

Modeling Towards Answers

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INTRODUCTION

I teach in a medium-sized inner-city school. Most of my students are not financially well-off. Some are but most aren't. Most of my students hear Spanish spoken when they go home at night. The unit I am presenting this year, however, is one that would be a vital tool regardless of the demographics of any particular school. It would be appropriate for all secondary students, and since it deals with the process of science, it could be adapted to any science course being taught. I can even envision this discussion taking place in the lower grades as well.

In this unit I am attempting to take a step towards bringing students and science closer together. My hope is to relate to the normal human mental activities in a way that would cause science to be pulled from the back burner and placed right in the center of everything. By this I mean to say that most students do not spend hours each day leafing through erudite scientific writings seeking inspiration and fulfillment; in other words, it takes some carefully chosen learning experiences and some guidance to steer students to where the exciting action is – which is, in science. The goal would be to have students begin to fight over the latest issue of *Scientific American* with the same ferocity they might bring to the decision of who gets to read the fan magazines first.

...science as unfolding drama as opposed to science in the funny room that smells odd and feels strange.

OBJECTIVES

Texas Essential Knowledge and Skills (TEKS) for biology includes under scientific processes:

The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information. The students will evaluate the impact of research on scientific thought and society. The students will evaluate models according to their adequacy in representing biological objects and events. The student will research and describe the history of science and the contributions of scientists.

The above excerpt from the TEKS provides the framework for this unit. The role of the model in science is considered in depth while the other TEKS are touched on and integrated where appropriate. The discussion imbedded in this type of work can become a platform for material that might be deleted from the overall curriculum for lack of time.

For example, a discussion of viruses in the context of the origin-of-life models (presented in the background information) could be fruitful. The notion of exactly what constitutes life in the scientific sense is also a topic that could be drawn in. Various aspects of molecular biology, including the complex metabolic pathways, are easier to digest in action and could be a side benefit. As we prepare for the standardized testing, the more we are able to make connections and repeat (with perhaps a different slant), the more we are able to entrench the neural pathways that

allow students to remember science information and to be successful under pressure. This work can only enrich the students as they prepare for the standardized testing.

RATIONALE

In science we record what we see, touch, taste, hear, and smell. Limiting ourselves as we do to objective evidence does not mean that we cannot delve into questions that deal with phenomena that occurred a long time ago (which we, therefore, did not directly sense), or phenomena that might occur in the future. We can. For example, the question that absorbs the interest of many scientists concerns the origin of life on earth.

Origin-of-life researchers work with models of what they think happened based on what we know with a degree of certainty. Scientific models are essential tools in the process of science. A model is a mental construct that can explain the data we can observe and can predict the data we might find in future investigations. However, sometimes students do not understand that what they are learning in science is the best understanding at the moment, as opposed to absolute truth. In math class $2 + 2$ has been 4 for a very long time. It will continue to be 4. In social studies class, George Washington was the first president of the United States, and he will undoubtedly continue to be that on into the future. In English class the comma is used to separate items in a list, and that will probably continue to be the case.

Some things in science are like that, too. Acids have been neutralizing bases for a very long time and will likely continue to do so, as long as our planetary conditions remain within certain parameters. But in science not everything is like that. Even our understanding of what acids and bases are and how they interact has changed with time and with the acquisition of new knowledge. When change happens, it can have a startling ripple effect on not only our scientific understanding, but also on our philosophies and our ability to sustain a world view. That is why it is very important for teachers to be responsible in what they put forward as scientific understanding.

As we begin the year, regardless of whether we teach chemistry, physics, biology, or all three, we begin with the process of science. That would be a good time to instill in our students an appreciation for modeling and the role that it plays, as we search for answers to the questions we have. Some of our questions are big, like *How did life on earth originate?* And some are small, like *What are the dynamics of the close association of clown fish and sea anemones?* In the one case, we may see a long tortuous history while in the second instance the resolution of the model may take only a short while, months instead of centuries. In both cases, however, a good model leads to hypotheses that can be tested such that the results of the testing will either validate the model or force a change in the model to encompass new data.

A good model is predictive. It tells in advance what will happen in the laboratories and the field investigations of the scientists working to find answers. If the predictions of the model turn out to be incorrect, the model must be modified to fit new information, new data that fly in the face of the model and requires modifications so that the model can maintain its ability to describe and predict.

In some cases we elect to model because we have no other choice. We were not here when life on earth began, so we do not have the luxury of directly observing that phenomenon. If life flew in on a piece of rock during a bombardment, we would have to construct a model of how that might have happened and then allow the hypotheses that would flow from such a model to be tested in the field and in the laboratory. If the results (of our hypothesis testing) steer us away from this import scenario, then we might veer more towards the direct chemical evolution of the life processes, which are essentially chemical processes, occurring right here on the planet under the influence of the conditions that prevailed on a pre-biotic earth.

In this unit, students will be asked to take a close look at a model as it develops over time. The student involvement will end with where the model is in its life cycle at the present time. Students will also be asked to predict what the future holds, based on the model, for scientists working on the questions the model is designed to answer. Models are very much like living things. They are born and they live out their lifespan, which in some cases (such as the scientific origin-of-life model) seems to be almost without end in sight. They grow. They develop and they can reproduce, spawning tangential lines of inquiry along the way. Models are not static. They respond to stimuli in the social climate in which they are immersed. They use energy, especially during periods of intense argumentation. (After experiments are done and results are recorded, scientists do not always agree on what the data mean in terms of maintaining or modifying a model.)

In science, we are continuously constructing and modifying models. It is the mental/physical mechanism that allows us to address questions which a stricter adherence to the methods of science would preclude. With it comes the possibility of error and unsubstantiated extrapolation, a price well worth paying for the benefits accrued. In other words, even when models have to be totally discarded because the hypothesis testing proves them to be unworkable and useless, the model paid off handsomely if it led to new and more relevant testing, and if it brought the scientists closer to a tenable answer for the question being asked (or conclusively pointed them in another direction entirely).

Students in this unit will start with the birth of a model, which would include pinning down the person or persons who first put it forward for consideration. The initial question to be addressed and the initial hypothesis would need to be ascertained. Then the student would proceed through the historical development of the model including the major changes, growth spurts, and periods of quiescence. Students would need to be able to explain how the changes in the model occurred. A description of the “life changes” of a model would need to include the key experimental findings that caused a transition from one phase to the next. Finally students would predict the future of the model and what science might look forward to in future research if the model were to hold without modification.

Students will be given an example of the work that is expected of them, so that they can see what it would look like if a real live model spoke in the first person and told a life story. One is included here as background information for the teacher to consider.

UNIT BACKGROUND

An Autobiography of the Scientific Origin-of-life Model

I was, I am sure, at some point born...but to pin down the exact moment of my advent could be challenging. My given name is the Scientific Origin-of-Life Model and if you had to find a birth certificate in order to validate my existence, it might be hard to track down.

I do have ancestors, but not all of them bore the name of science. My most ancient forbears may have been oral traditions, as opposed to written records, but I like to claim Aristotle as my creator (Fry 15). He taught his students that the simpler organisms sprang to life, were spontaneously generated, from mud, slime, or even from air. He asserted that the higher organisms, of course including humans in that group, were born to parents. He was able to sustain this kind of duality because, to be honest with you, there were not that many people writing books about origins at that time, so opposing viewpoints were not widely recorded.

The good thing about my life when Aristotle was taking care of me was that his incredible reputation as a brilliant thinker shielded me from most of the critics who might have wondered about my validity. In fact, I had a fairly calm existence for almost 2000 years. In 1651, however, my life trembled a little. William Harvey published a book called *De Generatione*, in which he

put forward the notion that all life came from eggs (Fry 23). He moved away from the notion of spontaneous generation, except he seems to have held to the possibility of putrefaction being a spontaneous life event. This was more of a threat than I realized at the time because, of course, if all life came from eggs (the ovist doctrine), which are alive, then one could not escape the conclusion that life only comes from life.

Scientists began to argue this point. (A scientific model has to expect and endure argument.)

Johannes Baptista van Helmont (1580 – 1644) asserted that mice could be made by simply incubating a flask of wheat with old rags. He undoubtedly had experimental evidence to bolster this claim, but, of course, back then science was rather young and perhaps a little sloppy in the area of controlling the variables and closely monitoring the observation process (Fry 20).

In 1668 Francisco Redi did an experiment in which he actually had a control of sorts (Fry 20). His results were published as *Experiments on the Generation of Insects* in which he said:

I began to believe that all worms found in meat derived from flies and not from putrefaction. I was confirmed by observing that, before the meat became wormy, there hovered over it flies of that very kind that later bred in it. Belief unconfirmed by experiment is vain. Therefore I put a (dead) snake, some fish, and a slice of veal in four large, wide-mouthed flasks. These I closed and sealed. Then I filled the same number of flasks in the same way leaving them open. Flies were seen constantly entering and leaving the open flasks. The meat and fish in them became wormy. In the closed flasks were no worms, though the contents were now putrid and stinking. Outside, on the covers of the closed flasks a few maggots eagerly sought some crevice of entry... Thus the flesh of dead animals cannot engender worms unless the eggs of the living be deposited therein. (quoted from Singer 440)

Redi's work did not kill me, per se – it couldn't kill an idea – but he did provide a rather conclusive argument for the non-spontaneous generation of organisms that could be seen with the naked eye.

I have to confess that during this period I was handed around rather roughly from person to person. Gone were the idyllic days of hiding myself in Aristotle's shadow, dualistic but peaceful. (I was a happy model then.) What matter that later on Aristotle's scientific claims would not hold up under the scrutiny of rigorous application of the principles of scientific inquiry? Students learned me, and they probably wrote me on their tests, and I was right for the time. But...change was coming

It was Pasteur who left me flopping on the beach gasping for air. In 1859 a contest was sponsored by the French Academy of Sciences in which it was purposed that someone would devise an experiment that would either prove or disprove spontaneous generation as it was put forward in that time. You have to understand that Pasteur and his fellows were much like the scientists of today. They needed prestige and money for research so that they could pursue their passion which was and is...finding answers to questions. So when money and prestige were offered to the scientist who could definitively answer the spontaneous generation question, Pasteur took the bait and swallowed it whole.

The prestige he garnered from this work was far greater than he most likely imagined at the time. His name is in every biology text and has appeared on every milk carton for the past 150 years, and all because he devised a simple crook-necked flask in which he placed an organic infusion that was then boiled. Air could enter the flask and contact the growth medium but, without defying gravity, the unseen airborne microbes could not enter and grow on the proteinaceous contents of the open flask. Allowing air to get into the flask was crucial because the critics of Redi's closed flasks maintained that the "life force" was in the air and that having

completely closed flasks kept out the force necessary to trigger life. Pasteur's flask was also a variation on the experiments of Needham and Spallazani, but Pasteur is the one credited with bringing a definitive answer to the question of whether or not life could materialize from non-living matter. As a side benefit he provided convincing evidence for the existence of life forms too small to be seen with the naked eye (Levine and Evers).

(This happens. Scientists looking for an answer to one question simultaneously provide answers to other questions.)

After Pasteur, the notion that living things could arise through abiotic processes did not get much air time. Darwin postulated it as possibly happening a very long time ago somehow. Darwin thought that in the state of the contemporary scientific knowledge of the time it was pointless to even think about the origin of life (Fry 56).

Darwin did consider the subject in some of his letters. His response to the idea that a primitive life form was produced on the ancient earth as a result of various physical and chemical processes was his now famous expression, "But if--- and oh what a big if!"

In 1870, however, T.H. Huxley delivered a pivotal address to the British Association for the Advancement of Science. In this bold declaration, he put forth the notion of *abiogenesis* (the gradual and primitive development of first life on the early earth from lifeless matter). This notion is, therefore, different from the belief in spontaneous generation in the here and now, that is, the ability of researchers to produce life in the here and now from non-living matter. (Even after Pasteur there were some who continued to try to engender, chemically induce, bring together life-forms in the laboratory which of course is a goal still sought after today. That is one of the things that makes the understanding of models so exciting, because the scientific origin-of-life model predicts that at some point scientists may indeed produce life in the laboratory or find it being produced under special conditions discovered in the field investigations here and elsewhere in the universe.)

Needless to say this eventuality breathed much-needed life into me, and from there I was picked up and courted by some weighty and influential scientists.

If you are a scientific model, you have to be ready to be the subject of argument. Scientists test hypotheses, and they get results, but then they argue about what the results mean to the existing models. Do they validate the models or do they necessitate modification? Actual experiments did not help me along at first. In fact, until the 1950s, I was not formally the subject of experimental research. That, however, did not stop scientists from postulating, ruminating, and cogitating. This activity was not limited to a few scientists, but was instead the province of many.

In 1924, before the experimental work of the 1950s, two scientists separately wrote papers on the origin of life. The Oparin-Haldane hypothesis, as their work was dubbed, became very famous. Their idea of an ancient, rich primordial soup, teeming with the essential life chemicals giving rise spontaneously to primitive pre-life and then life forms were dismissed as *wild speculations* by many reputable scientists of the time (Fry 66).

Therefore, it took a while for their ideas to filter down into the textbooks. By the 1950s, however, scientists were beginning to devise tests and collect data based on their work. The most famous of these experiments, and the one that found its way into most biology texts, was a clever one based on the understanding at the time of what the prebiotic atmosphere was like on earth.

The contribution of Stanley Miller and Harold Urey was to test the Oparin-Haldane hypothesis. They were not the only ones who attempted to test the hypothesis, but their work was significant enough to find its way into school texts, which is the world as high school students experience it. Urey and Miller wanted to test Oparin's model because they wanted to find out

which chemical compounds could have been produced under the reducing conditions that scientists believed at the time were prevailing on the early earth.

Specifically, Miller built a sealed system of flasks and tubes in which water vapor was obtained by boiling an “ocean” of water. The vapor was transferred to a gas mixture containing methane (a compound of hydrogen and carbon), ammonia (a compound of nitrogen and hydrogen), and hydrogen, a mixture simulating a reducing primordial atmosphere. Electrical discharges (which simulated lightning) served as an energy source to drive the reactions. The products were cooled, condensed, and in some cases dissolved in the “ocean.” Miller repeated the steps for a week during which time the “ocean” changed to a reddish-brown solution. Ten percent of the carbon was converted to organic compounds (organic compounds are those which have two or more carbons), and about two percent of these compounds were amino acids, which are the building blocks of proteins (Fry 66-74). These results meant that amino acids, among the most important molecules in a living system, could have easily been formed under the conditions thought to obtain on primitive earth. This abiotic synthesis of compounds previously thought to be synthesized only by living systems was an important consideration for origin-of-life scientists. These were results that the scientific origin-of-life model would predict and fully expect to see more of.

Scientists all over the world began to experiment similarly with different compounds and different conditions, attempting to synthesize additional organic compounds. In 1961, Juan Oro at the University of Houston was able to demonstrate the abiotic generation of the nitrogenous base adenine, an important component of the nucleic acids DNA and RNA (Fry 81).

The Miller-Urey experiment and the work of Oro and others around the world were good examples of hypothesis testing, in that the hypothesis that organic compounds important to life, (amino acids, etc.) can be synthesized in a specific reducing simulated atmosphere proved to be correct. The results of this hypothesis testing were very important to origin-of-life scientists who were working to come up with a model that could be tested in the lab and in the field. As that process proceeded and tests were devised and carried out, and as more and more scientists weighed in on the question (geologists and astronomers included) it became clear that nothing was clear about the prebiotic atmospheric conditions. Even the primordial soup was gradually questioned. This did not in any way diminish the importance of the work done by Miller and Urey. It did not really even significantly change the model other than to begin to hone it and make it more specific. The model of a prebiotic chemical evolution of some sort was intact. From there it fanned out and was taken up for study by more people and a number of serious variations budded.

This is not an abnormal condition for a model. It is not unusual for a model to be in the hands of several scientists at once, even several scientists who do not agree on what hypotheses should be tested.

This is what makes the life of a model exciting. The work of Miller and Urey was a breakthrough. Because of them people around the world are watching me closely and are intensely interested because another event of Miller-Urey proportions could happen at any time. In such cases science becomes headline news: ***Scientists produce life molecules in the lab under primitive earth conditions!*** The model would predict that scientists in laboratories will come closer and closer to bringing about a primitive living system through purely chemical means.

The famous Miller-Urey experiment produced organic compounds under conditions that were assumed to be the atmospheric conditions on early earth. I have to tell you that this period of my life was the most hopeful since the Aristotelian days of my childhood. I was finally becoming a good model. A good model is one with solid backing from research in laboratories and field investigations. Regardless of what scientists now think about the Miller-Urey experiment, at the

time it opened new lines of inquiry and gave new validity to the Oparin-Haldane Hypothesis. 1953 was a very big year, not just for me but for biology as a whole. It was not just because of the ground-breaking Miller-Urey experiment (that touched off such a furor of excitement among origin-of-life researchers), but also because of the work of Watson and Crick (and Wilkins and Franklin), the discoverers of the structure of DNA, which then led to increased understanding of genetics in particular and molecular biology in general.

Scientists took encouragement from the work of Miller and Urey. Scientists around the world met in groups to discuss the major questions of science, and now I was a legitimate major question. There was a great deal of optimism that perhaps the understanding of how life began was near. The good part about this was that a lot of researchers (I only have space to mention a few) took me on in earnest and gave me much needed attention.

Sidney Fox (University of Miami) suggested a model that brought life together in three stages: first, the spontaneous production of amino acids à la Miller-Urey, second, condensing amino acids into protein-like polymers he called “proteinoids,” and third, the formation of “microspheres” (cell-like chemical arrangements) under certain conditions (Fry 83).

Fox argued for his model by pointing out the molecular “natural” selection that would take place based on the properties and structures of the various amino acids. There are little ones and big ones, positively charged and negatively charged ones, hydrophilic and hydrophobic ones. These variations in property would lead to natural preferred bondings (Fry 85); in other words, it would set off what we normally expect from chemicals. Chemicals are going to do the easiest thing from an energy standpoint, even if it burns down your house or blows up a building, or triggers a chain of events that result in lifelike arrangements. In this case the hydrophobic molecules would by their nature avoid water and the hydrophilic ones would cleave to water. The biggest positive charge would inevitably be the preferred destination for the negative charges, etc. Fox’s point is that chemicals follow the laws of chemistry, and the laws of chemistry could in and of themselves produce the arrangements necessary for life.

Oparin and Fox were, of course, constantly under pressure from groups of scientists who questioned the validity of the model as it was developing. There were the “protein people” (people who thought that probably proteins formed first), and there were the “nucleic acid people” (people who thought that nucleic acids had to form first so that a replication mechanism for the proteins would be in place so that reproduction of organic molecular systems consistent with the complexity in a cell could occur) (Fry 87).

In 1967 Sol Spiegelman (University of Illinois) put forward the virus model (Fry 97). He regarded the virus as an adequate model for the half-living systems in the early earth. We usually teach that the virus is a non-living chemical entity, because while the virus can reproduce, it can only reproduce by invading a host cell. It has no cell support of its own and most scientists define life as having at least one cell. Being sort of alive but not really alive, a virus had been considered by Haldane as a good example of the prebiotic earth in which some replicative entity is immersed in a soup (cell resources).

As more and more was learned about the prebiotic earth, it became clear that nothing was clear (Fry 112,113). Scientists argued about the atmosphere and the conditions because these questions were crucial in determining what kind of chemical evolution could be possible. And changing the texts to keep up with the research was a lengthy process, so even as I was changing, the texts were still giving the notion of the primordial soup in a favorable atmosphere as being the best knowledge of the time.

This disagreement about conditions was further complicated because simultaneously scientists were uncovering more and more of the incredible complexity of the metabolic pathways

within each cell, and so the likelihood of chance happenings producing such complex systems was called into question more and more. The more scientists learned about life, the more I had to explain as a model. I have to tell you I was stressed by this, and I also have to say that until this day I continue to be challenged to account for all that is being learned that pertains to me.

The complexity of the cell metabolic pathways was taken head-on by Stuart Kauffman of the Santa Fe Institute (Fry 156-162). After all, in IPC students are taught the Second Law of Thermodynamics. This is not a hard law to grasp if it is based on real life experiences. Left to themselves, things do tend toward disorder... randomness not order. High school students know this from their rooms at home. Unless energy is injected into the room system on a regular basis, the living area becomes messy, random, a homogeneous equilibrium of socks, shoes, papers, soda cans, and homework assignments.

Highly organized systems, like living systems, were once thought to be incompatible with the second law. Nobel laureate Ilya Prigogine put forward the notion of systems that spring spontaneously as ordered but as also being dissipaters of energy, that is, ways of spreading energy and randomizing energy from systems that sustain constant input from external sources (Fry 157).

Kauffman grabbed this idea for his origin-of-life model (Fry 157, 159). His thinking is not based on experimental data from laboratory research, but rather on mathematical and computer models (Kauffman 10, 16, 285). His ideas go a step beyond the thinking in which the earliest steps toward life were self-replicating molecules. In his view whole systems consisting of interactive catalytic polymers would autocatalyze. Whereas a self-replicating molecule, such as an RNA polymer, is a single autocatalytic unit, doubling itself in each replication cycle, Kauffman describes an autocatalytic set of catalytic polymers in which no single molecule reproduces itself, but the system as a whole does (Kauffman 285-288).

Critics of Kauffman doubt the likelihood of the formation of a catalytic set from a population of catalytic polymers. There is also the important question of whether the catalytic cycles he postulated can evolve or change over time. Manfred Eigen had already in 1971 looked at the question of whether or not an autocatalytic set of peptides could evolve, only to find that any change in the system would require a synchronized series of changes throughout the system to maintain the system (Fry 160). Critics aside, I have to applaud Kaufman for breaking with the traditional "replication first" models. To Kaufman, a living system is whole, and it evolved as a whole entity, as opposed to chance isolated chemical events gradually aggregating via favorable bonding, etc. His model, admittedly a mathematically idealized model, is nonetheless based on the real scientific requirements of living systems. If he is right, experimental evidence will follow, and he will be touted as a forward-looking and original thinker because his reading of the data sent him in another direction entirely.

Scientists who think about the results of experiments done by others are no less valid in their work than those who continually devise and carry out their own experiments. Sometimes great thinkers can view the same data others are also perusing and see patterns and connections that others miss.

Sometimes I sit and think about the days I had with Aristotle, and I long for the simplicity of those times. On the other hand I have to say that today I am more interested in myself. I am being tossed around by many different scientists at such a rate that I can hardly keep up with myself. It is all happening so fast.

And of course I don't exist in a vacuum but always in a particular time in history (yes, I am by all accounts now old). The philosophical implications of even asking the questions I ask are deep. The answers to the questions that spawned me are important to people. It is of the utmost interest to so many. Those who know about me are interested in me. They want to know the very

latest developments in my life history. Those who don't realize the drama inherent in my life story are missing a prolonged series of thrills. I have only related a few of them and the future is bright for many more to come. There could be one in the headlines today...

BACKGROUND (PEDAGOGY)

By now most educators have viewed the Private Universe tapes (see bibliography). When I was a resident at the Rice pH Model Lab, our director made sure we had a chance to absorb thoroughly the lessons of the tapes.

College students are interviewed at their graduation ceremony. They are asked to give the science answers to 6th grade level questions, like, *Why do we have seasons?* Shocking answers are at the 5th grade instead of the college level.

How could that happen?

How could students at the pinnacle of the American educational experience be ignorant of simple science content matter? Well, by the time students get to 6th grade and we begin to take their science education seriously, they have already tried to make sense out of their world. They already have an answer to many simple science questions, and some that are not so simple. And, their answers are usually based on their experiences, and the wisdom gleaned from their experiences has been molded into a developing world view.

There is little doubt that ALL students were at some point told the best science answers that are available. They probably dutifully memorized the material and passed tests on the material. Evidently they did not believe the material enough to incorporate it into their personal understanding of the universe. They held on to their own notions.

We, as science teachers, are left with the daunting task of not just telling (yell and tell) students what we think is good science. We have a responsibility to allow the students to engage in learning experiences that will help them change their thinking.

We could avoid having to do this unit by simply saying to our students, "In science we use models to help us uncover the answers to the unanswered questions we have. These models change as more data are collected in experiments about a specific area of inquiry. As we test the hypotheses that flow from these models, our understanding of the universe changes. That partially explains why we had to buy you an expensive new textbook this year. It will also be on the test Friday."

Then on Friday we could pass out an exam. If they pass it, we could say that they learned the material. Or we could give a more telling test. We could wait until they are graduates from college and ask them again. If that is the test we want them to pass, then we need to make sure that the learning experiences we plan for them are life-changing, fascinating events. We must make sure that the learning environment is in-your-face chock full of objective incontrovertible evidence that will convince them of the validity of what is being taught.

You've heard the saying, "You can't understand until you have walked a mile in my shoes." In this unit we are asking students to get inside the skin of a scientific model and see how it feels on a day to day basis. Instead of saying that models change, we are allowing them to experience the changes, to trace them through time in the first person, to read the actual accounts of the ins and outs of the discoveries as they happen in real time. Viewed from this angle, it would be hoped that understanding the development of a model would not be a simple matter of answering a test question but would become a life experience that would not soon be sloughed off.

This unit would take time, maybe a whole week or more, but it would pay off by giving students an understanding of how content in science is born and how it develops. Students would have a more realistic grasp of what science is as an endeavor. It would portray science as a

journey instead of a destination. It would whet the student appetite for more, the next episode. It could conceivably result in a lifelong interest in the quest for answers.

Models are put forward by people. People are the stuff of which scientists are made. Students are people. As such they qualify for a place in science. Science is a uniquely human endeavor. Finding ways to encourage them to care about and participate in this part of being human is the province of the teacher.

People occur at specific times and places in history. People are immersed in the social, political, and philosophical moment. This human element in model-generation is important and students can understand it if we talk to them about it. If we artificially pluck the model from its native environment, trot it into the laboratory and surgically dissect it, we will understand it at one level but never in the fullest sense. It will never have the human interest factor, the excitement our students long for and deserve. It will never be a human story. It will never be alive.

(Find that student who begs you to bore him with dry, inanimate teacher talk. He cannot be found.)

LESSON PLANS

Lesson Plan One

In this lesson students will be engaged by handing out a brief test. Depending on the subject matter in the class, the questions should include science information that has changed over time (which would leave the field pretty wide-open, since science is constantly changing and rewriting itself.)

For example the test could have two questions:

1. What are the basic building blocks of matter? _____
2. Draw a diagram of the protons, electrons and neutrons within a carbon atom. Label any movement that might be predicted within the atom. _____

Immediately collect the tests and look at them right then and there. Start observing the answers to questions and start commenting. Hopefully someone will have written *atoms* as an answer to number one. You could then say, "Well, if you were a student of Democritus in 400 B.C. or even John Dalton in the 1800s, you would have scored well on that answer. In fact, however, scientists no longer believe that atoms are the basic stuff of matter....not even the protons and neutrons that make up the atoms are considered to be basic." How do scientists currently answer this question? How has the model for this question changed over time? Encourage students to contribute what they know, including questions they may have from the Discovery Channel presentations on this subject.

When dealing with the second question, allow students to say what they may know about the model. If the students draw the Bohr model, explain that while that model dominated the scientific scene for a period, it has been replaced several times over with models that include new data and new thinking. You could mention Albert Einstein's frustration (God does not play dice!) with the electron that cannot be pinned down to a definite mass and location simultaneously but rather must be shown as a probability. You could talk about the difficulty mentally of encompassing the development of a strictly Newtonian framework for explaining physical phenomena and then having to add in the tenets of quantum mechanics.

If you are teaching biology, students will likely come to you with IPC (Integrated Physics and Chemistry) on their minds and, of course, the history of atomic theory is taught in IPC. If this discussion takes place in a biology class, it should be greatly aided by what students remember from the previous year's physics and chemistry content.

Talk about modeling in science and explain that in order to understand more fully the role of modeling in science, each student will pick a model and write a narrative in the first person, bringing the model to life.

Assign the reading of a handout in which the assignment is *modeled*. Teachers can use the one included here as background information or come up with their own examples. Writing these narratives is fun, and it is a stimulating learning experience. Alert the students to the fact that the writing of a narrative can be done more easily now than in the past because of the role of the Internet in finding information. Caution them against sites that are not based on science. Remind them that the textbook is an excellent source, and the library is also an effective reservoir for information.

Students will select a scientific model that is of particular interest to them. The model will be researched, and then a first person narrative will be written from the point of view of the model. Assign reading and searching as a key element in selecting a model. In researching the origin-of-life model, a number of other models came to light.

For example, William Harvey, in addition to being a key player in the origin-of-life model, was instrumental in dramatically changing the model for blood flow and blood distribution in the body. While it was previously thought that blood was continuously generated in the liver throughout the day, his careful measurements of actual blood flow through the heart proved that the liver-as-generator model would have placed a 540 pound blood-generation demand on the liver on a daily basis. His model of continuous flowing and recycling of blood through the heart was an advance in understanding, but he never was able to extend the model to include how the blood was able to pass from the arteries to the veins, lacking as he did the delicate sensing devices necessary for elaborating the tiny capillaries. This point will likely be made over and over again, as students realize that the limits to our ability to sense data are what limit our ability to extend and test models. Gary Zukov in his book *The Dancing Wu Li Masters* (physics after Newton in lay terms) probably said it best: "The universe is not only stranger than we know, it may be stranger than we can know with the five senses" (Zukov 98).

Biology teachers may want to limit the models to life science, but that would not be necessary since biology teachers have to review IPC material for the TAKS test. Review within the context of discussion is usually more effective.

Lesson Plan Two

In lesson one we introduce students to the idea of change in science:

In lesson two we assign them two tasks. They must pick out a model that interests them after researching a number of models. The teacher could say, "Remember, you will be spending a lot of time with this model so be sure to find one that appeals to you strongly."

It can be a model that is no longer a model but rather essential scientific content (the Krebs cycle for example), or it could be a model that is still alive. It could be a model that attempts to answer a big question or a model that attempts to answer a question of limited scope.

Teachers would have to have input into this vital step, so that it could be ascertained whether or not the work would be helpful to the rest of the TEKS being taught and whether or not the resources would be available to carry out the study. In addition this step could be heavily exploited because as students searched through texts and websites, the question of whether or not a scientific model was in place for the answering of various questions would stimulate some good discussion. Is the case closed or should we leave the door open for future discoveries? For example: a question of great interest to most people is the question about cancer. How does it

happen? Why does it happen? Can we find better treatment, and eventually can we beat this class of diseases entirely as we have other illnesses?

In this instance there would be room for some model closing. Some of the work that has been done in cancer research seems to be pretty conclusive, but as we learn more and more about the biology of the cell, could it be possible that some of the models (based on old information and data) might need to be reopened in the light of new information? Again students can only benefit from the discussion surrounding this part of the lesson.

Having picked the model, it would be time to try to pin down a birth date using the example given in the handout, which would mean finding if possible a scientist or group of thinkers who first put forward the model. At this point it would be organizationally helpful for the teacher to have on file a form for each student. Inevitably the question will arise as to whether or not two students can research the same model. I might say *yes* to this, but I would definitely say *no* to group work. More learning will occur if each student brings his own interest to the subject. When I was reading Fry's book for the origins model, I picked certain scientists and not others. Another person might have been drawn to the work of different researchers. Having two different takes on the same model would provide for extremely interesting discussion. A limit would need to be set for the size of the autobiography. Teachers may want more or less at each step... the birth phase, the change phase, and the predictive phase.

The form might look something like this:

Student Name _____

Name of model chosen for study: _____

Birth date of model: _____ Progenitor(s) of model: _____

Resource materials for use in learning about the life of the model:

End date for model: _____ or Model still alive and well. _____

A byproduct of this unit would undoubtedly include many opportunities for learning on the part of the teacher. Each life history done by students should be buttressed by a list of websites and bibliography.

Lesson Plan Three

In this lesson we would put forward at least one instance in which the model went through a major change. For example the origin-of-life model changed from spontaneous generation in the here and now (heterogenesis) to the notion of abiogenesis, in which scientists first began to see the possibility of a purely chemical precursor to life.

Another example is the circulation model of William Harvey, when the notion of blood originating in the liver continuously was replaced by the conclusion that a set volume of blood was continuously recycled through the body.

In this lesson, teachers could ask students to devise tests (and provide keys) appropriate for different times in history to show the changes in models. These tests could be *modeled* after the one given to the whole class in lesson one in which the answer to the question concerning the basic stuff of the universe could be answered correctly but differently depending on the particular

historical conjuncture. This would be a way for students to directly involve themselves in the understanding of change in science and what it means for students in the classroom.

Lesson Plan Four

This work would include an assessment of where the model is now and what its future prospects might be. Again using the example of the background treatment of life's origin handed out in the first lesson, we could note that the model may not have a straight-line development from its inception until now, but that the developing life of the model was faster and slower depending on the state of science in each historical period. Future research should see (if the origins model holds) more and more work similar to the Miller-Urey breakthrough, in which the processes of life can be produced all or in part under simulated conditions. The origins model is at the moment being pulled in several different directions, but the overall model of abiogenesis is alive and well. For most scientists the Miller-Urey experiment is now dead, as in, no longer the beacon of hope it once was: showing students the old texts in which Miller-Urey is much touted as the wave of the future, and then showing them today's texts in which Miller-Urey is placed in its historical context as important for the time, but science has moved on.

At all stages students would be expected to share with the class the various stages in the life of their chosen models. It might be fun to have a birthday celebration complete with a cake and noise makers to commemorate the birth date of the models, and perhaps a memorial (commemorative) service for models that may have already been laid to rest. A great deal of science could be taught in the process of students getting to know each others' models.

This process of pinning down subjects in science that are of particular interest to individual students would be an excellent lead into having students pick their areas of research for the science fair later on in the year. During science fair students don the shoes of science and ask questions that have not been answered. They have to find a question they are interested in answering and they have to determine its history. They have to find out what is already known and what work has been done. The process of preparation for science fair is very similar to the assignment being put forward in this unit.

SUMMARY

The purpose of this unit is to explore the type of knowledge we get from applying the scientific method and to identify its attributes and its usefulness as outlined in the TEKS. In the context of carrying out this unit, students would be encouraged to think freely and discuss fully the hypotheses and theories of science as they actually arise in the course of history.

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During my residency at the model lab, we read books by Debbie Meier, and they are life-changing. (To order the books go to <<http://www.deborahmeier.com>>.) You will not be comfortable with teacher business-as-usual after reading these excellent resources:

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Nonie Harcombe is the mastermind behind the model labs in HISD. She is retired now, but before retiring she wrote some of her wisdom down in a book that will keep you turning the pages. Copies can be obtained by emailing her at nonie@rice.edu.