you agree with what was said? How would you phrase that? What do you think he meant by that?*

Sometimes a discussion catches and the students will take off with it. This is a time to step back and let them wrestle the truth out. These interactions will happen on their own and when they do, they are rich beyond anything you could create. The point is that you cannot create them. They happen or not, and the wise teacher knows enough to back off and let them happen.

The point, then, is that whiteboarding is a tool. It is a learning experience, not a final report. It is a free exchange of ideas, not a critique. It is a path plotted by a professional; you, not a free running discourse dominated by other novice learners (unless you get lucky)." (D. Yost, 2002 whiteboarding is a tool compilation)

B. Don Yost responding to an argument that students need to own their learning more:

"I do not deny, nor did I deny in the paper, the value of student participation. I do not deny the value of students owning their learning. What I do believe is that the teacher is in the best position to assure that the learning process is going in the correct direction and that comments made by the students are actually understood by the students. It is very easy for students to give the "correct" answer, but have the wrong ideas. This is where the teacher's job becomes critical." (D. Yost, G. Groeshel, and S. Hutto, 2002 whiteboarding is a tool compilation)

C. Greg Groeschel arguing for student directed discussion:

"The best whiteboard sessions are when students ask students - isn't this the art of classroom dialogue DH talks about - finding ways to get students to discuss science like scientists? I agree with Don that there are times when the instructor must step in and ask the questions that need to be asked - but if this is the central mode of WB presentations, it seems little different from standing in front of the class and asking questions of them ala lecture dialogue. When I went through the program back in 97-98, I remember Dave Braunschweig and Rex Rice extolling the virtues of getting students to be able to ask the questions that need to be asked, the instructor stepping in only if needed. *They also showed us ways to get students to ask the questions - by planting questions while students are making boards, having a group do a "wrong" solution on purpose (use once a semester), etc.*" (D. Yost, G. Groeshel, and S. Hutto, 2002 whiteboarding is a tool compilation)

D. Stan Hutto on the balance of student vs. teacher driven discussions:

"Once the students have been guided gently along the way to deeper scientific discourse they will then continue the practice and reap the rewards. Kind of like when Dad ran along beside the bike aiding you while you pedaled feverishly and finally let you loose. What a joy that was to suddenly have a whole new world of discovery and adventure to open." (D. Yost, G. Groeshel, and S. Hutto, 2002 whiteboarding is a tool compilation)

E. Paul Wendel on challenges of running whiteboard sessions (boredom and student directed discussions:

I find that I am often dissatisfied with the "Wells" model of whiteboarding. The main problems are: 1. Ideally, the dialogue should be between students, with me (the teacher) offering occasional guidance. Instead, I ask most of (if not all of) the questions. As a result, students sometimes feel that they are being publicly grilled rather than engaged in a genuine public conversation. When I try keeping my mouth shut for long periods of time, the conversation quickly loses its focus. 2. I have difficulty keeping 20+ students engaged in a single conversation. As soon as someone says something really interesting, it stimulates a half-dozen small group conversations, rather than a single large-group conversation. I grow weary of constantly regrouping the class, particularly when the small-group discussions result from genuine curiosity. I would like to see a video of Wells or some other expert in this technique. I suspect that I am missing something. In the last two years, I have been experimenting with the following reforms in whiteboarding methods:

1. Using the "board meeting" ideas presented in this listserv, *I have rearranged my classroom so that students can sit in a large circle while presenting.* This helps somewhat with issue #2, but does not address issue #1.

2. I have been experimenting with a "whiteboard gallery." I ask the students to present conclusions, solutions, etc. on their whiteboards, along with three check-boxes across the top. One box is labeled "yes," one box is labeled "no," and one box is labeled, "maybe." The students prop their boards around the classroom. Then each student (or group of students) examines the other boards and places a tally mark in the "yes" box, the "no" box, or the "maybe" box of each whiteboard. Afterward, I go from board to board, asking for comment. This seems to improve the student-to-student dialogue, and also greatly reduces the feeling of a public grilling.

3. Modifying the techniques developed by Lillian McDermott at U. of Washington, I divide the class into four groups, one group per corner of the room. The students work through materials until they reach specific "check points." When a group reaches a "check point," they call me to their group, where I roll a die to determine which student will be the spokesperson for the group. I ask a series of Socratic style questions about their work. If their answers are consistent with each other, I sign off on that part of the material and they move on to the next section." (P. Wendel, 2003)

2. Ways to improve whiteboarding

1. Don Yost

   "Do:
   - ask for clarification.
   - draw simple diagrams..
   - draw simple graph shapes.
   - include multiple representations.
   - be involved
   - consider whiteboarding as a learning process.

   Don't:
   - grade the learning process.
   - badger the student.
   - include raw data or intricate graphs
   - criticize answers.
   - expect students to provide all questioning.
   - consider whiteboarding as a presentation or report."   (D. Yost, 2003)

2. Greg Groeschl

   a. Add circle whiteboarding [whiteboarding in-the-round or "board meetings"] as an option for doing a worksheet where kids seem to have it pretty well understood or if you want to do a quickie.

   b. Set up a pole at each lab table with a pendulum clamp on the pole. Hang the boards and have students quickly present their solution. Again, this breaks up the pace. It also works for deployment labs or smaller activities.

   c. Keep the kids on their toes. Whiteboard of the week is my #1 tool to keep interest up. I take digital pictures of the group and their board -- works great.]

   In my first year of whiteboarding I ran into some problems that I found were common to other "rookies". These were:

   - Visual quality declined as the year progressed

   - Equality in presentations declined (1 student would not participate in presentations)

   - Apathy toward the process (due to monotony)

   - Students consistently did not ask questions

The following are a number of field-tested methods that I employ during the year to improve whiteboarding, thus increasing the quality of scientific discourse, which results in greater comprehension of physics by students. The most effective strategies are listed first.

#1: Whiteboard on Whiteboarding

Early in the year, after a couple of whiteboards have been done, have students whiteboard (WB) about what makes a good WB presentation. Also have them do a WB on what the audience should do and what kind of questions could be asked. Usually students come up with a few ideas about question types, and I summarize all classes and report on it the next day. This allows me to make sure that we have all the types of questions I want to see! I divide the question types into categories: Clarity, Helping, Quiz, and Expand the Ideas. I post these results as banners at the front of the room, above the chalkboard, to remind questioners of what they could ask. I post the presenter results in the back of the room as a reminder to them.

#2: Whiteboard of the Week

I select the best whiteboard, write up a little review of it (a la Siskel and Ebert), post the review with names of the presenters on the board, and put it on the "WB Wall of Fame". I give each student a copy of the review to take home. I plan to incorporate a digital camera so I can take a picture of the group and their board to post in the room or the trophy case outside our room in the hall. Kids love it. I leave the board in a special place in the room for all to see on a daily basis for the week. It also motivates and helps others to see what is good quality work and presentation. Not just pretty boards get acclaim - also great defenses of the work.

#3: Student Evaluations

Do we or don't we? Do the scores count for something? I don't know. I am hesitant to get caught in all that paperwork. My time is better spent focusing in on the conversations and ideas that are being floated about. Again, from some action research I did, I have the students evaluate each other. I make a 1/2 sheet of paper with a rubric on it based on what the students said was important from our earlier WB on whiteboarding session. I evaluate them once or twice using carbon paper for multiple copies.

They really appreciate the feedback. After the second time, I assign a group to evaluate another group. They use the rubrics, and each member who presents walks away with feedback. I get a copy for my records. This puts students in charge - they really listen to each other more than us anyway! I do not do this all the time, just when things start to slip. By then, I have only students evaluate students, giving me a copy of the results for my records. I have not used these as part of their grade, but it could be easily done.

#4: Assign Questioners

It took me two years to apply (this) to the classroom. The day you give the assignment, assign each group as the lead questioners for another group. For example, tell the red group that they will be in charge of questioning orange. This means you have to tell students what problems they will present the next day. Students report that it was great to know beforehand what they were presenting so they could spend more time on those problems and make sure they had it correct!

Along with their WB creation, they must work together to come up with one question per group member (or 2 per group - whatever). I have students write their question on the top of their page as part of the homework assignment and check it as part of their homework. I have not done it, but another option might be to have students write their questions on a 3x5 note card with their name on it and turn it in for additional credit or as a separate assignment. We have already discussed the types of questions students can ask (clarity, helping, quiz, expansion), so they have an idea of what to ask. Have the questions directed or addressed to a different member of the presenters to defend. This really works well if you take some time to discuss questions and questioning. If whiteboarding is becoming monotonous, the following are ways to change the pace.

If whiteboarding becomes monotonous, here are some ideas:

#1: Happy / Frowny faces

I use this one at the end of units quite often. Students are given a card of heavy stock paper, (yellow color) with a big smile on one side and a frown on the other. Whiteboards are assigned and created as normal. All the boards are put on the front chalkboard ledge and I stand at the front of the room, leading a description of each board. After my description of what they have written, the students vote: smile or frowns. If frowns, a discussion ensues with the frowner asking the WB creators a question, usually a "Why did you…." Students appreciate being able to field questions from the safety of their seats. This is very effective in getting through boards at a quicker pace, but not too conducive to question generation and expanding the ideas. As I said, I use this one primarily for review worksheets.

#2: Random selection of problems

Usually students enter class and see a whiteboard with their WB assignment already determined. Once in a while, to change the pace a bit, I will write a cryptic message on the board, usually in reference to Star Trek (example - "Freefall, the Final Frontier" or "Inertia - The Undiscovered Country"). I get out my Star Trek Playing Cards (a scene on each one with a picture and description) and I have each group select a representative to come forth and boldly go …"where no one has gone before." Each group rep picks a card and the number on the card corresponds to the worksheet problem they have to do. Before presenting the card I have them read the card and show the picture. Use your creativity here.

#3: Lucky draw picks the problem

This is a variation on the above card idea. Students again select the cards, but they get to pick which problem they want to do according to the order of the cards chosen. I always throw in a "death card" (Spock, Klingon, Romulan) and make that group do the "hardest" problem. Again, it's a fun way to shake things up a little.

#4: Random prize for the secret problem board

I have a ton of the old U.S. Navy physics formulas and facts sheets. Note - they still make these! Just ask the recruitment officer to send you some! I predetermine a problem set and award that group with their very own list of physics formulas. I make a big production out of it (well, not too big), and we have fun "collecting" the formula cards. Yes, this is a spin-off of the old secret word game.

#5: Out of Order

Remember that these worksheets are pretty cleverly designed. If you do get good questions from students, the best board to show next might not be the next one in sequence. For example, I did worksheet one from the Circular Motion Unit and the order of Boards went 1, 3 & 5, 2 & 6, 4, 7 & 8, 9 & 10. It made more sense, based on what the kids were thinking about. If you are doing a good job running a WB session, you will mix up the order now and then because you are in tune with the students and their thinking.

#6: Cut down the number of worksheets.

I extensively rewrote the worksheets in the first 5 units so that there were one or two fewer per unit. I tried not to skip any of the ideas behind the questions, attempting to keep the concept generation in sequence. I added questions I will ask to my personal key to make sure all ideas are covered properly. Unit 3 really got cut down - now there are only 4 worksheets. This takes time, but it really helps move things along. But be careful not to cut for the sake of moving faster – cut with serious intentions and understanding of the way ideas are developed in mind.

3. Jeff Elmer ideas/comments

Whiteboards can be used for multiple purposes! Consider using whiteboards to:

- *Share experimental results.* Students can assess the reliability of their results by comparing with those of other groups. For more sophisticated students, different groups can share the results of having used different experimental methods and equipment. New terms and concepts related to experimental results can be introduced in these sessions.

- *Present homework problems.* Students have at least three opportunities to work on their homework. First, they try it by themselves. Next, they discuss problems with their small groups while preparing whiteboards. Third, they ask questions and get ideas during their classmates' whiteboard presentations.

- *Predict*. Whiteboards can be used for interactive demonstrations where predict and/or explain physical phenomena in multiple representations.

- *Assess.* As a test, groups or individuals can use whiteboards to explain/predict solutions to problems or give a final project report. Assessment criteria include understanding of physics content (revealed by whiteboard or by responses to questions), use of multiple representations, and presentations.

Whiteboard Preparation

Students should be given enough time to prepare whiteboards, but not too much, as they will take all day if allowed. During this whiteboard preparation time, members of each group are engaged in the following activities:

1. Writing on the whiteboard. These boards should have students' names; work should be written large enough for all to see and should not be cluttered.

2. Deciding who will present what, and rehearsing the presentation.

3. Discussing and writing in their notebooks some questions to ask other groups.

4. Discussing other physics problems not assigned to their particular group for presentation.

Developing classroom climate

1. Tone of voice is a powerful tool. Always treat students with respect, and expect them to treat each other with respect.

2. Each member of the group shares in the presentation.

3. Audience responses are to be phrased in the form a question, rather than a correction. Examples include asking

    - for clarification of a statement or diagram
    - how an answer was arrived at
    - the meaning of a term
    - for an intermediate step during problem-solving
    - what assumptions were made
    - what happens if a particular factor was changed in a certain way
    - whether a certain analogy applies
    - what happens at the extremes of the parameters of a problem or tool
    - how a different representational tool could be used

    The list goes on. This takes practice!

4. Questions to presenters from the teacher should vary from concrete to abstract. Concrete questions help build confidence in the presenters. Concrete questions can be used help students learn the use of precise language. Abstract questions are used for more confident students, and become more common as the year progresses. Teacher's questions serve as a model of questioning for the students. Students can be reminded that the goal is for them to ultimately be asking more questions than the teacher is.

5. Train presenters to ask of there are any questions before they determine that their presentation is finished

6. When a group has finished presenting and members sit down, wait and let the next group realize it is their turn to present, rather than taking charge and directing the flow. This sort of training shifts ownership of the process to the students. They like it.

Adaptations

Whiteboarding can take a lot of time! In some cases, it is a good idea for students to put their boards up at once (e.g. boardmeetings or exhibits).   Students then study the boards and begin a more informal question and answer session. This speeds things up a bit, but the cost is that fewer students end up presenting their ideas.

3. How whiteboarding affects the pace of the physics course

"The thing that has saved me the most time is pushing them harder in the paradigm labs. I watched the students who worked efficiently and didn't waste time. I kept track of how much time it took them to perform the lab and analyze the data. That is how much class time *everyone gets now.* I tell them before starting the lab when I expect their whiteboard to be finished.

If the students fall behind, I expect them to come in outside of class to finish up. They have no other homework from me on those days. I have a stash of around 50 whiteboards so every group in every class is able to prepare a whiteboard the day before it is presented. Those who work well get it done in class; the others come in before their next class to prepare the board. I do not grade the whiteboards but do deduct from their lab grade if they do not have one to present." (M. Crofton, 2003)

4. Giving students the correct answers before the assignment

"I think what you mean is that by grading for the correct answer we focus their attention on it. I often give the kids the correct answer before they do an assignment in hopes that it focuses their attention on the process." (M. Reif, 2001, Give the correct answer?)

"By giving a numerical answer before the problem is attempted, I believe we are making that answer the judge of our process, instead of the letting the rules of physics be our judge. Therefore, students see physics as a strange, unordered mix of rules that are created on the spot just to get a certain answer that should be true. In my experience, this causes students to learn to think backwards, and they CAN'T think forwards, which is what I want. I would imagine this is a hot topic, and that I am probably in the minority, but I still thought I would try to explain what I think Mark was referring to earlier." (J. Lonon, 2001, Give the correct answer?)

"Assessing the way students are taught: In response to the comment on Oct 25, 2001. "I often give the kids the correct answer before they do an assignment..." Students are not given the correct answers to tests while they are taking the test and asked to determine what fits in the middle -- they often do not receive the answer for a few days afterwards, and in the case of standardized tests -- weeks or months may pass. I believe that if we are to teach students the way they are assessed we cannot give the students the answers prior to the test. While the prospect of knowing the answers to questions might ease the discomfort of my students, it does not support the success of my students. In response to the comment on Oct 25, 2001 "...in hopes that it focuses their attention on the process"

I have experimented with different teaching styles in my classroom (discrete trial -- where the correct answer is given immediately & continuous trial -- where the correct answer is not given immediately, if at all). I find that the continuous trial approach makes the students the most uncomfortable initially -- but they spend more time with a question, and in the end, they learn more. It makes them question their every thought -- to justify it with their view of the world. The students have no choice but to focus on the process and their thoughts – they become their own best resource. The continuous trial approach opens up a slew of colors in an answer that was previously black and white. A very loose analogy might be made by asking students if they think abortion is right or wrong, telling them the answer, and then asking them to justify their response. Who will be there to give them the answer when we ask them about genetic engineering? When students are given the answer to a problem, they can easily set the answer and the process aside, forget about it, and then remember they forget it when they are asked to solve it again.

Consider giving a difficult quiz question one day and then giving the identical question the next day and investigating the results. The student who is not given the answer will be better prepared to go through the same process that they went through previously to solve it -- except now they've practiced it and can go through it much quicker. The student who is not given the answer spends much more time with the problem than the student who is given the answer. Call me a control freak -- but I like that. I do not expect my students to be scientists when they leave my classroom, but I do expect them to think like they are one. As Feynman says "What I cannot create, I cannot understand." And if I don't get to that point, at least I can make them question a thing or two." (M. Hughes, 2001, Give the correct answer?)

5. Creating safe and supportive classroom climates

There are a variety of ways to make you classroom emotionally secure for your students. This security makes it much more likely for students to take cognitive risks during discourse. Here are some strategies:

A. *Inspiration posters.* Students create 8.5 x 11" collage posters that help represent who they are as individuals. These posters are shared with classmates and are posted in a special place on the classroom wall.

B. *"Why do we quit and what motivates us?" activity*. This activity helps students realize that a "quit" list is the same as a "motivates" list, except they all include the word "not". For example, we may quit something because are friends are not involved in it. We may be motivated for another activity because are friends ARE in it. I usually start this off with a "think-pair-quad-report" format. Students think about the two big questions alone, then pair up with a partner to share, then join another group and share. Ideas are gleaned from each group by the teacher and are arranged so that the similarities between the lists become easily apparent.

This activity is then concluded with a quiet visualization of something they have learned very well in the past. I often share my example of installing ceiling fans! It is something I knew little about, but after installing four of them I feel like an expert. We discuss, as a large group, why they feel they are an expert in their chosen area. Comments such as "I had to struggle" and "I consulted with an expert" provide wonderful foundation for the school year.

C. *Community commitments*. I have four whiteboards around the room. They have different titles on them.

1. What must you do to be successful in physics?
2. What must your teacher do for you to be successful in physics?
3. What must your classmates do for you to be successful in physics?
4. What does a successful classroom look like?

Students move from board to board as small groups writing responses to these questions. After each group has an opportunity to answer each question they go back to their first board and write a summary statement. These statements are the foundation for the classroom "rules", or commitments. There is a commitment list for the students, and a list for the teacher, which each are put on tag board and posted in the room. Each respective party signs their commitments as the first step in committing to one another. Sample commitments are in the Appendix C.

Appendix A

Some Hints on Creating and Maintaining Whiteboards

(Edited from the http://modeling.asu.edu/modeling/whiteboards2002.doc)

An inexpensive whiteboard is Marlite, kitchen/bathroom tileboard, or economy board. Whiteboards can be purchased at building materials stores, hardware stores, and home improvement stores like Home Depot or Loews. It comes in 4' x 8' sheets, for about $12 per sheet. Have them cut it into 6 equal pieces, each 24" x 32".

Marlite boards last a couple of years (using them for 5 classes daily) before they get too scratched up and stained to use. If you wax the boards after you buy them, that preserves them. Use Endust, Meguiars Mirror Glaze #26 or liquid car wax (Turtle Wax). You can clean stains with brake fluid. (Your school custodian may know these tricks.) Wipe them with a rag, paper towel, or whiteboard eraser, and don't leave writing on them over the weekend. Clean them occasionally with whiteboard cleaner ($1.50 from Sanford Expo), window cleaner,"Simple Green" (it's non-toxic & biodegradable; buy a gallon, dilute it 5-fold, and dispense it in small spray bottles from the craft store), or isopropyl alcohol (from grocery store: 70%) on a paper towel. Isopropyl alcohol (rubbing alcohol) is the main ingredient of the commercial cleaners that you can buy. A modeler said, "I always have to leave my whiteboards overnight with writing on them - I use 409 to clean them and it works great! My whiteboards are 8 years old and still look good." A modeler said, "When the dry erase marks get difficult to erase, clean the erasers with a hose vacuum cleaner." Wax them occasionally to guard against scratching.

A handle is nice but not essential. Have the shop class use a router to make a hole that's 6" long x 1 1/2" wide, placed 1" below the top. Or drill a hole and use a saber saw (jig saw) with the highest quality size 18 blade. The high quality fine blade is needed to prevent tearing.

Instead of making the hole (or in addition), you could use an easel to place the boards on when the students do their presentation. Make an easel - it's easy. Art stores have wooden ones. Or drill a small hole and hang the whiteboard from a hospital IV stand; these can be obtained in thrift stores or from people who have had long-term illnesses requiring IVs. (When you do circle whiteboarding, you can have the students set them upright on the floor, resting on their legs.)

You'll probably need from 12 to 36 whiteboards and 18 to 36 dry erase markers. For example, Larry Dukerich, our workshop leader, buys 2 Marlite sheets (that's 12 whiteboards) every couple of years; he finds that 12 whiteboards are enough for his 5 classes.

Excellent quality whiteboards, with handle on the long side and rounded corners, can be purchased in multiples of 6 for $7.95 per board + approx. $2 per board shipping/handling from:

> PLAYSCAPES, INC., 2600 Daniels Street, Madison, WI 53704 (800) 248-7529, (608) 222-9600; fax: 222-8100. Jennifer Newcomb, jnewcomb@playscapes.com.

These whiteboards are very durable; they don't scratch easily, they don't discolor or stain easily. Indications are that they will last for 10 years or longer. The trick is not to leave stuff on them for days; wipe with a rag or w/b eraser. Commercial cleaner or alcohol takes off stains.

Dry erase markers cost about $10 per dozen, wholesale. Sanford EXPO work the best. Don't use black; it stains! Blue and green leave fewest stains, blue, black, and red show up well - get broad or chisel point. If you can, have each student buy their own marker; it promotes responsibility (i.e., they replace the cap!). One teacher buys a classroom set of markers and then has each student pay her for one. She gives them the choice of keeping it with their supplies or else taping their name on it and storing it in a coffee can in the classroom. Another modeler suggests making "color coded 'eraser' bandanas for each team. A couple of markers and a small spray bottle of 'Simple Green' cleaner can be tied inside the team bandana."

The "low-odor" markers are difficult to erase. They leave a stubborn residue.

If you accidentally use a PERMANENT marker on the w/b: to remove the stain, use hair spray, acetone, or fingernail polish remover; or write over the permanent marker with a dry-erase marker; wipe as usual.

Appendix B

Sample Presentation Instructions for Whiteboarding

Whiteboards should be complete. Please include:

Experiment Whiteboards

1. How the experiment was set-up - labeling any diagrams or underlying assumptions
2. Graphs - with scale showing variables and units, and minimum and maximum values
3. Equations - with units and variables
4. Statement which explains your findings
5. Group members' names on an upper corner

Homework Whiteboards

1. There is a labeled diagram of the situation, when appropriate.
2. All numbers and graphs are labeled with appropriate units.
3. Models used in the solution are shown.
4. Group members' names on an upper corner

Everyone in the room should easily read any item on your board!

When presenting your whiteboard your group should:

1. Be present at the front of the room (for Socratic modeling only). While one person serves as "spokesperson," the other members should assist in clarifying items brought into question by the class.
2. Bring at least one marker to make necessary changes when prompted
3. Bring your lab work
4. Bring a calculator
5. Speak clearly and intelligently

Appendix C

Sample Classroom Commitments

These are the commitments developed during the last three years in Jim Schmitt's classroom.

2001-2 Class Commitments
- Do your best
- Work together
- Be respectful

2002-3 Class Commitments
- Be responsible
- Be respectful
- Work hard
- Actively participate (pay attention, encourage, question & listen)

2003-4 Class Commitments
- Be collaborative
- Be respectful
- Be positive
- Actively participate
- Be prepared
- Work hard

2001-2 Teacher Commitments
- Be organized
- Be encouraging & helpful
- Be passionate
- Be consistent
- Be open to different learning styles

2002-3 Teacher Commitments
- Be motivating
- Be respectful
- Be understanding
- Encourage others
- Listen to students & ask their opinions

2003-4 Teacher Commitments
- Be fair
- Be respectful
- Be a student/learner
- Provide help
- Use a variety of teaching methods

Appendix D

Sample Whiteboarding Assessment

Whiteboarding Assessment

Presentation	**Exemplary**	**Proficient**	**Developing**	**Emerging**	**Not Yet**
Clearly identifies purpose and conditions of the experiment					
Speaks clearly					
Uses eye contact					
Summarizes results					
Gives intelligent responses to questions					
Prepares in advance					
Shares equally					
Preparation					
Easy to read					
Uses correct format					
Shows all calculations					
Identifies the problem					
Statement of relationship is clearly written					
All labels are shown					
Listening					
Attentive					
Respectful					
Compares with own results					
Asks questions					

Appendix E

Sample Whiteboarding Assessment – Daily checklist

Whiteboarding Assessment

Presentation													
Clearly identifies purpose and conditions of the experiment													
Speaks clearly													
Uses eye contact													
Summarizes results													
Gives intelligent responses to questions													
Prepares in advance													
Shares equally													
Preparation													
Easy to read													
Uses correct format													
Shows all calculations													
Identifies the problem													
Statement of relationship is clearly written													
All labels are shown													
Listening													
Attentive													
Respectful													
Compares with own results													
Asks questions													

Codes:

Exemplary (E)
Proficient (P)
Developing (D)
Emerging (E)
Not Yet (NY)

Appendix F

Whiteboarding Presentation Rubric (Descriptive)

Whiteboarding Presentation Rubric

	You are SO There!	*You're on the Right Track*	*Not There Yet*
Comprehension	Your use of appropriate models is accurate. We can tell you think like a physicist.	There are some holes in your use of models; it doesn't make sense, but you're starting	You're making this up.
Analysis	You are at a high level – you're making judgments, forming your opinions, and being a good critic of science	You are comparing and contrasting, asking questions, interpreting and distinguishing about the elements of the models	You don't move beyond. We want to know what you think, not just telling us what is on your board.
Expression of Ideas	You inspire us to think deeply or about other items. You use prior examples.	You explain your ideas with examples from prior learning. You make sense.	We don't know where you are getting these ideas- and maybe you're just not expressing them clearly.
Conventions (Discussions)	Your body language shows that you are part of the discussions. You respond to the class in verbal and nonverbal ways. You make connections from the previous group's contributions. There's no question about whether or not we can hear you.	You are part of the discussion. You're definitely listening and contributing. With some more confidence, you'll be awesome.	Your body language shows that you'd rather be anywhere else. You're not responding to anything. If you do speak, we can't hear you.
Conventions (Written)	If there are errors here, we hardly notice them. Have you ever thought of making whiteboards for a living?	There are a few errors on your boards, but they don't get in the way of our reading.	There are too many errors-we can hardly tell what you're writing.

Oral Presentation Assessment

Criteria	**Exemplary**	**Proficient**	**Developing**	**Emerging**	**Not Yet**
Content					
Organization					
Eye Contact					
Interest					
Visuals					
Delivery					
Overall					

Appendix H

Constructivism and Learning in Science:

Critical Background Necessary for Understanding How to Effectively Facilitate Discourse in the Physics Classroom

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Core learning principles

Three core learning principles identified in the landmark book ***How People Learn*** (National Research Council, 2000), are based on research and provide a vital insight on how people learn.

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Implications for teaching

These learning principles lead to implications for teaching (NRC, 2000).

1. Teachers must draw out and work with the preexisting understandings that their students bring with them.
2. Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge.
3. The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas.

Implications for designing classroom environments

The authors then articulate the implications for designing classroom environments:

1. Schools and classrooms must be learner centered.
2. To provide a knowledge-centered classroom environment, attention must be given to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like.

3. Formative assessments - ongoing assessments designed to make students' thinking visible to both teachers and students – are essential. They permit the teacher to grasp the students' preconceptions, understand where the students are in the "developmental corridor" from informal to formal thinking, and design instruction accordingly. In the assessment-centered classroom environment, formative assessments help both teachers and student monitor progress.
4. Learning is influenced in fundamental ways by the context in which it takes place. A community-centered approach requires the development of norms for the classroom and school, as well as connections to the outside works, that support core learning values.

What students should accomplish

These themes are reflected in the Content Standard for Science as Inquiry in ***Inquiry and the National Science Standards*** (NRC, 2000) for what students should accomplish in grades 9-12:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

Six teaching standards

To help students accomplish these goals, the National Research Council points to six teaching standards for science educators.

1. Teachers of science plan an inquiry-based science program for their students.
2. Teachers of science guide and facilitate learning.
3. Teachers of science engage in ongoing assessment of their teaching and of student learning.
4. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.
5. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
6. Teachers of science actively participate in the ongoing planning and development of the school science program.

Essential features of classroom inquiry

Features of classroom inquiry have also been identified in this text. If one were to observe a classroom rich with inquiry, and several items would be apparent, and are listed below.

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented question.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

Instructional models

Science in general, and physics specifically, are often taught in cycles. Inquiry and the National Science Standards demonstrates that there are common components shared by instructional models in all content areas.

- Phase 1: Students engage with a scientific question, event or phenomenon. This connects with what they already know, creates dissonance with their own ideas, and/or motivates them to learn more.

- Phase 2: Students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe.

- Phase 3: Students analyze and interpret data, synthesize their ideas, build models, and clarify concepts and explanations with teachers and other sources of scientific knowledge.

- Phase 4: Students extend their new understanding and abilities and apply what they have learned to new situations.

- Phase 5: Students, with their teachers, review and assess what they have learned and how they have learned it.

Inquiry learning: Common Myths

Myths about inquiry-based learning and teaching are identified in ***Inquiry and the National Science Standards***, and summarized below (the myths are written in *italics*, followed by classroom implications to counter the myths written in plain text.).

- *Myth #1: All science subject matter should be taught through inquiry.* This calls for the use multiple strategies to improve effectiveness and reduce boredom
.
- *Myth #2: True inquiry occurs only when students generate and pursue their own questions.* The nature of generating questions is more important than its source.
- *Myth #3: Inquiry teaching occurs easily through use of hands-on or kit-based instructional materials.* The teacher still needs to be the "chef" in their classroom.
- *Myth #4: Student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring.* Engagement merely guarantees student participation.
- *Myth #5: Inquiry can be taught without attention to subject matter.* The process of learning is not an end itself. Science cannot be learned in isolation from specific subject matter. Students start from what they know and inquire into things they do not know.

How students learn science

Research finding on student learning are summarized in ***Inquiry and the National Science Standards*** and ***How People Learn***.

- Research Finding 1: Understanding science is more than knowing facts.
- Research Finding 2: Students build new knowledge and understanding on what they already know and believe.
- Research Finding 3: Students formulate new knowledge by modifying and refining their current concepts and by adding new concepts to what they already know.
- Research Finding 4: Learning is mediated by the social environment in which learners interact with others.
- Research Finding 5: Effective learning requires that students take control of their own learning.
- Research Finding 6: The ability to apply knowledge to novel situations, that is, transfer of learning, is affected by the degree to which students learn with understanding.

In Search of Understanding: The Case for Constructivist Classrooms (Brooks and Brooks, 1999) calls for students to have opportunities to express their point of view as a key part of the learning process. Additionally, asking students to elaborate on their thinking should be a mainstay in a classroom to promote learning, not as a sign that a student gave an incorrect response. An example, given by the authors, points to this issue:

> "As part of the third lesson, the students were asked to consider tow pictures, one of a single pulley with a 100 lbs. Bucket serving as a weight and one of a more complex pulley system with a 100 lbs. block serving as a weight. The teacher used this opportunity to ascertain the nature of Katie's understanding of the concepts explored up to this point. The teacher asked Katie, "In which picture do you think it would be easier to lift the object?"
>
> Katie chose the complex pulley. The teacher asked why. Katie responded that he bucket was heavier. Although she chose the picture her teacher suspected she would, the teacher couldn't understand her reasoning. The teacher, unsure that Katie comprehended that the weight in each system was the same, drew the label "100 lbs." on each picture. The following dialogue ensued:
>
> Teacher: They each weigh 100 lbs. Do they weigh the same?
> Katie: Yes.
> Teacher: Which one is heavier?
> Katie: The bucket.
> Teacher: Why?
> Katie: Because the bucket's heavier.
> Teacher: But they each weigh 100 lbs.
> Katie: But the bucket has sand in it and it looks heavier." (p. 81-2)

The authors later point out, "Student conceptions, rather than indicating "rightness" or "wrongness," become entry points for the teacher, places to begin the sorts of intervention that lead to the learner's construction of new understandings and the acquisition of new skills." (p. 88)

The authors add that nonjudgmental feedback is critical to promoting learning. "Responding to students' questions with additional questions, to students' assertions with plausible contradictions, to students' requests for assistance with requests for explanations of their thinking to date, and to students' arguments with responses such as "I can see that this is important to you," or "That's something I haven't studied very much," or "you've' convinced me," or "your idea makes sense to me; what do your classmates think of it?" Such reactions place the responsibility on students for assessing the efficacy of their own efforts, and make pleasing the teacher far less important." (p. 95)

Brooks and Brooks (1999) summarize characteristics of teachers who understand the constructivist nature of learning and how they facilitate their classrooms.

1. Constructivist teachers encourage and accept student autonomy and initiative.

2. Constructivist teachers use raw data and primary sources, along with manipulative, interactive, and physical materials.

3. When framing tasks, constructivist teachers use cognitive terminology such as "classify," "analyze," "predict," and "create

4. Constructivist teachers allow student responses to drive lessons, shift instructional strategies, and alter content.

5. Constructivist teachers inquire about students' understandings of concepts before sharing their own understandings of those concepts.

6. Constructivist teachers encourage students to engage in dialogue, both with teachers and with one another.

7. Constructivist teachers encourage student inquiry by asking thoughtful, open-ended questions and encouraging students to ask questions of each other.

8. Constructivist teachers seek elaboration of students' initial responses.

9. Constructivist teachers engage students in experiences that might engender contradictions to their initial hypotheses and then encourage discussion.

10. Constructivist teachers allow wait time after posing questions.

11. Constructivist teachers provide time for students to construct relationships and create metaphors.

12. Constructivist teachers nurture students' natural curiosity through frequent use of the learning cycle model.

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