Atomic Conversation

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WHY

Let me be honest with you. I have never felt relief like the day I got out of high school. That was a glorious moment. It brought to an end countless hours of severely painful boredom, that bone-crunching, mind-frying boredom that threatens to measure itself in eons but is mercifully limited to hours, days, and years. The severity of the boredom was always puzzling to me because I liked to learn and I was always reading things that I didn't have to read. I imagined it stemmed from the fact that maybe the teachers really didn't know very much. Perhaps in college things would perk up. Thank God for band, chorus, and gymnastics. Those extracurricular activities got me through without too terribly much scar tissue being formed. I got good grades, took every course offered, graduated valedictorian, had lots of good friends, and almost cried with joy the day they let me out of that place. I've never gone back to even one class reunion.

In college I was more than a little horrified to find the same boredom bearing heavily down upon me at every turn. Could this be happening? Why? I had worked hard to get to college and it was shocking to find myself enjoying my part-time job as a waitress at a hamburger joint more than my studies. For this the government was paying for my education? I was studying science, and that was when we were still trying to warm up the Cold War, so I had a scholarship. Was it because science wasn't my bag? I paid close attention in all those intro courses. Maybe philosophy, or literature, or anthropology was my destiny. The first year I strained to win the battle. My teachers were kind of pleased to see a freshman picking heartily at the bones being thrown.

But by the middle of the second year, I began to bow my head and accept the inevitable. I was bored stiff and nobody cared and I really did not understand why. In the mid-70s when I started teaching science in the public schools, I made a vow. I promised myself that, no matter what, I would not subject my students to what I had gone through. I began to do all kinds of crazy things to keep kids from yawning off to sleep. I wrote songs about the concepts and facts I was trying to teach. I made up dances and skits and I got kids working on the science fair; in fact, in my first year of teaching I hosted the first science fair my school had ever had. I worked hard and spent my own money to get supplies for the participants, and after three years of working like a slave, I burned out and went to work for the railroad, making twice as much money as in teaching and doing a fraction of the work.

Then a teacher friend of mine lured me back into the profession by offering me a job at the High School for the Engineering Professions. He told me those kids were so much fun to work with. At the time HSEP was something of a national item, and the principal, Susan Sclafani, was a dedicated, hard-working, visionary young woman who had winning ways, so I jumped back into the fray. This time I didn't even last two years. I had a whole stable full of dogs and ponies but the show was too much for me.

Then I had a child of my own. I stayed home with him for eight years and home-schooled him. We were not ever bored. Then he decided he wanted to go to school. He thought school consisted in getting new book bags and new clothes and being with other kids. So I went back to teaching and he went to school. After one week the novelty wore off, and he was complaining about being bored. I told him he would have to stick with it because I had signed a contract and not only that, I needed this little commodity we affectionately call money. During the eight years we had lived on my husband's salary only, we had grown accustomed to rice and beans as the staple; but in the short time I had been working again, we had become addicted to having the salt back in the soup. I decided a dose of reality would not hurt him. I never planned to rely on the schools for his intellectual development, and I never did. I handled that from the home front. Now he attends Sam Houston State University on a violin scholarship. At least he gets to play in a great orchestra every day. He and some friends have started a band and they try to work in as many practices as they can. He is coping.

OK, so here is the punch line. I finally found out why school is so boring. It took 25 years of stumbling around wondering what the heck the problem was, but I finally got a mental breakthrough. It happened this year when I was included as a year-long participant in the Rice Model Lab at Lee High School. The mastermind behind the program is a rather unassuming Yale graduate who very deftly and patiently maneuvers her teacher-students into a position to be able to see – inevitably for the first time – the proverbial light. Dr. Nonie Harcombe takes a full year to help teachers begin the process of reflecting on teaching. She very graciously and carefully steers her protégés towards an initial understanding of why they have struggled so long with so little to show for it. This is a hard thing to be sure, because most teachers pour their hearts into what they do and it is not a light matter to admit that most of what we do is singularly ineffective.

Since I don't have a full year to convince you of what I am about to say, I run the risk of writing this in vain. Teachers, as I said, work hard and are not flippant about changing their ideas and their methods. One of the reasons I think HTI has us write these long introductions to our curriculum units is because it takes some time and effort to sell teachers on any course of action that they themselves did not generate, and for good reason. Our ideas are our ideas. They are ours; we own them and we are comfortable with them. Trying someone else's idea is like wearing clothes that don't fit. We are not likely to do that. Millions of dollars spent on professional development are wasted for this reason.

That being said, allow me to make one more preparatory paragraph before just telling you something you may not want to hear. Some very interesting research was done at a Harvard graduation ceremony. Researchers circulated among the happy graduates and asked them questions like, “Why is it warmer in summer than in winter?” and “How does light affect sight?” It was surprising to find that very few students were able to give the scientific answers to these questions. In fact, the answers given were very similar to the answers given by sixth graders. The implication is that people have ideas of their own about how and why things take place, and years of education do not really change the ideas held. Obviously the Harvard graduates had at several points “learned” the scientific answers and given them back to teachers on tests, but they had not incorporated them into their own world view. All of them had an answer. Only a few gave the answer of science. A whole series of fascinating videos (Private Universe) have been made on this subject.

This brings me to the assertion that students have ideas. They already have an idea about almost everything. Unfortunately we do not acknowledge this in our teaching. We rarely ask students to give their ideas. We act like their brains are a clean slate. We imagine that when we tell them the science answers we want them to hold, that they readily receive them. The notion that the ideas we are trying to sell have competition from the ideas the students already have in place is not something we normally accommodate in our methods.

At the Model Lab we tried this on our IPC students. We asked them to give their ideas about how light affects sight. We asked them to draw a picture with an object, an eye and a light source and to put arrows showing the interactions among the three. After some prodding, because students are not familiar with the notion that we want them to share what they really think, three separate models emerged. We asked for volunteers to come to the board and draw the models. This resulted in Luis’ idea, Christian’s idea and Silvia’s idea being blazoned across the front of the room. The rest of the students aligned themselves with one of the three ideas such that a nearly equal amount peopled each group. Then the groups met to discuss ways they could devise actual experiments that would validate their thinking. Discussion and arguments developed. Some heat was generated. Everyone was alert, alive and thinking. It took several class periods to resolve this conflict and some students never did ascribe to Christian’s idea which happened to be the science idea. The alternative conceptions were not that easy to dislodge. The process was not boring.

This amazed me. I had on occasion allowed my students to debate issues. When Dolly was cloned we staged a debate. Certain environmental issues had been treated as well but never had I thought about arguing dogma. Dogma is sacred – yeah right! That’s why we have to buy new science books every few years. By the time a text goes through the printing process it’s already wrong. According to Dr. Harcombe, the debate over the light-sight issue was probably one of the few times our students were even sort of learning all year. And I thought back to my own high school debacle. What was I able to remember? Well I remembered the debate we had about evolution. It had raged thick and hot and heavy over several class periods. I remembered it with great clarity and that had to be a feat because at 56 I can forget what I said five minutes ago. I remembered the genetics class where the teacher and I had argued over one of the problems and I turned out to be right and the teacher was not even mad about it. I remembered that. The rest was a blur and I was not able to remember anything at all from college except for my chemistry professor whose name was Dr. Fink and whose back was completely towards us as he lectured to the blackboard day after day. I cannot remember anything he said because I never heard anything he said but I do remember the students looking askance at one another every time he wheeled around to the board and began lecturing.

I now know that the reason I was bored out of my skull in school was because I was rarely asked to think critically. I was not asked to give my ideas, defend my ideas, and compare my ideas to other ideas. I was told what they wanted me to know, then I was tested to see if I knew it, which I usually did since I memorized and crammed for every test, and then I promptly forgot what they wanted me to know. That vicious cycle, tell-memorize-test-forget, is what made school intolerable.

With that in mind, in this unit my purpose is to detour around the cycle and substitute another sequence. "Question-hypothesize-test-debate," is a way to avoid boredom and stimulate thinking. I will move on to the "What" section of this but be warned that I will not be able to stop injecting the "Why" and the reason for this is because I see it as the most important aspect of the unit being developed.

WHAT

Teaching IPC-level chemistry is almost impossible without a rather thorough understanding of the water molecule. In the past I have spent good cash buying materials with which to construct a Bohr model of H2O. Beautiful models in hand, my students promptly forgot what the models meant and by the end of the year they could not even draw them let alone use them to predict outcomes. Niels Bohr on the other hand, probably went to his grave still bearing a thorough understanding of his models and their implications. They were his models. He had gone through a mental journey to arrive at them. My students had not, so they easily dismissed them in spite of my hands-on activities.

Bohr knew what previous thinkers had contributed to the problem of atomic structure. Using their thoughts and experiments he came up with a more advanced model than anyone before. Bohr's ideas did not spring out of a vacuum. The human race had been grappling with the question "What is the universe made of?" for thousands of years before Bohr added in his two cents. Somehow we expect the student brain to spring nimbly into a mindset that was a very long time in forming. After all, we have to "cover" the atomic theory because it is in Project Clear. And we can't take a great deal of time doing it because there is so much else we have to "cover." And of course the manifest reason it is in Project Clear is because this document has been distilled out of a vast swirling mass of knowledge that just might be on ***THE TEST***. (Right about at that point all true teachers should begin to quiver and quake with awe and a most proper reverence because ***THE TEST***, as we all know, is being entrusted with such portentous tasks as deciding the future of students, the pay of teachers, and the list goes on. It would be highly irregular to sniff at ***THE TEST***.)

But, the work of the Private Universe people indicates strongly that even the best of the best, the test takers par excellence, the Harvard graduates themselves, do not really learn much about science in our schools. So for those of us who teach science, and for those of us who feel that teaching science is important, and for those of us who kind of suspect that a lack of science literacy might adversely affect the continuance of human life on the planet, well, maybe just for that select group, we could possibly take a little more time and really teach some things, as opposed to rushing along preparing for a test, and not really teaching anything. It is a wild, bizarre, and radical idea but maybe for some of us it is an idea whose time has come. I know for me it is.

So let's look at the atomic theory. Most books credit Democritus (400 B.C.) with the first stab at it. He was not a scientist. Back then it was not in vogue to set about everything in a scientific way. The educated dudes of the day, and dudes they were, not dudettes, sat around pondering questions, thinking. Happily, this thinker was evidently strongly influenced by the sense data he had taken in, in the course of his time metabolizing on the earth. Or at least I like to imagine that he had been strongly influenced by what he had seen, touched, tasted, heard, and smelled – otherwise how could he have put forward a theory that was not significantly improved for thousands of years. According to him, matter is composed of tiny atoms (atomos), too small to see in their individual manifestation, and these atoms are in constant, random motion. His atoms were solid spheres, like very small marbles.

One might say, oh well, my students believe in atoms. My students know what the universe is made of for heaven's sake. They have accepted atomic theory. Oh really? I would submit that they have not. But since that is a testable hypothesis we can begin to try some things. Give each student a small cheese cube and a plastic knife. Ask them to cut it in half. Encourage them to eat one half and cut the other half in half. Continue eating half and cutting half until it gets very hard to actually carry out the task. Then pose this question to the whole class: If I had the strongest microscope in the world and the tiniest knife, how long could I continue this process. Would I ever reach a point where the cheese could no longer be cut and still be cheese.

I let the students pretend that the cheese is a piece of pure gold. Is there such a thing as the smallest possible piece of gold, which cannot be further divided?

We did this activity in the model lab. A percentage of the class was totally put off by the question. They were seemingly unable to think beyond their actual experience. I would say that 4 out of the 28 students were in that predicament. Another rather sharp section of the group proposed that one could go on indefinitely dividing and dividing, on to infinity, just like one can do with numbers. Another segment of the population said that they thought there might be an end point to the process but they had no clue as to what that end point might be. One student, one lone student, an immigrant from Pakistan with a thoughtful gaze said, “You would eventually be left with just one atom (she pronounced it ‘ay-tomm’, accent on the second syllable) of gold.” She was the only one who was a ninth grader with an intellectual commitment to the concept of the atom. Her educational history had taken place in another country.

So there we had it, the product of many days of vertical teaming, right, and only one student had bought up the notion of the atom. Well what do we do then? How do we jump from the pre-Democritus mindset to the Bohr model, much less the de Broglie model? Do we just say, “Look kid, we told you in grade school that these little particles called atoms make up the universe. We also told you that in middle school. Things haven’t changed. We are still trying to sell you the same product. Just buy it and let’s go on to the next part of Project Clear before we get hopelessly behind. We are teachers. Our job depends on whether we are all teaching the same thing on the same day in the same way. I have bills to pay. I can’t be worrying about whether you really are learning anything. Just spit this back at me on a test and we will call it even, ok?”

Or do we do what we did in the Model Lab, reflecting on teaching based on the students actually learning something, as opposed to teaching so we can show our lesson plans to the department chair who will then assure the principal who will then assure the district superintendent who will then assure the general superintendent who will then assure the governor who will then assure the president that no child has been left behind? I know that sounds ridiculous but the reason it sounds ridiculous is because it is totally insane. Ridiculous doesn’t capture the level of stupidity and even insane falls way short but sometimes words are not enough.

The next class, we gave each student a beaker of water. The teachers went around and dropped several dollops of blue dye into each beaker. The assignment was to meticulously observe the changes that occurred in the system thus created and to try to write in the logbook a description that would represent the activity observed. After the writing had been done students were also asked to put forward a theory of matter that might be useful in explaining what had been seen in the beaker.

This time we picked up a few proponents for Democritus. A number of students, not the majority for sure, postulated that the only way the phenomenon observed could have been pulled off would be if teeny tiny invisible particles in random motion were doing their thing. To attempt to rope in a few more, we tried an activity. We gave 5 students each a piece of blue paper. Then we laid down some rules. All students were to travel at a reasonable pace; we demonstrated the definition of reasonable, in straight lines until they happened to gently bump into either an object or a person at which time they would change direction such that the angle of incidence equaled the angle of reflection. In this way we hoped to help students visualize what might actually be happening in the beaker.

At several points we called on all the ‘particles’ to freeze and we asked the people with blue paper to hold up the blue paper and we noted their distribution around the room.

These activities were not culled from a model lesson. They were not taken from the Internet. They were devised in response to the intellectual needs of our students.

Our students had already had experience with Newton’s laws. They were ok with the particles moving in a straight line until their course would be altered. What they weren’t ok with was the concept of a macroscopic world being composed of invisible particles carrying on like crazy. As teachers it was our job to help them confront that aspect of reality. We had to do a lot of prodding to get our students to begin thinking for themselves. After 8 years in a system that rarely asked them to postulate and cogitate, we had to be pretty demanding about asking students to formulate ideas and propose hypotheses.

“You have come to the end of all the years you have spent just accepting what you are told,” we told them. “Every one of you must take a position and not only take a position, but be willing to defend the position taken by offering objective evidence to support your notions. In this class we are going to let nature, the physical realm, speak for itself. We are all here to learn and we are going to let nature teach the class.”

Of course it is easier to do this when light is being investigated. When we had insisted that our students align themselves with Christian, Luis, or Silvia on the matter of the relevance of light to sight, the students proposed and carried out all kinds of experiments to try to prove or disprove ideas. In fact our classroom had black paper completely covering all windows for a whole month, because we never knew when an idea about a possible experiment might surface and be given its day in court.

We had also been able to test Newton’s laws in the classroom, and the behavior of electricity. But now we had to teach atoms without an atomic force microscope. No electron microscope. We were challenged, as teachers, to orchestrate experiences that would help students to bridge the mental gap between the seen and the unseen.

Our next step, therefore, was to the side instead of forward. We did some work reinforcing the ideas of Democritus and John Dalton, whose theories are quite similar but Dalton’s approach being that of the scientist as well as the thinker. We began to use Dalton’s ideas to try to predict what would happen in various instances, just to see if the ideas were useful in that way.

Even before doing that, we rehashed the atom notion several ways. One day we brought a bunch of legos. We put a big stash of legos on each table and asked each group to connect them all together to make one connected whole thing. Then we asked each group to take apart the THING and to make separate piles for each type of piece or particle.

Each table had then about twenty different stacks of identical particles, or components. We asked them then to imagine that the universe was the THING, and we asked them to come up with what the particles could represent.

Another day we went to the farmer's market and bought about 15 different bags of brightly colored seeds and beans. We passed out paper plates and said they represented empty space. Then we asked them to construct a universe on the 'space' using the 15 different beans as atoms. Then we put the artwork on the wall and talked about how some people had constructed living things, others had constructed buildings, others had made geometric shapes but all of the THINGS were made of the beans (atoms).

You may wonder why we kept rehashing the same ideas in different ways. The reason is because in actual fact not all the students were able to think in terms of atoms. How could that be when they were already in high school? How could they get all the way to high school without knowing about atoms? Well, I guess the same way the students at Harvard graduated without understanding the seasons, or the way light works. No one ever took the time to really teach them. EVERYONE covered the material; few taught.

We next asked our students to guess what might happen if we put one beaker of water with dye on a heater, and had another beaker of water with dye that was not on a heater. We actually let them set the whole thing up except for putting the beaker on the heater. They had to write in their logbooks what they thought would happen but, more importantly, they also had to write a theory or an idea of why they thought it would happen. We did not allow anyone to test an idea that had no theoretical basis. We went so far as to have them draw a life-size drawing of what might happen to the particles in each beaker. We encouraged them to talk to each other about their ideas before settling in on any one notion.

We had worked on some ideas about energy, both kinetic and potential, earlier in the year and we encouraged them to draw on those to the extent that they could. We went on the next day to getting the students, using Dalton's ideas, to predict what would happen to ice if we put it in a beaker on a hot plate. We insisted that they support their predictions with the whys and wherefores. We let them carry out the experiment and then the next day we tried dissolving sugar in cold water, and warm water, and hot water. For all these experiments, Dalton was enough. Their predictions held. Then we deliberately put forward a situation that we knew Dalton could not handle.

We asked the students to weigh out ten grams of salt and ten grams of sugar. We asked them to visually inspect the two piles of crystals. Then we asked them to predict how many ten-gram piles of salt could be dissolved in 100 ml. of water compared to the number of ten-gram piles of sugar in 100 ml. of water.

Almost all the students predicted that more salt would be dissolved than sugar and this prediction was based on the fact that a ten-gram pile of salt is smaller than a ten-gram pile of sugar. So, if the particles of water, in random motion, had less to support and keep afloat, they would be able to take on more salt than sugar. So the race was on.

When sugar won by a landslide the students were ready to admit that maybe the Dalton atomic theory wasn't enough. It was valuable in some instances because it could explain some things, but in this instance it fell short, or so it seemed.

Of course Project Clear and the text are quick to point out that the next step in the development of a useful atomic theory was made by J.J. Thompson. He was the dude who found out that a beam of electrons is bent towards a positive electrode. He assumed therefore that electrons are negatively charged particles. His theory of the atom was then that the atom was a mass of positive charge in which floated the negatively charged electrons, kind of like a plum pudding or a chocolate chip cookie.

How to break this news to the students? Just tell them? Hmmm . . . maybe not. Why risk having them be like the Harvard grads? Well we made a compromise at this point. We told the students, "Look. Your ideas about the atom are developing as you look at various things happening in the physical realm. Well that is how the atomic theory has developed through time. It has developed in response to evidence gathered in laboratories around the world. Now we are in a situation where we have laboratory evidence we cannot explain using the Dalton atomic model. We need a better model. So what we propose to do is to step back for a moment and study the model of the atom as it developed. In the course of doing that, we hope to get to a point where someone in this class says, EUREKA! THAT MODEL EXPLAINS THE SUGAR-SALT PHENOMENON!"

We had six dudes and six tables and yes the six were still all dudes. We gave each table a piece of poster board, the big kind. The teams had to divide the work. One person had to put the face of the guy on there. Another had to write the dude's ideas about the atom. Yet another had to elaborate on how the ideas of the dude were an advance over what was previously thought. The dates for the birth and death of the dude had to be on there. A cooperative presentation had to be made with a videotape recorder. The tape had to be watched by the whole class.

So we had Democritus, thinking before the birth of Christ, and advancing beyond the idea that earth, air, fire and water were the basic stuff of the universe. Then we had Dalton, whose thinking was quite similar to Democritus' ideas but having the edge of being based on lab experiments that could be repeated by anyone. Then J.J. Thompson came with the electron, being a big advance in that the electrical subatomic particle begins to emerge. Then Rutherford arrived with his alpha particles that shone through the gold foil with very little deflection, indicating a preponderance of empty space making up the atom, and the positively charged nucleus being of very small size compared to

Thompson's pudding model. And then along comes Bohr with his energy levels for the electrons that explained a lot but were superceded by de Broglie's model that gave the electron a possible location in an orbital but certainly not the nice neat planet-type orbitals of Bohr.

This was a lot of stuff for kids to swallow. We realized that and wished we were smart enough to come up with more and better ways to move the kids along through the various ideas. We did not drop this in on them and leave it. Every day for several weeks after this activity we played a thinking game with them. We drew six huge circles on the board side by side. We put a line above each circle and two lines below each circle. We said, "OK, let's practice coming up with an atomic theory. Let's talk about what the universe is made of." We offered the chalk to each student in order. The goal was for each student to put something on the board. Or, if they did not put something on the board they could correct something that was already there. We pointed out that every student would have to be able to fill in the entire chart if they were going to really understand the modern atom and be able to make predictions using their understanding.

The circles were to be filled in with drawings of the six models, starting with Democritus and Dalton, both of which were easy to draw because they were solid spheres like marbles. The third circle was Thompson's chocolate chip cookie with a big positive area suffused with little chocolate chip electrons. The fourth circle was a small tiny positive charge in a small tiny nucleus with electrons further out. Then the fifth was the Bohr model, looking like a sun with planets in their orbits and the final circle would contain the de Broglie dots representing where the electron was most likely to be.

The line above the model was to have the name. The line below the model was to have the dates, approximately. And the line at the bottom told how the model was an advance over previous ideas.

At first it took forever to play the game and only a few students scored. We stopped playing the game after almost all students could contribute substantially to the creation of the chart. An additional step would be to allow students to *be* the various scientists and give them a chance to argue their ideas back and forth. But once we got to this point we zeroed in on the Bohr model because it was the Bohr model that would be the most likely source of understanding for the experience that sent us down the atomic theory road.

We still could not explain why salt was less soluble in water than sugar. To get us to that place we began practicing building Bohr models. To accomplish this we used our beans again. We drew a full page model using lines to represent the orbitals and then we set about practicing the building of Bohr atoms. We used the periodic table in the back of the book as a reference.

The teacher would call out the name of an element, for example hydrogen. The students would use the chart to find the number of protons, the atomic number, and then they would infer that if there were one proton in the nucleus with one positive charge, a neutral hydrogen atom would have to have one electron, with one negative charge. At first we did not consider the neutrons. We had not included Chadwick in our all-star line-up of atomic theoreticians. We just had a lot of fun building neutral Bohr models. We worked to see who was the fastest individually. Then we used a big atomic model we have that is part of the CPO put out by Tom Hsu who wrote the textbook we use in class. It is a huge board the size of a Chinese checkerboard. There are little indentations for marbles like Chinese checkers and there are marbles for the neutrons, the protons and smaller ones for the electrons. Students began to see how the energy shells fill up and we began to put forward a campaign to have students to start thinking like a chemical. Chemicals don't like to work extra. If a chemical has two electrons it will likely keep them close to the nucleus. It takes less energy than it would take to hold them further away from the positive charge of the nucleus. That is why the 1st orbital fills up first. Chemicals also like to have a full outer shell. It takes less energy to have a full outer shell than it does to try to hold open unused spaces within a shell. Chemicals are lazy like that. In fact, having a full outer shell pretty much is all a chemical thinks about.

We worked with building atoms as teams, as individuals, and finally we had duels between experts using big models on the board that used magnets as protons, electrons and neutrons. We added Chadwick to the picture and began using the atomic mass to calculate the number of neutrons. We then began to talk about how atoms might act in a social situation.

To do this we asked the kids to think about how people function in social situations. We talked about what motivates people to get married: love, money, looks, loneliness etc. We assured the students that in order to understand chemistry they would have to begin to think like chemicals, not humans. Chemicals don't bond for love or money; they bond to fill the outer shell. We made up a song to the Wizard of Oz tune "Ding dong the witch is dead!"

Our song was "Ding dong my shell is full, which old shell, my outer shell. Ding dong my outer shell is full." We had so much fun doing this that we actually designed a marriage license application for chemicals (see Appendix B). We spent whole class periods letting students pretend to be chemicals and marry each other repeatedly and in multiple ways. Instead of using the Wedding March we sang the song we had made up.

We plumbed the Bohr model to its depths. We made up a skit about the self-ionization of water using the Bohr model (see Appendix A). And I include all this because it was an attempt to deal with abstract concepts in ways that students would care about.

Were we successful? Did we ever get a model that could explain the extreme solubility of sugar as opposed to salt? No. Again my email address is dcobb@ev1.net. We not only didn't solve the puzzle, we found that even experts were hesitant to offer a truly comprehensible and sound theoretical underpinning for the phenomenon. As high school teachers we may not always be able to get our hands on the *right* answers to things but we can go through the process and get as far as we can. We can help students appreciate science for what it is: a way of approaching questions. The answers to questions are still in flux and that situation will not change any time soon.

And what did that do for our students? Well they saw us heading down a road trying to understand the universe and trying to comprehend any order that might exist in its composition. We at least had a model that could explain why a polar molecule like water would be able to dissolve sugar that is also polar, or salt that has positive and negative ions. We didn't have the whole story but we had a great time trying to come up with a meaningful ending.

HOW

How is it that we have some people fascinated by the question, "What is the universe made of?" and others not? Well let's see. Do I care about this question? Yes I care a lot. I voraciously read anything on the subject I can get my hands on. OK. Why do I care? You do not have to assign reading to me on this subject. All you really have to do is continually remind me of my financial limitations so that I will not accidentally overspend by clicking on too many online booksellers.

Do students see adults caring about this question? Actually do they get a chance to see adults caring about any questions? No they don't often. And why is that? Well let's see. The reasons for that are multiple. For one thing, in our schools there is rarely a forum for discussion. Each teacher shuts the door and "covers" material while an administrator stands by with a haggard look bemoaning the test scores. For another thing we have cowered down in fear of the courts as we see teachers victimized for having opinions. It is not ok to share your thoughts with students in this democracy. In this particular form of democracy one must keep it sterile and content-oriented. Students cannot know your worldview.

This year at HTI, what happened in our "Exciting Experiments and Ethics" group? Well we were all really civilized and orderly until the day somebody kicked off a debate over *Evolution vs. Intelligent Design*. Wow! The gloves came off and suddenly we needed a moderator whereas none was needed before. Our expert professor discarded the calm reason of intellectual fervor and became a magnificent, caring, red-faced (his blood was really circulating) proponent of evolutionary theory. He had a little extra oomph left over from a discussion he had had earlier in the week at a church social in which he and a friend had gone several rounds. I saw this and thought, "Our students need to be here."

They need to see these adults alive and alert and awake and caring a lot. They need to know that the condition of being human includes interchanges of this sort. In my home school, Sam Houston High, there are two gentlemen who often square off over lunch. I love to be in the lunchroom when they are talking because I learn so much. One is a liberal and one is a conservative and both of them know a lot of history so when they have their go-rounds it is always a learning experience for those who are listening. I rarely get a chance to interject anything into the discussion because I am not as well-read as they are, but I can always follow what they are talking about and I always enjoy the opportunity to be around them. I see their passion and it stirs something within me because I care about things too. From them, I am learning to care about things I did not formerly know about. I am watching them care and I am hearing the issues and I am thinking about whether I agree with one or the other or maybe neither.

Does it matter what the world is made of? Yes it matters a lot. Does our position on this issue affect anything? Yes. Let's see. I think it makes all the difference. Consider a world in which particles are colliding and bouncing off each other and that is the sum total of the story. Could we but calculate the future collisions we could know the future in great detail. Consider a universe in which particles as we think of particles don't exist. What about a universe where matter is just energy arranged a certain way?

What about a universe where non-particles bleep in and out of existence and act more like words than things? What effect could all this have on your worldview?

When we send kids to college we begin to lighten up a little but usually it is too late. The forums and debates are usually peopled by students who come from homes where discussion and debate were encouraged as a part of life. Our schools are social rites of passage rather than seething cauldrons of intellectual development. Our schools are boring because they are divorced from the questions people really care about.

It makes a big difference if we talk about John Dalton as one of the guys who made it into the text and therefore, he MUST be important so let's be sure to remember his name in case they ask us about him on a test OR if we talk about John Dalton as a guy who cared about what the universe is made of. And the reason he actually made it into the text is because he cared enough to do some experiments. He did not just sit and cogitate; although sitting and cogitating are big parts of science. He actually set up some situations in which nature could get a chance to enter the debate and have a voice.

What does the hydrolysis of water have to say about atomic theory? Well if you set the thing up fairly, you will end up with two parts hydrogen and one part oxygen, more or less. And every time you set it up fairly, without a bunch of extra variables, hydrogen and oxygen will appear in the 2-1 ratio. So, when atoms combine, they combine in definite ratios and that notion was an advance over the ideas Democritus put forward.

What other experiments could we set up that might help bolster the cause? Are there experiments that might militate against this notion? My email address is dcobb@ev1.net and I would appreciate any input from others who yearn to teach this way. I am tired of teaching any other way.

But for Dalton, as well as Democritus, the atom was a tiny, solid, spherical marble. And that is when J. J. Thomson said, "Wait a second. There is more to this story. That little solid sphere is not like any marble I know. In fact the particles streaming out of it are attracted to a positive charge. There is electricity going on here. I THINK the atom is more like a plum pudding, or in today's terms, a chocolate chip cookie."

You may not have the wherewithal to set up cathode ray tubes etc., but you can buy a box of chocolate chip cookies on the way to school at the grocery store. The cookies will help students visualize Thompson's idea of the atom. The chocolate chips would be the negatively charged particles, (the electrons), and the cookie dough could represent the positive mass he envisioned, until of course good ole Rutherford showed up with his gold foil and his alpha particles. (Tape some small magnets to the back of a piece of cardboard. Turn the cardboard over and slide some magnets along the slanted cardboard and watch the hidden magnet attract the seen magnet, a model if you will, of negative particles being attracted by positive particles).

Now you may not have any gold foil and you may not have any alpha particles, but what you can do is line up the chocolate chip cookies on a table right next to each other. Then, ask the students to predict what would happen if you drop a bunch of M&Ms onto the chocolate chip cookies. Most students will predict that most of the M&Ms will bounce right off of the chips and cookie dough thus arrayed. If Thompson was right, most of the alpha particles should bounce right off.

But Rutherford found to his surprise that most of the alpha particles went right through. Go to Home Depot and buy some plastic (or metal) chicken wire. Have the kids throw the M&Ms at the wire. Most will go through. So, which model: the chicken wire or the array of chocolate chip cookies?

Could the atom be mostly empty space? Not little marble-like spheres? Not chocolate chip cookies? Well, since he had invited the gold foil and the alpha particles into the debate and allowed them to have a voice, Rutherford had no choice but to put forward that notion. So now we have an atom with a tiny positive nucleus and a LONG ways out we have the negative electrons sporting around. Well, until Neil Bohr came along.

What did Neil Bohr do? He fired a bunch of energy into the atoms. The sporty little electrons got all excited. And, when they came back down to their original state, they did not give off the energy in a nice even continuum. Hmm.... Instead, the energy was released in discrete packets, or quanta. So Bohr said these electrons are not as innocent as Rutherford imagined – not at all. They are not just out there somewhere; they are in distinct energy levels.

To illustrate this, buy a cheap gumball machine at Wal-Mart – I own stock. (Just kidding.) Actually at Easter I found one at Kroger's that was shaped like a nice rabbit with sunglasses. Put the gum in the little machine and then point out that no matter how you get the gum out of the machine, even if you open up the lid and pour it out, the gum comes out in discrete packets, quanta, balls. You never get half a gumball. You do not ever get one long piece of gum. You get gumballs. This is the kind of data Bohr was dealing with.

Of course some smart student is going to point out that you are getting out what you put in. Explain that atomic theory is fueled by lab work that does not readily lend itself to the typical high school lab, you know, the one with drains that don't work and chemicals that were ordered last year but over the summer got hijacked by hyperactive roaches or something. And then of course since we can't get anything out of a system that we didn't put in, tell her she is schooled beyond her years. Or whatever, but talk about the discrete quanta and then let students chew if gum chewing is allowed in the interest of science. A better model which we also used was that of a chicken who lays eggs. Right around Easter when this question arose I found a wonderful little yellow chick at the grocery store who sang when pressed. I bought a bag of candy eggs and pointed out that no matter how energy enters the chicken, it comes out in discrete quanta called eggs. Chicks eat all day and they eat all manner of items but when the energy is released it comes out in the packets, the bundles we call eggs. I even brought two chicks to school at one point, and they were real little chicks, neither of which could lay eggs, due to extreme youth, and both of which squirted out energy in random gooey piles that could not be predicted. This made the chick from the grocery store with the song in his heart, the far better choice for a model of quantized energy.

Finally de Broglie is in the book. What was his contribution to the discussion? Well he pointed out that these minuscule negatively charged electrons, nearly massless as they are, cannot be put into a neat Bohr model. Why not? The Bohr model is wonderful and useful. We use it all the time to construct models so that we can see the electron configurations and predict bonding. There is nothing like a good Bohr model for looking at the polar nature of water, or the ionic bonding that occurs between a sodium and a chlorine ion. But, just because a model is useful, doesn't mean it is right necessarily.

De Broglie said that the solar system model of Bohr would not work because you could never truly locate an electron, not without changing it. What you could do, is you could say where it would most probably be and thus the electron cloud model of de Broglie shows where the electron could be at any given moment and also it shows where it would most likely be but it certainly does not show where it is. Now this is not a difficult concept. Anyone who has ever kept cows could understand this model very well.

Suppose you were to go to the pasture to retrieve your cow. Well, your cow could be anywhere in the pasture, but the cow will most likely be where the grass is thick and green. The cow could be standing high up on a rock but that would not likely be the case. The cow could conceivably be levitating and quoting a mantra but the probability of this eventuality is almost negligible.

So to let the students visualize de Broglie's idea, have them draw some lush tufts of grass on a large piece of white paper. Next have them design and cut out a small cow. Then allow them to move the cow around on the paper and discuss the probability of finding the cow in various locations. There is always that possibility that the cow leapt the fence and went to Soup-n-Salad. It is not likely but there is again a negligible chance. Which by the way, can affect your worldview, fundamentally. (I once had a cow who escaped the fence and came very close to having me fined for failure-to-contain. Living in a world where anything is possible is exciting sometimes.)

It is possible that some children will come up with a cloud model for the location of the cow, with the positive nucleus being the grass tufts that are attracting the negative cow electron. It is also possible that no children will come up with this model. De Broglie did, so he got into the text for contributing substantially to the discussion. Teachers could sit around making cloud models for the probability of their students coming up with a cloud model at all for anything.

Now these are not lesson plans, and yet they are lesson plans. It is useful to practice being and not being simultaneously so that you can be prepared for things that are particles and not particles, waves and not waves.

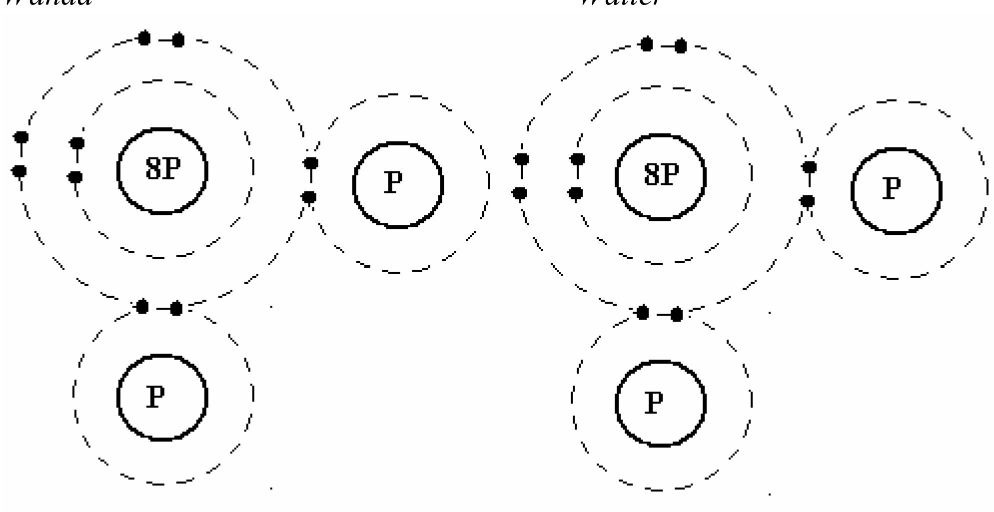
APPENDIX A

The Life and Times of Walter and Wanda Water Molecule
(Science Soap Operas)

Wow! I did not know that water molecules even have a life!

One day Walter and Wanda got too close to each other. They looked like this:
(Sometimes when you get too close to someone, things can happen.)

Wanda *Walter*



- electrons negatively charged

P protons positively charged

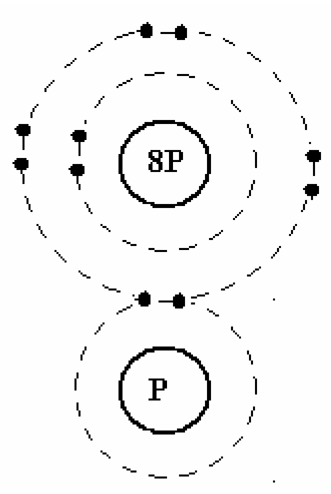
Notice here is the exciting part where Walter and Wanda are soooooooo…close together!

One of Wanda's little protons was feeling very attracted to Walter's oxygen end. The little proton was thinking, "You know, all of Wanda's 10 electrons with their negative charges are spending all their time circulating around Wanda's big positively charged oxygen nucleus. And I guess I can't blame them because I am just a single positive charge. What is my one positive charge compared to oxygen's eight positive charges? Wanda's 10 electrons are ignoring me. I'm lonely I guess."

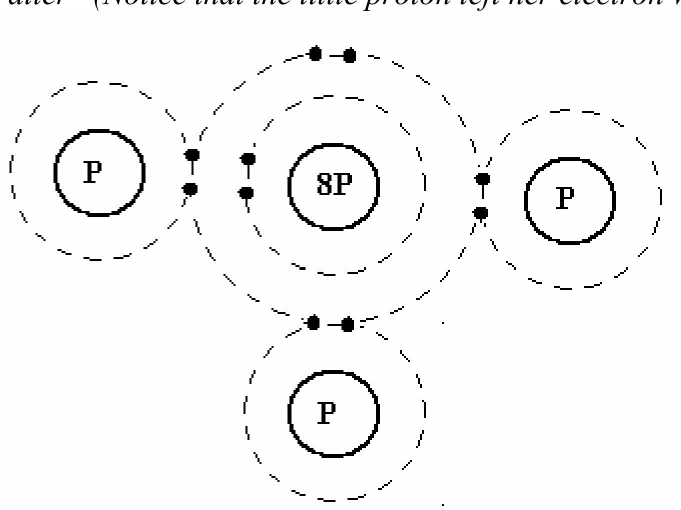
But Walter's oxygen end is so very attractive. All of his ten electrons are on his oxygen end too. Ten electrons circulating around only 8 protons? Wow, extra negatives. "Wow. I just can't help myself."

Then the unthinkable happened. The little proton (hydrogen) left Wanda (no hard feelings of course…all's fair in chemistry) and JOINED Walter. It looked like this:

Wanda



Walter (Notice that the little proton left her electron with Wanda)



Wanda got on the phone with her friend Woneesha.

Wanda: Girl! You aren't going to believe what happened to me.

Woneesha: What happened? Tell me!

Wanda: One of my protons got ripped off by Walter.

Woneesha: That's it? That's the big news? That's nothing. Happens to me all the time.

Wanda: It does?

Woneesha: Yeah. No biggie. You are fine. Check your outer shell. Is it still full?

Wanda: Let me count. 1-2-3-4-5-6-7-8. Yeah it's full.

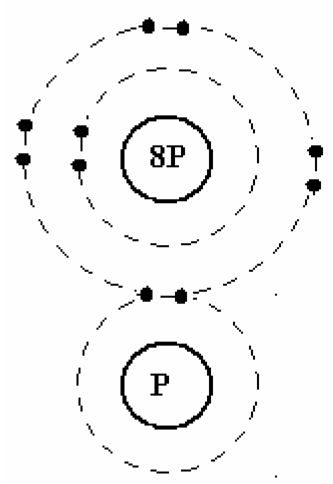
Woneesha: Is your hydrogen ok? The one you have left, does it still have two electrons in its outer shell?

Wanda: Yep.

Woneesha: Check your oxygen. Are there still 8 electrons available to its outer shell?

Wanda: Yep. The little proton that left me for Walter got so excited about Walter's negative end that he forgot to take his electron with him. Besides, his electron was ignoring him anyway. You know how attractive my big plus 8 oxygen nucleus is to little negative electrons.

Here is a close-up of Wanda. She is checking herself after the proton (one of her hydrogens) left to join Walter. She is now an ion because she has an unequal number of positive and negative charges, but she does not realize her new status as yet.



Woneesha: So are you ok?

Wanda: What do you mean am I ok?

Woneesha: I mean what I always mean. We are chemicals, remember? You know. Are your outer shells full?

Wanda: Well yes….

Woneesha: Then what's the problem?

Wanda: Well when that little positively charged proton left to join Walter's negative end, that left me with 10 electrons and 9 protons. I am not a neutral water molecule anymore. I have more negative charges than positive charges.

Woneesha: Been there. Done that. In other words you are charged! You go girl!

Wanda: It is making me act different. I don't know if I like this.

Woneesha: Of course you like it. What's not to like? You are an ion, a charged particle! Let's see…I think you even have a new name. You aren't a water molecule anymore. You are now a hydroxide ion. You are the kind of particle found in ammonia. You probably have an odor.

Wanda: Ammonia is a base. I don't want to be like ammonia. I don't want this for my life! I am not soap!

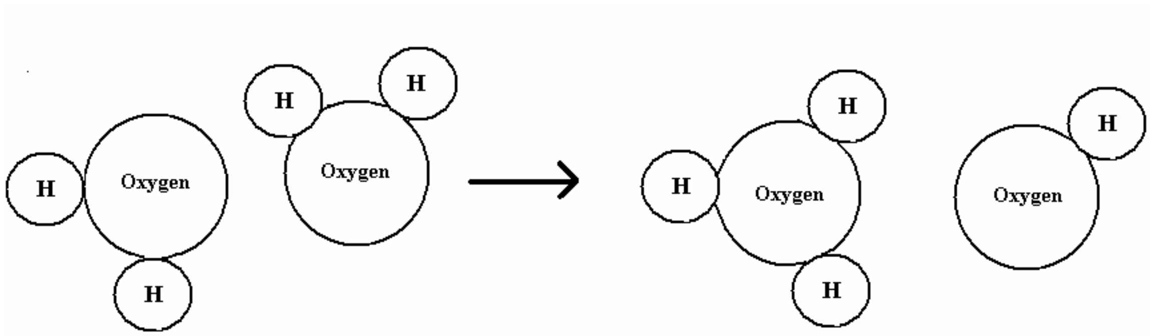
Woneesha: Oh baloney. You are a chemical. Nothing matters to us but our outer shells. I can't believe you are getting so bent out of shape over something so common as the ionization of water. Where did you come from, a polar ice cap? Are you fossil water or something? Regular water ionizes itself all the time.

Wanda: No. Seriously. I WANT to be water. Water is good. 70% of the human body is water. 75% of the earth's surface is water. Water is important. I like being water. I WANT to be water.

Woneesha: Oh well. Whatever. Don't get your electrons excited. Calm down, ok! You allowed Walter to ionize you. He is such an acid now. Ever hear of hydrochloric acid, HCl? Well that is the chemical in your stomach that breaks down food. It's a tough chemical. Walter is headed down that road. Meet me outside.

(They hang up.)

Here's a little diagram about what happened to W and W. In the self-ionization of water a proton (hydrogen ion) transfers from one water molecule to another water molecule. The result is one hydronium ion (Walter) H3O+ and one hydroxide ion (Wanda) OH-.



Wanda: We've got to stop Walter. Acids are terrible. You know that stomach acid can dissolve a penny don't you?

Woneesha: Oh please get over yourself. You are acting like a human for heaven's sake. Who cares? Besides, acids can be great. Orange juice is acidic. Lemonade is acidic. Vinegar is acidic.

Wanda: I wonder if Walter agrees with you.

Woneesha: Only way to find out is to find him and ask. Let's ask everyone we see if they've seen a dissatisfied hydronium ion.

Wanda: I can't stand to think of Walter as anything but a useful, neutral water molecule.

Woneesha: Hey Wesley. Seen Walter?

Wesley: Bumped into him earlier today; he was helping us dissolve some sugar, but I haven't seen him lately.

Woneesha: Hey Winona. Seen Walter lately?

Winona: Nope. Saw him a week ago in the bathtub but not today.

Wanda: We gotta find him. We just gotta.

Woneesha: Hey Wilbur, seen Walter?

Wilbur: Have I seen him, yes, I just left him. He's hysterical.

Woneesha: Don't tell me: he's a hydronium ion.

Wilbur: How did you know?

Woneesha: He ionized Wanda earlier today. Don't act like you never heard the term. You weren't formed yesterday. I'm sure you've ionized your share.

Wanda: Well (sob), it's my first time and well, I'm not very happy right now.

Wilbur: Yes, that first time can be traumatic.

Woneeshe: Yeah ok then Wilbur. We gotta keep looking for Walter.

Wanda: Hey look! There he is over there. Hey Walter, wait up a second. Come here. Look we gotta talk. I'm not the courageous type. I don't enjoy being different.

Walter: Sorry to hear that. I am enjoying being a charged particle. This is wild. It's hysterical. Man I am so positive about everything! Wow! What a rush! All the negative charges in the world are attracted to me. This is great.

Wanda: (*carefully*) Well . . . I'm negative and I am really attracted to you my dear. Come a little closer.

Walter: Whoa. What's up with you and this closer stuff?

Wanda: Trust me, you are gonna like this. Closer my dear. Little bit closer…
Walter: OK . . . what the . . . you are right…I like this.
Wanda: (*snatches her proton back*) OK Walter, it's over between us. I got what I wanted. I don't need you anymore. You are the weakest link I think. Later!
Woneesha: That's my girl. Spoken like a true chemical.

Additional Information about the Soap Opera

Costumes for this play were made by folding a large sheet of butcher paper and cutting a hole for the student's head and then drawing the Bohr model on the paper, life size, with the little proton being detachable and reattachable. Each team that presented had a costume designer, a narrator, a director and the cast of characters. We also left off the ending so that each team had to construct a scientifically defensible ending. The one given here was just one of several different endings created. The names of the ending writers have been omitted to protect the innocent.

APPENDIX B

Marriage License Application (Operation Think-Like-A-Chemical)

*Name*_________________*Symbol*____________*Atomic Number*______
*Mass*________*Group or Family Name*____________________________
*Number of Energy Levels (Period)*________________________________
*Number of Electrons in Outer Shell*________________________________

*Name of Chemical(s) you are proposing to marry*____
*Symbols*____________*Group or Family name*_____________________
*Number of electrons in the outer shell of intended spouse(s)*____________

*Once you have been united what will your name(s) be?*____
*Why do you want to enter into this bond?*___________________________
*List any previous marriages*____
____
____
____

*Signature of marriage official*_________________________

ANNOTATED BIBLIOGRAPHY

Philosophy

Duckworth, Eleanor. *"The Having of Wonderful Ideas" and Other Essays on Teaching and Learning.* New York: Teacher's College Press, 1996.
This student of Jean Piaget has written a book that might not make the No Child Left Behind people very happy. The notion that everyone understands the same way and that some have more smarts than others from birth onward is taken to task in this readable and helpful book. This reading will make you stop and think about the students you previously considered to be failures. You may end up wondering about how the criteria for success are determined.

Hazen, Robert M. and James Trefil. *Science Matters.* New York: Anchor Books/Doubleday, 1990.
When teaching science it is helpful to understand the importance of what you are doing. Science is not just another interesting course. It is not just a new vista. It has been and will continue to be even more so, a survival issue. In this book the authors argue the case for science literacy. They also strip away the math and the formulas and talk about science in every day language, which, of course, makes it sound attractive.

Meier, Deborah. *In Schools We Trust.* Beacon Press. Boston, Massachusetts. 2002
I would calmly assert that this book is required reading for everyone in America who cares about education starting with the President himself. As the front flap of the book states, "Deborah Meier believes fiercely that schools have to win our trust by showing they can do their job. But she argues just as fiercely that standardized testing is the wrong way to that end. And in the meantime, the tests undermine the kind of education we truly want." If you have a weak stomach and cannot tolerate the notion that perhaps everything we do in this country is not completely democratic, then fortify yourself before attempting to read this book.

Meier, Deborah. *The Power of Their Ideas.* Boston: Beacon Press, 1995.
This author, more than any other I have read this year while participating in the Rice Model Lab, is a revolutionary. Her thesis, which is that unless we train thinkers and questioners we are dooming our democracy to failure, is ably supported in the reading but I think the most helpful thing I learned from her is that children DO have ideas. If we nurture and help them question their ideas, we strengthen them. If we tell them things and expect them to memorize what we say, well, we hurt them and we hurt the democracy we are entrusting to them. She has written additional books, articles, pamphlets, and all of them are on the MUST READ list for teachers in America. Whether one agrees with Meier or not, there is definitely an obligation to form some kind of coherent response.

Rodriguez, Eleanor Renee and James Bellanca. *What is it about Me You Can't Teach? An Instructional Guide for the Urban Educator.* Arlington Heights, IL: Skylight Professional Development, 1996.
If you ever felt unimportant, then this is the book to read. If you even thought that your attitude and your performance might not impact kids, then read this. If you are at a loss as to how to reach kids more effectively, then read this.

Schneps, Matthew H. and Philip Sadler. The Private Universe Project. Harvard-Smithsonian Center for Astrophysics.
A series of films that have to be seen in order to be believed. Very powerful anecdotal evidence for the inefficacy of science education as it is currently practiced.

Sizer, Theodore R. *Horace's Compromise: The Dilemma of the American School.* Boston: Houghton Mifflin Company, 1984.
This is must reading for the educator who thinks that everything is A-OK. And it is comforting confirmation for those teachers who sense that something is terribly wrong. The comfort stems from the fact that the book is based on the findings of a major study of high schools. The evidence gathered indicated that there was a pervasive mindlessness in the schools so much so that they were almost relegated to the status of a ritual rite of passage rather than a rigorous and stimulating intellectual journey.

Science Reference

Hsu, Tom. *Integrated Physics and Chemistry*. MA: Cambridge Physics Outlet, 2002.
This text is the one we use in the Rice Model lab and it is truly wonderful. It has an entire set of equipment that comes with it including roller coasters, photogates, atomic models, circuit boards, etc. etc. It has everything you need to allow nature to enter the debate at all points.

Mc Laughlin, Charles William, Marilyn Thompson, and Dinah Zike. *Integrated Physics and Chemistry.* Glencoe/McGraw-Hill, 2002.
This text is the one we have for our school and it has some wonderful aspects to it.

Project CLEAR. Houston Independent School District. June 2004.
<http://dept.houstonisd.org/curriculum/>
The official organ of the HISD science program.