TABLE OF CONTENTS

PREFACE

You can know the name of a bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird... So let's look at the bird and see what it's doing — that's what counts. I learned very early the difference between knowing the name of something and knowing something.[1]

- Richard Feynman

HOW LAKEETA CALCULATES THE VELOCITY OF A CAR MOVING WITH VELOCITY 9.5 M/S

It was a great struggle getting my high school physics students to turn in their homework, even when I asked simple, rote questions. It was an even greater struggle when I asked challenging, contextual questions. "It is too hard." "I tried, but couldn't do it." "What homework? I didn't know there was any homework." I gave everyone more and more time, more and more chances, and more and more help and hints. I was available to anyone who wanted extra help any time. The homework was an important part of their grade for the class. Almost all my students wanted to pass and here were some easy points. It was confusing to me why so few submitted their homework. There appeared to be little investment and certainly little success.

Recognizing the need to get the students going and on board, I made the homework easier and easier, more like the "fill in the blank" type that they were used to. In other words I pandered. I lowered academic standards.

Eventually, partly in frustration and partly to make a point, I decided to include the following question (verbatim) as one of the problems:

A car moves with a constant velocity of 9.5 m/s. What is the velocity of the car?

I wanted the class to see that they should read the question, see what was right in front of them, and understand what is being asked. On an intellectual level, I thought that I could convince everyone that they could get started on problems by reading them and thinking about them. On a practical level, I thought that everyone could get some credit on the homework and work towards passing. I was therefore disappointed when few students submitted the obvious answer to the question about the velocity of the car.[2] Like many other first year teachers, I blamed the kids, the school, and the families. Most of all though, I blamed myself.

---

1 Feynman, R. (1969). What is science. *Phys. Teach.*, *7*.

2 9.5 m/s.

Lakeeta was an average performing student. All year I had to point out basic rule infractions (such as eating or texting in class) to her. She let me know bluntly that she did not like to be told what to do. Whenever I asked Lakeeta a physics question to try to get her to understand something, she reminded me that I was the teacher and that I should be giving her answers, not asking her questions. I found humor in my relationship with Lakeeta. I think we both enjoyed our banter and we got along okay. Despite her requests, I never stopped doing what I thought was best to try to get her to succeed. In return, she never stopped eating, texting, and grumbling.

Lakeeta was not very inquisitive about the subject matter and did not seem to care about learning physics, but she tried to get all of her homework in and wanted to pass the class. Like many of my students, she was a product of the system. To her, homework (and class work) was a means of accumulating points. If she looked beyond her report card grade at all, it was about being able to do what she thought was important to prepare for the end of year culminating state exam. To her that meant being told what she had to know. It meant being given the explicit procedures needed to answer the questions. I pleaded with Lakeeta explicitly and implicitly to work towards meaningful understanding of science. I tried to teach her that this was critical to real success. This was foreign to Lakeeta.

One way or another, Lakeeta was able to do much of her homework without me every time, but she sought me out for the problem above about the car. This was the one troubling her. She came to extra help. "I could not do this one because I do not know which formula to use."

Lakeeta solved her homework problems with strategies that I saw my college physics students use. Which formula had the matching symbols? Which of the problems in the book had comparable surface features? Lakeeta was not alone in her confusion. Lakeeta's struggle with the car question was not a quirk or an exception. It was a representative outcome of the way many students approached learning in school.

I asked Lakeeta to read the question back to me. She did, albeit with a little attitude. I just looked at her quietly, knowing that she would get annoyed at me. She did not disappoint. After a pause I asked her to read it again, but asked her this time to pay attention to what she was reading. After a short time, she smiled at me. Apparently she understood, both the problem and my point.

DIARY OF A SABBATICAL

As a college professor, it is common to take a sabbatical to travel, write, or research. I spent my sabbatical year as a full time public high school science teacher in a poor neighborhood in New York City. Many colleagues reacted with amazement. Some reacted with horror. Almost all expressed admiration and respect.[3]

For more than 20 years, I have been a physicist and a science educator, primarily at the college level. My research is on understanding and improving the learning of science, from elementary school science through quantum physics. Since 1999 I have been Professor in the School of Education and the Department of Physics and Program Director of Science Education at City College of New York (CCNY). In that time I have had the privilege of working with hundreds of K-12 students, with over a thousand science teachers in and around New York City, and with even more college science students who are graduates of the city school system. I wanted to improve my ability to work with all these groups. Choosing to spend my sabbatical where the rubber meets the road was an easy decision.

In the following 12 chapters, I give a diary of my 12 months away from being a college professor. Anyone who teaches high school science, particularly in an urban setting, will likely recognize the accounts as unsurprising. All of these examples, stories, quotes, and data are genuine and representative, including what I wrote about Lakeeta. However, to present 12 critical themes of science education coherently by chapter, I have shifted some of the chronology around. I have also added experiences from the college level and from other K-12 schools in which I have taught, worked, or volunteered. For obvious reasons, I have changed some details which have no bearing on the substance of the accounts. For example, all names are pseudonyms, usually (although not always) reflective of the gender and race of the person. Minor other changes have been made so that schools, students, and teachers with whom I have worked are not readily identifiable.

PERSPECTIVE

When discussing education, everyone brings a perspective which colors the way events are interpreted. I am no different. The above quote by Richard Feynman, a renowned scientist, educator, author, and Nobel Prize winning physicist, is revealing of my perspective. So are the quotes at the beginning of each chapter by other great scholars, scientists, and cultural figures. Each quote ties to the theme of the chapter.

Instructional strategies described in and after each chapter are also revealing of my perspective. In particular, I have frequently used the curricula of Prof. Lillian McDermott and the Physics Education Group at the University of Washington, which I consider exemplary.[4] With these curricula, students are actively engaged in activities where they build a functional understanding of the subject. Instructional

---

[3] I wish that admiration and respect would be given to the many wonderful teachers who do this every year. I wish that this admiration and respect would then be translated into meaningful support, resources, and ongoing professional development.

[4] I had the privilege of working as part of this group as a postdoctoral research associate from 1992-1995.

strategies are based on what is known about how students learn and address specific difficulties that students have.

Most of all, my perspective is that the very highest academic standards and accountability need be paramount. Any policy that compromises high achievement of students must be reconsidered. I make no secret of my worries about recent and current trends in education which come under the banner of "standards" and emphasize "high stakes testing." My observations as well as my systematic research have created a perspective that these trends are functionally moving students towards rote and authoritarian learning. I see a focus on a limited view of math and literacy and no meaningful emphasis on science and reasoning. I see results completely counter to high academic standards and accountability. I see what is happening in education as problematic. I see doing nothing about it as worse.

Despite my perspective, in this book I have avoided the oft-cited phrase about American education being a "mile wide and an inch deep." I have also avoided the "research has shown," "in the published literature," and "statistics indicate" approach to writing. High quality research is paramount in meaningful educational reform. Unfortunately, too often I have seen these phrases point carelessly to data which are subject to very different interpretations. These phrases are therefore often followed by conflicting perspectives, depending on whatever point the author is trying to make. So instead I have elected to make this book a narrative of my specific experiences and my direct interpretations. *All* of the experiences and interpretations are representative of what I saw on sabbatical and what I see in education today. They are genuine and real. That said, research has shown that my interpretations are consistent with what is prominent in the published literature and statistics indicate that students learn better when using the instructional strategies which are in opposition to the mile wide and inch deep approach.[5]

MATTHEW, RUSSELL, MAKENZIE, AND LILY

Matthew, Russell, Makenzie, and Lily are the only children names in this book that are not pseudonyms. They are the real names of my own children. There is so much that I want for them, some of which relate closely to my work. With respect to my sabbatical, it was particularly exciting to me that my oldest child Matthew was simultaneously taking the same standard New York State high school physics class that I was teaching (in a different school).

At various times, I have heard from one (or more) of my children that when they grow up they want to be a doctor, engineer, executive, judge, lawyer, military officer, pilot, scientist, and teacher.[6] In none of these professions is the training that Lakeeta is used to helpful. These professionals do not work in isolation on de-

[5] In other forums I follow a careful research paradigm. I share detailed findings and compelling interpretations built on work of other scholars and researchers. My work, and that of so many others, unambiguously inform and support the main ideas which are presented in this book.

[6] Curiously, I have never heard professor.

contextualized short answer problems with no access to resources of information. Rarely in these professions would there be reward for identifying the technical name of something not understood or for plugging numbers into an obscure formula which might or might not be relevant. Instead, these professionals work as part of a team on meaningful, complex problems while skillfully navigating through vast amounts of diverse information. Rewards come from being able to think critically and communicate skillfully.

The training that Lakeeta is getting is not helpful. In my opinion, it is actually harmful. And my concerns about a poor education are not tied to career choice for Lakeeta. When I think about what preparation leads to a good doctor, engineer, executive, judge, lawyer, military officer, pilot, scientist, and teacher, these are the same skills that benefit workers in all arenas. They are also skills of value for customers and merchants, voters and politicians, friends and neighbors, and just about everyone else.

I do not think about how the *perception* of education can be improved as my children go through their school years, I think about how education can *really* be improved. My year in the high school, coupled with my long and diverse related work, has given me insight into the way things are and the way things could be. When I think of failings in education and how to fix them, my children's welfare is a strong motivating factor.

FORMAT OF BOOK

In Part 1 of this book, I describe the beginning of my sabbatical, before teaching in the high school. I give a summary of a summer program for high achieving New York City high school students. In this program it is evident that even the best and most motivated students are not learning science in their schools. However, after they experience a very different learning environment, it becomes clear that real learning is possible. This summer program explores goals of science education, serves as a motivation for much of my work, and frames the rest of the book. Also in Part 1 I describe other relevant motivating experiences. These include teaching college physics, working with high school science teachers, and my own formal preparation to become certified to teach high school science in New York City. I use all of these motivating experiences to present my perspective on what is meant by inquiry.

In Part 2, the chapters each describe a month of my teaching high school during the school year. Each chapter delves into a theme in education largely through presentation of vignettes, such as the one about Lakeeta. There are examples where student performance is alarming. There are examples where educational experiences are exemplary. In total, the chapters reveal my sabbatical experience teaching in the high school.

In Part 3 I both look back and look forward. I reflect on my sabbatical and what I would do differently if I could do it all over again. I relate what I learned to implications for teacher preparation, science education, and systemic change. I also describe how the community of science educators needs to keep the conversation going and move towards education reform.

At the end of each chapter is a reflection on the chapter theme. There is a section called "Strategies that work." This is a discussion and sample instructional strategies, curricula, and assessments related to the chapter theme that science teachers can use to promote more authentic learning. Finally, there is more on the quote at the beginning of each chapter.

ALTERNATIVE BOOK TITLES THAT I CONSIDERED

In case you are still not clear of what to expect in the remainder of this book, here are a few alternative titles that I considered before settling on the one on the cover:

An inquiry into education, where the rubber meets the road

The complete idiot's guide to not creating a generation of complete idiots

Your child left behind

Race to the top of what?

Solving all of the world's problems through improving science education in order to teach future generations to think and reason intelligently

GRATITUDE

I am indebted to the many wonderful people who supported the work that led to this book. In particular I thank the dedicated principal at the high school in which I taught and his amazing teaching and support staff. I was fortunate to be at such a wonderful school. I am also grateful to CCNY for continuously supporting my work in science education. Most of all, I am grateful to every student with whom I have ever worked who at any point was open to trying to learn or able to teach me. There is no doubt that they are the reason that I love what I do.

With respect to the writing of this book, I am grateful to many friends and colleagues for discussions, suggestions, feedback, constructive criticism, and other support. These include Greg Borman, Sebastien Cormier, Beverly Falk, Adiel Fernandez, Joel Gersten, David Hammer, Takoa Lawson, Federica Raia, Joe Redish, Issa Salame, Waylon Smith, Ken Tobin, my parents, and two sons. Most of all. I thank my wonderful wife Liz for her unending support and encouragement on this book and for everything else in my life.

PART I

SETTING THE STAGE

A motivating summer experience

CHAPTER 1: JULY

THE SUN GOES AROUND THE EARTH

Goals of science education[1]

> *Since the mass of pupils are never going to become scientific specialists, it is much more important that they should get some insight what scientific method means than they should copy at long range and second hand the results that scientific men have reached. Students will not go so far, perhaps, in the 'ground covered,' but they will be sure and intelligent as far as they do go. And it is safe to say that the few who do go on to be scientific experts will have a better preparation than if they had been swamped by a large mass of purely technical and symbolically stated information. In fact, those that do become successful [in] science are those who by their own power manage to avoid the pitfalls of a traditional scholastic introduction into it.*[2]
>
> *- John Dewey*

JULY 31: TEACHING IN THE SUMMER SCHOLARS PROGRAM

July 31 was near the end of the Summer Scholars Program, my last activity at the college before going off to my sabbatical teaching assignment in the high school. All of my students were so enthusiastic and engaged. This was a real turn of events from the beginning of the summer. The students were experiencing a very different learning experience and by the end of July genuinely enjoyed it. They also recognized the contrast of the program with the way they typically learned science in their schools.

Every summer for the previous seven years, I taught in this program at City College of New York. It is for students from New York City who just finished anywhere from ninth through eleventh grades. The program is academically selective. Admissions requirements vary slightly from year to year but include a minimum of a B average and a letter of recommendation from the guidance office. Many of the students are from specialized high schools. Most are academically very successful. All have elected to spend their summers studying science.

---

[1] The research presented in this chapter and the assessment of results are described and documented in detail at: Steinberg, R. N., Cormier, S., & Fernandez, A. (2009). Probing student understanding of scientific thinking in the context of introductory astrophysics. *Phys. Rev. ST Phys. Educ. Res.*, *5*, 020104.

[2] Dewey, J. (1916). *Democracy and education*. New York: The Free Press.

Like other summers, there were about 20 students in the science cohort. They met 4 days per week for 6 weeks starting right after their high school year ended. A total of 4.5 hours per day was formal class time divided equally between a chemistry class and an astronomy class. Both were delivered in the same spirit. The astronomy class was mine.

Curriculum and instruction were not predicated on covering a prescribed body of information or teaching towards a standardized test. We took this as an opportunity to focus on the scientific process. We focused on depth of understanding of an accessible scope of content. This is in contrast to typical high school science instruction in New York City – and most other places. The contrast resulted in a great culture shock for the students. In school they were accustomed to (and skilled at) succeeding on curriculum and assessment which focuses on memorized facts, prescriptive problem solving, and multiple choice / short answer exams. This class was different, very different.

Observational astronomy is a rich context to exercise student thinking about science. How do you know that the moon goes around the earth or that the earth goes around the sun?[3] How is it that some of those bright dots in the sky (*all* of which seem to revolve around the earth daily) are distant stars but others are planets going around the sun?[4] Models of the universe are not developed simply or directly from observations. They need to be reasoned inferentially from extensive observations, integrating multiple domains of mathematics and physics. It is one thing to state the answers to these questions. It is something very different to be able to understand the nature of science and scientific thinking that underlies how one comes to know the answers. In my astronomy class, students were not told the answers to these questions. They had to answer them on their own.

Due to the nature of the program and the dispositions of the instructors, classroom atmosphere was comfortable and open. Students were encouraged to question, challenge, discuss, and have fun. Nevertheless, the majority of students began the summer clearly out of their comfort zone. They needed to be given a great deal of prodding to provide reasoning, to negotiate what they were doing with each other, and to defend the arguments they made. They readily admitted to seeing a science lesson as a body of information to be provided and written down. They were surprised that we prodded them into figuring things out for themselves instead of just telling them answers. Of course we were there to help them and guide them, but not to do it for them.

As the summer progressed, most students grew increasingly comfortable with the nature of the class. Their skills with working with each other to answer their own questions increased. After repeated practice, they learned the difference between knowing something because they had been told it to be true and knowing something because they understood (and had often executed) the steps

---

3 From observation, it looks very much like the sun goes around the earth each day.

4 In a given day, planets appear to move nearly identically to stars. One certainly does not "see" them go around the sun. The leap to the conclusion that planets go around the sun is a big one.

that underlie the idea. By the end of the summer such practices were largely self-directed, typically with pride and self-awareness.

"PROVIDE A COMPLETE SCIENTIFIC ARGUMENT"

Early in the first day of the program, even before the course was defined, the question shown in Figure 1.1 was given. Students answered the question independently and were given all the time they needed. They were in an unfamiliar academic program with new classmates. All indications were that they tried their best to answer the question. This identical question was also given at the end of the program.

> Which of the following do you think best approximates the relative motion of the earth and the sun?
>
> A. The sun goes around the earth.
>
> B. The earth goes around the sun.
>
> C. Neither A nor B are correct.
>
> D. I do not know.
>
> As best as you can, provide a proper and complete scientific argument for your answer.

Figure 1.1. Question asked of all students at the beginning and end of the summer program.

More than 90% of the students selected choice B on that first day. This was just like every summer. Choice B reflects agreement with the scientific community. However, there is more to the story when you look at the reasoning they used.

Zhi wrote as a scientific argument "The earth goes around the sun because of many reasons. One is the amount of time and days it takes for the earth to go around the sun. Another reason to account for this is the cycling of seasons we have in each year. This is why the earth goes around the sun." Zhi wrote clearly and in full sentences. He made accurate references to relevant material. In a typical high school class his response likely would have resulted in a reasonable score and positive feedback. The problem is it does not address scientific justification for answering that the earth goes around the sun at all. Referring to the time it takes the earth to go around the sun as a reason that the earth goes around the sun is circular at best. The seasons can be accounted for in the geocentric and the heliocentric model equally well, so citing seasons as scientific justification for the earth going around the sun has no merit.

The scientific argument that Firoza provided was "According to Copernicus's geocentric theory the earth goes around the sun. Also the change of night and day shows that the earth takes different positions and revolves around. Sun setting and sun rising also changes our view of the sun as we travel around it." As with Zhi, this is reasonably well written but without any substance. Like many students, Firoza referred to authority (Copernicus) and jargon (regardless of her choice of "geocentric" instead of "heliocentric"), neither of which constitute scientific justification. The rest of her answer demonstrates a lack of understanding of the relevant ideas as night and day have nothing to do with the conventional description of the revolution of the earth around the sun.

Almost all other student answers also demonstrated a complete lack of any substantive scientific reasoning.

During class, immediately after the written responses were collected, there was a whole class discussion. Student agreement that the earth goes around the sun (choice B) is the right answer was overwhelming. Many prefaced the choice with "of course" and "everyone knows." Explanations matched those written on the pretest such as those of Zhi and Firoza, even as students were given opportunity and encouragement to elaborate.

When my questions revealed holes in their explanations, students asked questions like "Is it the seasons?" or "Does it have to do with the planets?" and then waited for an authoritarian yes or no from me, which never came.

Me: *Could the earth going around the sun cause seasons?*

Jae: *Yes.* (True.)

Me: *Could the sun going around the earth cause seasons?*

Jae: *Yes.* (Hesitantly, but true.)

Me: *Are there seasons?*

Jae: *Yes.*

Me: *What do we know about whether the earth goes around the sun or the sun goes around the earth from seasons?*

Jae: *I don't know* (which is different than "I can't know"… it is unclear which the student intended).

This discussion was a prelude to the substance and philosophy of the summer program. With respect to the exchange about the seasons, the class analyzed the logic of: "If Jane smokes, it will cause her to cough. Jane is coughing. Jane must be a smoker." They articulated to each other whether they agreed or disagreed with this argument and explained their reasoning. They related what they learned about Jane's coughing to the argument about the seasons. Eventually they were able to state clearly why the existence of the seasons does not provide any justification as to whether the earth goes around the sun or the sun goes around the earth.

The students were eager to have the answer to the seemingly simple question about the relative motion of the sun and the earth given directly to them. This was not done at any point during the summer.

INSTRUCTION

Both the instructional philosophy and curriculum employed were largely from the Astronomy modules of *Physics by Inquiry*.[5] Subject matter included daily motion of the sun, size and shape of the earth, phases of the moon, daily and annual motion of the stars, and motion of the planets.

Throughout, the emphasis was on the process of science rather than the presentation of facts. Students actively made observations and used these observations to develop multiple scientific models of the universe. Students made shadow plots of the sun. They experimented with a flashlight and nail and reasoned that they can account for the daily apparent motion of the sun by moving the flashlight or by moving the nail.

After making and sharing observations of the moon, students observed the appearance of a ball near an illuminated bulb in an otherwise dark room. As before, students experimented and reasoned. They came to recognize that they can account for all of their observations of the moon either by thinking of the earth rotating while the sun is stationary or by thinking of the sun and moon going around a stationary earth.[6]

With some help, students observed that the angle between the semicircular phased moon and the sun is indistinguishable from 90°. They then maneuvered the moon ball and sun bulb until they saw the semicircular moon and thought about the angle between the "sun" and "moon" in the model for an observer on the "earth." They literally had to walk all the way across the room from the bulb with the ball in hand before they were able to get the angle even close to their liking. They realized for themselves that the only way the angle between the sun and semicircular moon can be 90° is if the sun is much, much further from the earth than the moon. They were able to articulate exactly how they know the relative distance of the sun and moon from the earth. They reasoned for themselves what they can conclude about the relative size of sun and the moon, given that they appear about the same size in the sky but the sun is way farther away from the earth than the moon.

Daily motion of the stars and planets were explored in a similar manner, with similar results.[7] This process continued with an analysis of the sun, stars, and planets over many months.[8]

---

5 McDermott, L. C., & the Physics Education Group at the University of Washington. (1996). *Physics by inquiry*. New York: John Wiley & Sons, Inc..

6 If one thinks of the sun going around the earth daily, then the moon is going around the earth daily as well, although at a slightly different rate.

7 If one thinks of the sun going around the earth daily, then the stars and planets are also going around the earth daily, but not quite in the same way.

Students learned about the astronomy, how they know about the astronomy, and how to articulate their scientific reasoning. All summer, they were not given answers. Instead they were guided to develop ways in which they could account for their observations. They were constantly asked to justify, explain, reason, and interpret. Given the unanswered question from the pretest, early in the program students repeatedly asked what the right answer was. As the summer went though, there was a shift towards them wanting to answer the question for themselves.

In addition to the observational astronomy, we covered Newton's Laws of motion in a similar inquiry-based spirit. Included was a development of an understanding of gravity and the relationship between force and motion for circular motion. Near the end of the course, but prior to the post-test described below, we covered important relevant historical observations such as phases of the planets and the moons of Jupiter. Implications of these observations and Newton's Laws were alluded to, but still not stated outright. Students were guided to making relevant connections to how we know the earth goes around the sun.[9]

"PROVIDE A COMPLETE SCIENTIFIC ARGUMENT" TAKE 2

At the end of the summer, the identical question shown in Figure 1.1 was asked. The *reasoning* of the student responses to the question both at the beginning of the program and at the end of the program were evaluated with the rubric described at the end of this chapter. On a 5 point scale with 5 being the best reasoning, the average rubric score at the beginning of the program was 1.4.[10] The average rubric score at the end of the program was 3.9. Figures 1.2 and 1.3 show two typical student responses along with the rubric scores.

Like many students, Venkat started the summer with a combination of authoritarian statements and circular reasoning to support his choice of B. (See Figure 1.2.) By the end of the summer, he still answered that the earth goes around the sun. However, he now recognized that the basic observations can be accounted for in either the heliocentric or geocentric model. To support that the earth goes around the sun as the better choice, he integrated Newton's laws and appropriate, more subtle observations of Mars.

Hariti also selected choice B at the beginning of the summer. (See Figure 1.3.) Hariti's support for this choice is difficult to follow. It is based on irrelevant and incorrect observations and reasoning. Her response reflects many students' written and later spoken justifications which were convoluted yet stated confidently. By the end of the summer, Hariti changed her answer to choice D, "I do not know." Regardless, in contrast to her pretest response, her reasoning was much stronger and more clearly developed. She properly justified her choice (regardless of

---

[8] The vast majority of observations of the sun, stars, and planets over many months can be equally well accounted for in either the heliocentric or geocentric models.

[9] Newton's laws and detailed observations of the planets can delineate between the heliocentric and geocentric models of the universe, unlike simple observations of the sun, moon, stars, and seasons.

[10] Data and examples throughout this chapter are from multiple years.

whether it is the answer considered correct) by noting how it is possible to account for her observations in either model of the earth and the sun.

Venkat response at beginning of program:

Choice B, "We know that sun is stationary and does not move. But, earth moves and is not stationary. Also by looking at the Heliocentric Theory, we know that earth revolves around the sun and that's how we get our years." (rubric score 1)

Venkat response at end of program:

Choice B, "Before Newton's Laws were introduced, both A and B would have been possible. If A were the case, then the sun would move clockwise around the earth, and if B were the case then the earth would move counterclockwise around the sun. Both would account for the same conditions. However Newton explained that the more mass an object has the more gravitational pull. From our observations the earth has less mass than the sun, so the gravitational pull is greater. Also we discussed Mars coming closer and the only way that could be accounted for is if the earth and Mars orbits around the sun, and as they orbit the distance between them changes. The laws of motion and force support that the earth goes around the sun." (rubric score 4)

Figure 1.2. Sample verbatim responses to question shown in Figure 1.1.

Hariti response at beginning of program:

Choice B, "The earth goes around the sun because the different hemispheres of the earth receive the sun at different angles at different times of the day. The sun, however is always in the same position when it is visible. Therefore, the sun does not change position, rather, the earth does." (rubric score 1)

Hariti response at end of program:

Choice D, "The relative motion of the earth and the sun can be accounted for in both ways. Through observation. I saw both ways to be accurate. I saw that the earth can go around the sun counter clockwise and account for the relative motion of the sun and the earth. I also saw that the sun can go around the earth clockwise and it still would account for the relative motion of the sun and earth. There is no reason to choose another model using only the sun and earth's relative motion. Therefore, I do not know which model is better because with this information, the results are reproduced with the same amount of accuracy." (rubric score 5)

Figure 1.3. Sample verbatim responses to question shown in Figure 1.1.

Figures 1.2 and 1.3 refer to scientific justification and reasoning. Also of note is the percentage of students who selected each of the choices A through D in Figure 1.1. Prior to instruction, 93% selected choice B. At the end of the program, 52%

selected choice B and 43% selected choice D. One can interpret this as instruction having the opposite effect of improving success since many students switched from the "right" answer to "I do not know." Instead, this result highlights the limitation of multiple choice questions which emphasize recall. Correct responses at the beginning masked student lack of understanding of underlying scientific thinking. Explained "I do not know" responses at the end revealed student insight into well-developed scientific reasoning. In other words, the multiple choice response was not a reflection of student knowledge of science or astronomy.

The split responses between A and D on the post-test are consistent with the instructional approach of having students figure out scientific ideas for themselves. Students were given opportunities to make observations and build scientific models. While support and guidance were provided, answers were not stated authoritatively at any point. In the end, roughly half of the students were convinced that there is sufficient evidence to support that the earth goes around the sun. They justified their answers accordingly. The rest of the students remained unconvinced (even though they were well aware of the "right" answer) and appropriately explained why. Either way, student responses reflected their own thinking and are connected to legitimate scientific reasoning in contrast to parroted, non-understood answers.

"PROVIDE A COMPLETE SCIENTIFIC ARGUMENT" TAKE 3

In addition to being asked to provide a scientific argument about the relative motion of the earth and sun at the end of the summer, students were asked the question about black holes shown in Figure 1.4. The earth-sun question addressed material explicitly covered in the program, even though the question was not answered directly. The black hole question addressed material not at all covered in the program.

> Which of the following is most accurate?
>
> A. There are things in the universe called black holes from which not even light can escape.
>
> B. While the expression "black hole" is popular in science fiction, it is not something that really exists.
>
> C. Neither A nor B are correct.
>
> D. I do not know.
>
> As best as you can, provide a proper and complete scientific argument for your answer.

Figure 1.4. Question asked of all students at the end of the summer program. Black holes were not covered.

Most of the students (95%) selected choice D, “I do not know.” To gauge student scientific arguments, we developed a rubric similar to the earth-sun one. The average score using this rubric was 3.9, similar to the average score on the earth-sun post-test.

Many of the quotes on the black hole post-test reflect the approach to science emphasized in the program. Juanita wrote “I have absolutely no idea whether black holes exist or not. I have heard of them mentioned, but I never really learned about them, so I really don't know…” Patricia wrote “… Since it isn’t something I learned based on observations or experiments, I can only say that ‘I do not know’ unless I wish to spit out information I don’t fully understand.” Many were more explicit about referring to what they had learned in class such as Swatti who wrote “If I hadn’t taken this class I would have said A, but now I know that I don’t have anything to justify that other than ‘I read it in a book.’”

The scientific arguments of Juanita, Patricia, and Swatti reflect a strong perspective of the origin of scientific knowledge. However, since they all selected choice D it also represents a potential limitation of their learning science content after having participated in this program. We certainly want our students to have an understanding of science which extends beyond what is constructed from first principles and personal observations. To reach higher levels of understanding of science, students need to be able to recognize how scientific ideas are constructed, when they are able to construct those ideas for themselves, and when they should accept the findings of others having gone through similar steps properly.

WHO CARES ABOUT ASTRONOMY?

The entire astronomy course was built around exploring the relative motion of the earth and the sun. Students got to participate in the process of science, develop their reasoning skills, and negotiate conflicting arguments. These and many other important skills are transferable to so many domains in and out of science. All of these skills are best developed when practiced in a real context. Students also learned science content. Observational astronomy just happened to the context.

There are so many other topics with which this could be done. For example, the complementary chemistry course in the Summer Scholars Program, taught by my colleagues Issa Salame and Takoa Lawson, followed the same strategies of the astronomy course. However, in that course they explored how we know about the nature of the atom. What are the specific observations and experiments that have led to the understanding of atomic structure? Are there multiple ways to account for our observations? What is the nature of scientific models in atomic physics?

In previous years, I taught with the same spirit but the topic was introductory quantum mechanics. Students started with simple observations of light bulbs, shadows, water tanks, and long springs. They built on their own observations and reasoning until they understood electron diffraction and the probabilistic interpretation of subatomic particles. Alternatively I have had students follow a similar path from thrown balls, emitted sound , and illuminated light on moving trains to Einstein’s Theory of Relativity.

The best context in which to teach science in this spirit though might be the theory of evolution. What evidence is there that points to the age of the earth? (And what does that have to do with anything?) What are our observations of similar but different species and the environments in which they live? What can we learn from fossils? How do we know about genetics and how do we relate this to the theory of evolution? What experiments can we examine today that relate to the theory of evolution?

Scientific literacy ties at least as much to an understanding of the process and reasoning of science as it does to the body of information that is known. And there are so many wonderful contexts in which the students can engage to learn it all simultaneously.

REFLECTIONS ON UNDERSTANDING SCIENCE AND GOALS OF SCIENCE EDUCATION

In addition to the often discussed and detailed need for understanding specific scientific content, one of the goals of science education needs to be that students should be able to think and reason scientifically. The results presented in this chapter, from a dedicated and academically successful population, indicate that we are failing to meet this goal. After traditional instruction, even this privileged group struggles with basic understandings about the nature of scientific thinking. I have administered the same instruction and questions with thousands of other pre-college students, K-12 teachers, and college science students from all over the country. The results are fundamentally the same every time.

There is a need to look into what is happening in schools and explore how it comes to be this way. What is it that is going on in science classes that leaves the best students unable to give reasons that the earth goes around the sun, or even understand what it means to give a reason?

Faulty approaches to learning and knowing science are the norm. Faulty approaches to learning and knowing in general are also the norm. But I firmly believe that this can change. When given the opportunity to participate in the process of learning, students can succeed, and they embrace the opportunity. The Summer Scholars Program convinced me of this.

If the question in Figure 1.1 were a standardized test question, the 93% "correct" response rate would be interpreted as high success. Students and instructors would be lauded. There would be a march to more advanced material where it would be inevitable that students would have an even harder time understanding the nature of science and the underlying concepts and reasoning. They would therefore revert further into a strategy of memorize and repeat. Only after some probing does it become clear that student understanding is inadequate. Even if this probing is more challenging than a typical standardized test can accomplish, it is important if we are to emphasize a meaningful understanding of science.

Educators of science, as well as all other disciplines, need to prioritize the best interests of students regardless of the system in which we teach. We should identify that which is of value in the way our students are assessed and work towards them having success on these assessments. I certainly prefer that students recognize the community consensus about the relative motion of the earth and the sun, but this need be in conjunction with understanding why it is the community consensus.

Educators of science, as well as all other disciplines, need to redirect the system to one which results in education of our children that is of most value. What is successful in the Summer Scholars Program can and does work.

JOHN DEWEY

John Dewey published the words at the beginning of this chapter in 1916. I first learned of the significance of Dewey and his educational philosophies as a graduate student at Yale. I still remember how much sense he made to me then. I look at these words today and they make even more sense now. Fleeting collections of non-understood statements coupled with a perspective that learning means being told is of so little value. Learning how to think and reason scientifically by actually doing science is a much better idea. This is regardless of the breadth of content covered. This is regardless of whether the student will eventually be going on to a career in science. However, I can't help but fear that these words of Dewey are not being given the attention they deserve.

RATING STUDENT REASONING ON THE EARTH-SUN QUESTION

Table 1 describes the rubric used to score student responses to the scientific argument question of Figure 1.1. The answers are verbatim and representative. "Pre" and "Post" refer to whether the response was given prior to or after instruction. A, B, C, and D refer to the multiple choice response given to the question.

Table 1. Rubric used to score student reasoning for earth-sun question.

Rubric Score	*Description*	*Sample answers*
1	Students use jargon, authority, circular reasoning, or irrelevant observations / experiments and it represents a significant part of their answer.	Pre, B "Copernicus's heliocentric theory proves that the sun is the center of the solar system and all contained celestial bodies orbit around it." Pre, B "The sun is the center of our solar system. All nine planets revolve around this star. We know that the earth revolves around the sun because we have night on one side of the earth, and day on the other. The changing of the seasons is also a result of the earth revolution." Pre, B "The earth turns on its own axis while following an elliptical orbit around the sun in which at some points it is closer or further from the sun. This full path around the sun is the duration of one year. The sun also spinning."
2	Student cites relevant observations / experiments in support of their choice, thoughts are not clearly connected, little or incorrect development of ideas or reasoning, no distinction between models.	Pre, B "I believe the sun has greater gravitational force than the earth does. So the sun pulls in the earth and the earth has no chance to move around the sun" Pre, B "The earth goes around the sun because the sun has a greater gravitational pull than the earth does. Therefore, rather than the sun being pulled into the earth's orbit, the earth and the rest of the 9 planets get pulled into the sun's orbit"
3	Student refers to relevant observations / experiments but part of explanation is erroneous or problematic OR student recognizes an inability to answer to the question.	Pre, D "I don't know, in some classes you are informed the earth goes around the sun, proof by scientific observation (through change of seasons, shadows of grounded object etc), however, like all scientific theories, you never know if it is true all the time (someone can always find another plot to say it is wrong). People used to think the sun goes around the earth, so I really don't know what's the true answer of this question." Post, B "The earth goes around the sun because from the observations I made about the other planets going around the sun. The planets are much smaller than the sun so they revolve around the sun. According to Newton's law F=ma and smaller things revolve around bigger things. Since the force between the sun and the earth is the same and the mass are very different. It means that the earth will have a lot more acceleration than the sun since earth is little compared to the sun"

4	Student cites observations / experiments distinguishing between models in a consistent way but explanation is not developed or is incomplete.	Post, A “We can perfectly account for all our observations w/ this model: seasons, phases of the moon, planets going around and moving backwards and forwards etc. but there is one characteristic that shows that this is the best choice: WE DON'T MOVE! Although proponents of the alternative view say that this model is so complicated and will get less migraines, they still not been able to explain why we don't feel ourselves moving. Also, just because it’s complicated doesn't mean it's wrong, we must accept what is there is not a fantasy that is easier. The sun goes around the earth, no doubt about that.”
5	Student cites observations / experiments distinguishing between 2 models and supports choice with proper explanation relevant to their answer (regardless of multiple choice response).	Post, B “Based on our observations, we can account for the daily motion of the sun, stars, and planets using both models (geocentric & heliocentric). If we strictly rely on this as far as we can tell we do not know. Using our knowledge of physics, we may find evidence that gives the heliocentric model preference over the geocentric model. We know that the size of the sun is much greater than the size of the earth. (The distance between the moon and the earth is much greater than the size of the earth and in pt 1 we showed that the distance between the sun and the earth is much greater than that, but yet the sun appears to be the same size as the moon in the sky therefore the size of the sun is much greater than that of the moon and of the earth) By Newton’s 3rd law the force that the sun exerts on the earth is the same exact force, opposite, with the same magnitude that the earth applies on the sun. In order to maintain circular motion, at as constant speed, k, the direction of the force must be towards the center of the circle (earth/sun). If the geocentric model was true, the acceleration that the earth has must be much less than that of the sun. This implies that the earth's mass is much greater than the sun so the sun can orbit around earth. However we know that the m_earth < M_sun. So the earth revolves around the sun” Post, D “The relative motion of the earth and the sun can be accounted for in both ways. Through ray observation. I saw both ways to be accurate. I saw that the earth can go around the sun counter clockwise and account for the relative motion of the sun and the earth. I also saw that the sun can go around the earth clockwise and it still would account for the relative motion of the sun and earth. There is no reason to choose another model using only the sun and earth's relative motion. Therefore, I do not know which model is better because with this information, the results are reproduced with the same amount of accuracy.”

CHAPTER 2: AUGUST

AWAY FROM THE IVORY TOWER

Inquiry

In theory there is no difference between theory and practice. In practice there is. [1]

- *Yogi Berra*

AUGUST 15: A CHANGE IN CONTEXT

With hopes of following up on my experience in the Summer Scholars Program, I accepted a position as a full time science teacher in Urban High School (UHS)[2] in New York City. I knew that most of the students would be different than those in the Summer Scholars Program. I knew that the environment and expectations would be different. I knew that there would be so much for me to learn. As I went through my orientations in August leading up to teaching at UHS, I was eager, hopeful, excited, and more than a little nervous.

Prior to my sabbatical, from my experiences learning physics I saw the beauty and elegance of the subject matter, often delivered to me by master physicists. From my experiences in education I saw the importance of setting up an environment, both affectively and cognitively, conducive to maximizing learning. From my experiences conducting science education research I saw the need to understand and address specific difficulties students have learning the subject matter. From my experience at orientation at UHS on August 15, I learned that all my other experiences meant nothing compared to getting through the day unscathed (sometimes literally). I also quickly learned that all that mattered to the school was my students' success on a standardized test that I was confident correlated little with anything that was important about knowing physics.

It was clear that teachers are taught one way, are taught to teach it another, and are told something different still by the school system. We are then put in a room where none of it works. First year teachers quickly recognize that classroom management is a big part of the challenge, but not the only one.

My experience was in a poor community in New York City. Almost all of the students were Black or Hispanic and from modest means. In this particular school

[1] Although this quote is often attributed to Yogi Berra, it is not clear who the original author of these words is. Regardless, this is typical of the kind of thing that Yogi Berra would say.

[2] Urban High School is a fictitious name I use for the school in which I taught. I was tempted to use "School of Sabbatical" since the acronym would have felt more appropriate, but went with the simpler UHS anyway.

there was strong leadership and good support services. There were fewer than 25 students assigned in each of my classes. A relatively large proportion of the students from UHS go to college. However, those that know more than me about the New York City school system told me that student background, student discipline, and overall challenges at UHS are not very different from what is encountered in many New York City public schools. This particular school encourages students to take physics though, which allowed me to have a full cross section of students. It also presented the challenge that many of them would not be motivated or interested in taking the course.

During that last month of August, before classes started, I thought a great deal about both my motivations for wanting to teach at UHS and in the very challenging context in which I was about to be immersed. I aspired to build on what I did in the Summer Scholars Program, but there was more to it than that.

MOTIVATION 1: WORK WITH COLLEGE PHYSICS STUDENTS

There were many motivations for wanting to teach in (and understand) a New York City high school. One came from my teaching college physics. Most of my CCNY students are in the School of Engineering. They are largely graduates of New York City high schools. Practically speaking, they represent the higher performing, more motivated, better prepared of the high school graduates. Like many physics professors (at CCNY and elsewhere) I am often disappointed at the overall preparedness of these students for legitimate college level work. Many do not survive the introductory course. They are subsequently not eligible for careers in science or engineering.

Along with Joel Gersten, my colleague in the Physics Department, we administered a baseline diagnostic test for incoming engineering students taking physics.[3] By any reasonable expectation, the questions should have been solvable by this group. Questions were like:

A gallon of gas costs $1.20. How much gas can I get for $1.00?

Solve: $\frac{x}{2} = \frac{3x}{4} + 1$

We are growing a population of bacteria in a jar. At 11:00 a.m. there is one bacterium in the jar. The bacteria divide once every minute so that the population doubles every minute. At 12:00 noon the jar is full. At what time was the jar half full?

[3] Many of the questions we used were taken from or based on the *Diagnostic Test of Basic Skills* by Jerome Epstein.

Students averaged less than a 70% on the diagnostic. Fewer than half got the question above about the bacteria correct.[4] Results of the diagnostic and many other measures of student readiness are conclusive. Too many students are coming to college with insufficient math (and literacy) aptitude. Their ability to perform high school level math skills is poor. Their ability to transfer these skills to unfamiliar contexts is even worse.

When teaching college physics, I find weak math skills to be a problem, but I find student approaches to learning an even greater problem. When working on a homework assignment, the strategy that students use is to find a nearly identical solved question as a model to copy from. If one is not available, they look for a formula with a collection of variables that looks similar, regardless of whether the formula is relevant. These are not effective strategies for learning physics. These are not useful strategies for success outside of a physics classroom. I would rather listen to a student rub her fingernails against a blackboard than watch her do physics like this.

When learning the material, rarely do I see a student identify the big idea, try to relate the situation to the real world, or integrate conceptual understanding to problem solving. I believe that student math skill weaknesses are easier to overcome than these flawed approaches.

One of the standard problems that I assign in introductory physics is:

A 10 kg piece of zinc at 71°C is placed in a container of water. The water has a mass of 20 kg and a temperature of 10°C before the zinc is added. What is the final temperature of the water and zinc?

This problem can be solved using some involved, but still high school level algebra. Mark was a good student in one of my introductory physics classes. He was intelligent and routinely submitted homework, prepared for exams, and cared about his grades. For the most part, he even set up the mathematics of this particular problem correctly. However, like so many other students, Mark did not calculate the right value for the final temperature. He came up with 3°C.

Here is a college student who left high school without reasonable mastery of high school algebra. Regardless, somehow, Mark was comfortable with (blind to?) a 71°C piece of Zinc combined with 10°C water resulting in a final temperature of 3°C. He did not have an approach to problem solving where he tried to relate his calculated result to what makes reasonable sense. He presented an answer for the final temperature of the two substances which was not between the two initial temperatures. He should have seen this nonsensical outcome as a clue that something was wrong and gone back to check his work. He did not.

Most of my students are not coming to college with the skill sets they need. When resolving vector force components, they could only do the trigonometry when the forces are parallel to one of the edges of the paper. They struggle with

4 One minute earlier.

electrostatics problems because they only know algebra if the symbol "x" is the unknown. They report the mass of a swinging pendulum to be more than the mass of the sun. They do not think to start with the big idea that the initial and final energies of a system must be the same unless told explicitly to do so. Ohm's law is applied even if there is an open circuit and no path for the current to go. Students like Mark should come to college with mastery of high school mathematics, strong problem solving strategies, and a disposition to make sense of what they are doing as they go. They come with none of this.

Therefore, one motivating question that I had going into the high school was what could I learn that will make me a more informed college physics professor?

MOTIVATION 2: WORK WITH SCIENCE TEACHERS

Another motivation for wanting to teach in (and understand) a New York City high school came from my role as Program Director of Science Education at CCNY. In many different capacities I work with, teach courses for, and advise New York City science teachers. I am pretty sure in my understanding of the subject matter, of the nature of science, of pedagogical strategies, and of how students learn. I am completely sure that this is not enough.

I routinely hear from teachers in the program that what they learn in my courses is wonderful and that it reflects the way that science classes should be taught. They appreciate learning science the same way that the Summer Scholars students do. They enthusiastically see the value when reflecting on the process. They appreciate having the opportunity to analyze how their students do and do not learn real science. Nevertheless, they tell me that it is all irrelevant because that is not the way the schools work. "That won't help prepare them for the state tests." "Kids can't do that." "It's all about classroom management."

There seems to be an understanding of the right way to teach the content, skills, reasoning, and processes of science but that it is irrelevant to what goes on in real science classrooms. There is something very wrong with this picture.

Therefore, another motivating question that I had going into the high school was what could I learn that will make me more effective when working with science teachers?

INQUIRY INTO INQUIRY

In preparation for my sabbatical, I spent the previous year participating in an alternative teacher certification program. I continued in the program through my year teaching at UHS. I'd like to say that I was motivated to do this to maximize my ability to succeed as a teacher. However, the truth is that I did this because I was not permitted to teach in a public school without the proper certification. As a result, I took the courses (several of which I had previously taught) needed to obtain the right credentials.

Classes were daily in the summer and one evening each week during the school year. I did all of the required class work, projects, and homework assignments. I did my field work, where I visited a wide variety of classrooms in multiple schools in the community. In the end, I appreciated the opportunity to learn and to experience what other teachers experience when entering into the teaching profession.

One recurring term in all of the education classes (and later in many professional development sessions that I went to) was "inquiry." However, while so many used the word, there was never clarity in what it meant. Some common associations with inquiry were "hands on," "interactive," and "group work." All of that sounds good to me. One dictionary definition of inquiry is "seeking truth, information, knowledge." I never heard that one in any of the classes that I took, but I like that too. I particularly like the "seeking" part, which is in contrast to just "having" or "being told." Science is inquiry. Learning is inquiry. I guess learning science should be inquiry squared.

To me, what my students did in the Summer Scholars Program exemplified learning by inquiry. I also saw all kinds of other wonderful examples of activities where students were actively constructing their own understanding of all kinds of topics by what looked to me like inquiry learning. Some were in science and others were not. Some were in one period lessons and some were in extensive units. Some were on prescribed curricula selected by the instructor and others were extensive group projects where the students helped define a topic and a research question. It was very exciting and looked very successful.

However, while hands on, interactive, and group work can facilitate learning by inquiry, more often I saw it described when the activities were not what I would call inquiry. Students were not seeking truth, information, or knowledge. They were not making sense of the world, not exploring ideas, not inquiring. Perhaps they were actively engaged with hands on activities by making a model of the solar system with Styrofoam balls. Perhaps they were working in groups to come up with mnemonics to memorize the periodic table. They were not however doing things that led them to understand where knowledge comes from or how it is understood. The teachers claimed to be teaching science by inquiry. Activities like these might serve a function in science classrooms, but students are not learning science by inquiry.

This is not good enough. In the Summer Scholars Program I saw how it was possible to have students build a scientific understanding of the whole universe based on their own investigations, construction, and reasoning. If this could be done for the entire universe, surely it could be done for much smaller things. Things like projectiles, circuits, and atoms. Things like ecosystems, plant life, and cells. Maybe even for things like global warming, nuclear energy, and recycling.

In the Summer Scholars Program I asked the black hole question where students did not have the opportunity to learn that material by inquiry. I had concern with some of their responses. Even when material is introduced by authority and not by inquiry,[5] students need to understand the process of science and the process of inquiry so well that they can identify explicitly reliable knowledge that they have not developed on their own. They also need to understand the kind of inquiry that was done by others to come to that knowledge. Science and inquiry need be understood so well that students can tell whether someone else has done it well, poorly, or not at all. Science and inquiry need to be understood so well that students can identify when they have obtained information without having participated in the process. How can any of this happen if students don't have extensive opportunities to do scientific inquiry themselves?

And if inquiry is really understood, it should also be part of things like politics, religion, society, and more. The science classroom is a great place to learn, develop, and exercise the skills of inquiry. The entire world is a great place to have those skills.

REFLECTIONS ON GOING TO UHS

My preparation for teaching at UHS was a culmination and a beginning, filled with so much excitement. I had worked hard and long in my career trying to understand and affect science education, often concerned about what was happening in classrooms at all levels. Here was a great opportunity to try to learn. What better learning opportunity is there for a science educator than immersion into a setting like this? For me it was inquiry into inquiry where the rubber meets the road. The rest of the book is a reflection on my seeking of truth, information, and knowledge.

STRATEGIES THAT WORK: INQUIRY

It might not be easy to articulate what classroom inquiry is, but I agree with the consensus that it needs to be a focus in education. The astronomy curricula elaborated on in the previous chapter is inquiry. Students given the opportunity to learn this way succeed in learning astronomy. They are learning science. They are learning more. Below are two lessons on other topics which are inquiry in nature. In each case, students construct for themselves an understanding of scientific knowledge and process. They are also learning content specifically identified in many "standards."

The first lesson is on the speed of light. It is intended to be done after an understanding of the heliocentric model of the solar system and an understanding of planetary motion. Before the lesson, there is a whole class discussion on whether light propagation is instantaneous or extremely fast *and* on what specific scientific evidence any answer is based. In the lesson below, students are able to

---

[5] It is obvious that some portion of material that students should know will need to be presented by authority.

integrate their knowledge of mathematics and astronomy to calculate a reasonable estimation of the speed of light.

The second lesson is on the nature electrical interactions and how one comes to understand these interactions.[6,7] This activity is particularly intended as an exercise for science teachers, a lesson in both electrical interactions and pedagogy. Charge, neutral, and polarization have been deliberately replaced by the fictitious words "sharge," "nukral," and "posterization." The purpose for this is to focus on the science of electrical interactions that arise from simple observations and reasoning. Use of the fictitious words preempts attempts to mask a lack of understanding of the concepts with half-understood application of technical jargon.

Lesson on determination of light speed from astronomical observations[8]

The moon of Jupiter Io is observed to appear out of an eclipse every time it orbits Jupiter with a period of 42 hours, 30 minutes (+/- 2 s). One observation of Io emerging from an eclipse is just east of south at 11:44:45 pm on June 28 (+/- 2s).

1. Predict when the moon would come out of the eclipse after 97 more orbits.
2. It is observed that Io comes out of the eclipse 6:36:58 pm December 24 (+/- 2 s) Is this consistent with your prediction? If not, resolve the conflict.
3. Estimate the speed of light. Explain your reasoning

Lesson on the nature of electrical interactions

A. Interactions

Press a piece of tape (about 15-20 cm) firmly on a smooth unpainted surface. Peel the tape off quickly. Describe in your own words the behavior of the tape as you bring objects toward it (e.g. a hand, a pen).

Make another piece of tape as described above. Bring the second piece of tape toward the first. Describe your observations.

How does the distance between the tapes affect the interaction between them? Explain how you know.

---

6 This lesson is based on the charge tutorial from *Tutorials in introductory physics*, L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington (Prentice Hall, Upper Saddle River NJ, 1998), which also includes many other inquiry-based activities.

7 For a description of the research that underlies the Tutorial activities and documentation of their effectiveness, see the published papers cited at: http://www.phys.washington.edu/groups/peg.

8 These fabricated data are similar conceptually to early observations of Ole Römer in the 17th century, but are different in detail to make the calculation of the speed of light more accessible to high school students.

Each member of your group should press tape onto the surface and write a "B" (for bottom) on it. Then press another tape on top of each B tape and write "T" (for top) on it. Slowly pull each pair of tapes off the table as a unit. After they are off the table, separate the T and B tapes quickly.

Describe the interactions between the following when they are brought near one another.

- two T tapes

- two B tapes

- a T and a B tape

- a T tape and a small piece of paper

- a B tape and a small piece of paper

- two small pieces of paper

We say that a material is ***sharged*** if it behaves in the manner that the T tape and the B tape behave. Otherwise we say that the material is ***nukral***.

Describe a procedure that you could use to determine if an unknown object is sharged or nukral.

Is nukral a type of sharge? Explain.

Obtain a rod and a cloth. Rub the rod with the cloth and then hold the rod near newly made T and B tapes. Determine whether the rod is sharged or nukral. If it is sharged, determine if it is sharged T or sharged B. Explain specifically how you know.

B. Other Sharges

A person brings to you a material that she claims is sharged, but is a different kind of sharge than both the T tape and the B tape.

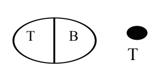
Explain how you can determine if the unknown material is in fact sharged.

Explain how you can determine if the unknown material is sharged differently than both the T tape and the B tape.

Is it possible that there are 3 different types of sharge? 4 different types? Explain.

C. Posterization

A small ball is sharged T on one side and equally sharged B on the other side. The ball is placed near a T sharge, as shown to the right.



Would the ball be attracted toward, repelled from, or unaffected by the T sharge? Explain.

Hang a small nukral metal ball from a string. Then bring a sharged rod near the ball without touching it. Describe what you observe.

The situation above suggests a way to think about the interaction between a sharged object and an unsharged object. Use your answer to question 1 above to try to account for your observation in question 2. Draw a sketch showing the sharge distribution on the ball to support your answer.

YOGI BERRA

Some of the greatest minds in history have helped me form and frame my ideas presented in this book, from Plato to Einstein, from Churchill to King. For this chapter I went with a baseball lifer who quit school in eighth grade, someone who seems to always make so little sense but in reality makes such perfect sense: Yogi Berra.[9] To talk about science teaching, learning, standards, and assessments in theory is one thing. In practice, what happens to students (and to teachers) in a real science classroom is not the same. I have spent my entire career trying to understand the best way to teach science and to work with teachers and students of all levels. What can I learn from teaching in today's educational climate in an inner city science lassroom? A lot!

[9] Whether or not Yogi Berra was the original author of these words is not important here.