A Model-Centered Approach to High School Physics

an invited paper by David Braunschweig, just retired from Madison West HS, Madison, WI.
AAPT Summer Meeting: 1997 (edited 4/98)

When I began teaching, I used the same textbook that I had learned from in high school: *Modern Physics*. Of course, I began by trying to "cover" all the material. It didn't take too long for me to begin to feel uncomfortable with that approach. I tried several other books and finally settled on the PSSC text. A few years later my high school began offering two physics classes - one using the PSSC text and the other using *Project Physics*. During this time we were also involved in modular scheduling and learning packets. The 80's brought computers and interfacing. Now, block scheduling appears to be the experiment of choice. So in my 35 years of teaching I have seen many different approaches to education as a whole and in physics in particular.

My journey to modeling probably began in 1981 when I attended my first AAPT Summer Meeting. It exposed me to more physics teachers and what was happening in physics education. One of the workshops I attended was on using computers in the classroom; that marked the start of my own use of them.

The next big impact for me was the 1985 PTRA program which put me in contact with even more physics teachers. The PTRA program gave me lots of good materials to use in my classroom, but perhaps most importantly as I look back, it encouraged me to start reading the literature about physics pedagogy. I had avoided that because many of my education courses had been terrible. I just concentrated on the physics concepts.

One of the approaches that came from the PTRA program that I used to work on misconceptions was discrepant events. However, I gave up on the approach quickly because when I asked my students to predict what they thought would happen in a demonstration, it didn't take very long before their explanation would become, "Well, I think 'A' is going to happen, but because my predictions are always wrong I know it is going to be 'B'." That was their only defense for their predictions, and that never happens with modeling. They can now give me very good reasons why they think something has to happen, based on the models that we have developed.

My next step toward modeling came in the late 80's. I was fortunate to work in the LabNet program where the ULI was being developed and MBL tools were being used to work on the physics misconceptions. I followed it with the Project PhysLab workshop in Portland, Oregon, which gave me a good familiarity with all of the MBL materials.

Now my curriculum was based on using MBLs, particularly *Real-Time Physics* in mechanics and the CASTLE materials for electricity. My students really were making progress in correcting their misconceptions. But after several *Real-Time* units or CASTLE units, I would get comments from them like, "Why are you killing all of these trees? There are so many hand-outs. And all the fill-in-the-blanks. And all of these questions to answer." But I kept giving them the paper and they kept learning even though they didn't like all the paper.

During the previous summer's AAPT meeting at Notre Dame University, I had received a brochure from Arizona State University about modeling. After looking at it and giving it some thought, I threw it in the wastebasket because after 33 years and all the changes I'd been making, I thought I had arrived at what I wanted to be doing for the last few years of my career; I wasn't going to make any more changes.

On a cold winter night the next school year, as I was struggling with my students' complaints about all the paper, another modeling brochure arrived. I read it again. You know - something from sunny, warm Arizona on a cold night - so I thought, well maybe I'll apply and learn more about modeling. And after the first year of teaching using the modeling method, I wished I had learned about modeling years ago, because it greatly changed the way my classroom operated.

With that background on how I got to this point, let's learn more about the modeling approach and how it has affected me and my school's physics program.

To begin with, it is very important to establish the appropriate atmosphere for learning and establish the rules of engagement: how the student to teacher and student to student interactions will work. What is established the first day is important so that the students realize that they are truly partners in learning.

Most of our modeling cycles begin with an experiment. The experiment itself isn't necessarily remarkable. The very first one I use is a simple pendulum. The next cycle begins with a toy car rolling across the floor at constant speed. The third cycle begins with a ball rolling down a ramp. These are the initial experiments in the first three units. Nothing remarkable about them at all. What is different from the traditional experiments that I had always done is that I would start by giving the students a hand-out detailing all the steps they were supposed to follow, along with all the questions they were supposed to answer, and then put them to work. Of course you all know that half of them never read the instructions. They fumbled around, and they always found a way to put an answer down on that question sheet for you. And then they would go on to do something else.

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.

Next comes the task of narrowing the list down. I set the standard in my labs that when the students graph they must have at least six data points that they can plot. So I said, "humidity - can we really get six different humidities in our classroom that are widely spaced in a one hour class? No, we can't do that." It really is beyond what we can control, what we can change. By the end of the discussion we have narrowed the list to things we can control, like mass, length, and amplitude - although we don't call it amplitude yet: we call it something else, like how far to pull the ball to the side or how high above the table you release the ball. How amplitude will be determined might be different in every class. I don't allow the use of words like amplitude unless they define what it is.

After the class and teacher have determined the variables and the purpose for the experiment, the students go to work. This is where it's different from the past where I handed out the instruction sheet ahead of time and had them do the experiment. The students do the experiment in cooperative groups. This wasn't new to them; they've been working in groups since at least 9th grade, but the difference is that they now design the experiments. They have to determine the procedure, they have to figure out how to determine the amplitude - how are they going to measure that? How many cycles are they going to time? What masses to use? Often we'll use computers to collect the data, but in the first experiment it is just a stopwatch and meter stick. They're not even allowed to use a computer to plot their first graphs; they have to do them by hand first. Once they have drawn their first graphs we begin using *Graphical Analysis*. They'll find the relationship between the variables they've investigated as they evaluate the data.

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.

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.

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.

At the end of this presentation period the teacher comes back and pulls together all the things that have happened during the presentations. The teacher helps the students put together the model they have developed.

During the modeling lab, the teacher sets the stage at the beginning, draws it all together at the end, and tries to stay out of the way in the middle as the students develop their models. It was very hard for me at the beginning of this process to keep quiet and let them talk and try to discover what they were thinking, because I always wanted to hop in and give my opinion about what they should have done. It takes time for the teacher to learn good questioning techniques.

I've done this for two years with over 240 students in ten classes, and each year I have them do an evaluation of the modeling process. The first question asks them to compare the labs they've done in physics with the labs they've done in biology and chemistry. I went through the evaluations and selected out a few comments that they made, and I will share a few of those with you now. Remember, they're comparing the labs they've done in the past with the labs they've done in physics using modeling. This is out of 240 students and the remarks are very similar from student to student.

- "I prefer the labs in this class because they caused each student to think, really think about what they are doing."
- "I don't like labs where the instructions are fill-in-the-blank. Fill-in-the-blank labs don't let you come to your own conclusion." That comment came up over and over. Probably half the students made a comment about not liking fill-in-the-blank type labs. This surprised me, I didn't think they were really like that.
- " Results are a not a foregone conclusion, you learn for yourself and remember it better that way." This one came up many times; I was so glad to see it.
- "Other types of labs are easier, but I think you learn better with these. You find out for yourself."
- "You don't have to do the lab exactly the same way as everyone else, and it gets you thinking for yourself." What many of the students mentioned is that they like having multiple ways of doing the lab. In the third experiment that we do, I think I had four different possible apparatus set-ups of measuring equipment that they could use. They could choose which way they were going to do it. And it helps when they compare their results and realize that they all came up with the same basic mathematical model regardless of what type of experiment they did. That I think is powerful because none of them do exactly the same thing with the same equipment.
- "I enjoy being able to figure out why something happens. We are really free to make our own mistakes and learn from them."
- This next one I like very much. "It shows confidence in the student's ability to figure things out." They feel more ownership in this learning process.
- This one really surprised me, it came up so often: "It is an easy way to understand physics." They talk about physics being easy. It's the first time this has happened!
- "I can trust myself without blindly accepting."
- "Everyone has a chance to get into it." That's something that's especially important; the kids can't just hide in a corner and not say anything. They have to be involved. In my classes, at least twice a week every student is in front of the class - at least twice a week, sometimes more.

Of course not all the comments were positive. Out of 240, ten of the students liked the old style of labs better. Ten out of 240. I thought that wasn't bad. However; out of those 230 who liked this method better, they still had things they didn't like. What they really didn't like is the lab write-up. “It takes me too much time to write up the lab.” This comment sounds like a negative but I don't think it is. They put it in the ‘I-don't-like’ part of the survey: "It puts a lot of responsibility on the experimenter to think." In the modeling approach we spend a lot of time into labs; labs are really taken seriously.

There is one more thing I would like to discuss, and that is model deployment. In the model deployment, we include things such as other experiments, worksheets, problem sets, lab practica, discussions, segments that you might call a lecture, just ten or fifteen minutes where you draw things together, very practical. The part I will concentrate on is the whiteboard part with worksheets. My traditional experience with problems is that I gave the problems, end of chapter problems; I told the students to do them and watched the students scribble out answers as they walked into class. After seeing this for a few years, I gave up on that. Of course, I would work the problems on the board, and by the fifth class I was an expert problem solver. I could do the problems; the students couldn't. I heard the comment and you've all heard it, "I understand the problem when you do it on the board." I gave up on that, and I would assign the problems and ask if there were any questions; I didn't bother to work all the problems any more. And then of course I put the responsibility on the students to do the problems and ask questions, and the grades went down.

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 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.

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.

Modeling isn't all good; there are some things we don't do. 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. A positive thing in my school is that the three physics teachers take time talking to each other and trying to figure out why we're doing something. What is it that we are trying to accomplish?

I would like to share one of my success stories from last year, a result that really surprised me. We had done kinematics, we had done dynamics, and we were now doing two-dimensional motion. I started with a standard demonstration: dropping a ball and shooting a ball horizontally at the same time. In one class I asked the students to predict what they thought would happen when we did this and then to explain why it would happen. I gave them about five minutes to work on this and then I collected their papers. One hundred percent of the students in this class predicted the right result: that the balls would hit simultaneously; and every one of them gave reasons to support their answer, that the same forces were acting on each ball. That never happened before! Ordinarily answers for this question were spread between the three answers. With the result in modeling classes I can say that we had made progress. Students could predict and explain what was happening. In my other classes I tried similar things and we got similar results.

Recently I was talking with my son,who is a musician, about modeling. We decided that modeling is the jazz approach to physics. You know how a jazz piece can be played. The leader often gets the piece started and then sits down and plays with the band. You improvise during the piece; performers go off in different directions but in the end you all come back together and the leader signals the end. My son and I think that teaching in a modeling format could be called the jazz model of teaching physics.