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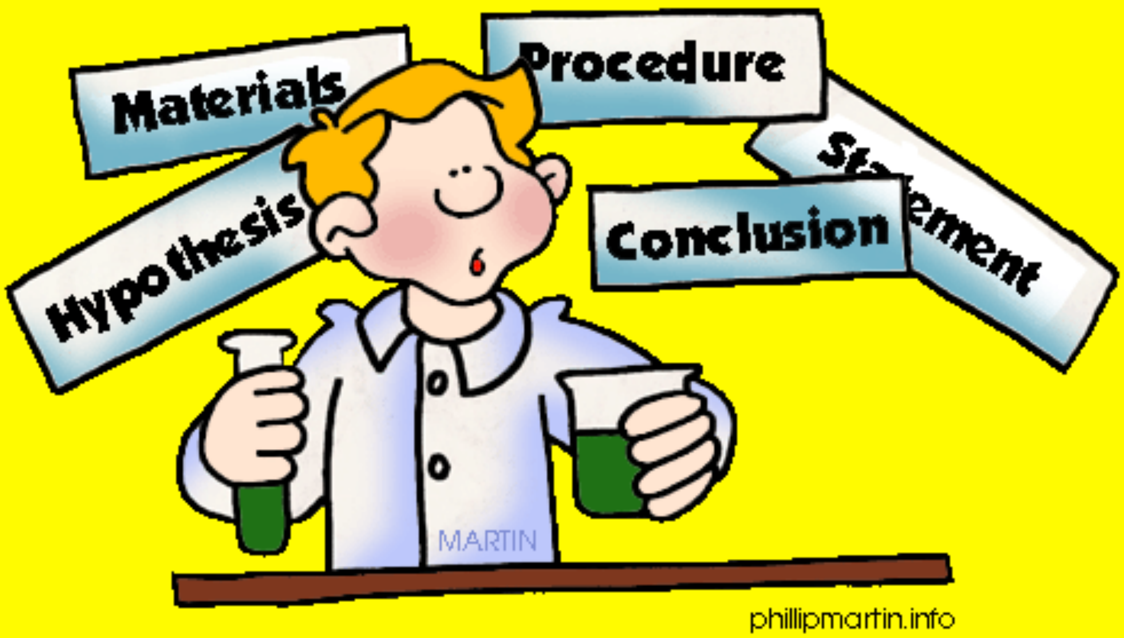

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Phillip Martin
Artist
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About the Artist: I've always considered myself an artist, but for most of my life I was an artist who didn't know what to do with my talents. For many years, I taught art at international schools around the world (Morocco, Philippines, Zambia and Belgium). In the evenings I tinkered on website work with my cartooning. Eventually and unexpectedly, the website work turned into a full time career, giving me opportunities I never imagined. I now find a lot of uses for my art and not nearly enough time in the day. You can find links to several things I do at phillipmartin.com. That list includes clip art, illustrations for pppst.com, PowerPoint templates and my world travels. If you have a lot of time on your hands, you could soak up a lot of time wandering my site.

Every week I hear from people all over the world who use my art. It's amazing to think that it really is used and recognized all over the planet. The email messages I get bring surprises that I never imaged. One of the best was when I heard from a woman in Namibia who wanted to know if it was okay to use my art to decorate an AIDS day care center for orphans. I said, "YES! but, I had to come help." That was my first mural and I knew it wouldn't be the last. Since then I've painted 31 murals with communities on 4 continents and 15 countries. I don't know where my next mural will be. I'm just waiting for another surprise to come my way.

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Don't forget to submit **YOUR** article for the next issue of ***The Science Teachers Bulletin***

Deadline for the FALL issue is JULY 15, 2013

See guidelines for submission on Page 50!

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Not All Words Are Equal: Promoting Disciplinary Literacy in the Sciences through Vocabulary

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Abstract: The authors first outline expectations for New York State science teachers in the domain of literacy, given implementation of the *New York State P-12 Common Core Learning Standards*. The authors then review recent research on literacy in science classrooms, and find that successful approaches to adolescent literacy support, in particular, depend heavily on student background knowledge and sound vocabulary instruction. The authors then highlight an approach to promoting disciplinary literacy in the sciences that emphasize consideration of linguistic and background knowledge demands. Finally, the authors provide two classroom-based examples of effective and advanced vocabulary instruction that help students build knowledge as well as acquire and use language important to disciplinary study.

Since 1784, the Board of Regents has governed public education throughout the State of New York including, in particular, the establishment of learning standards for students across the State. Standards have been a particular point of focus for Regents (and the New York State Education Department [NYSED]) since the 1990s; in the past two decades, NYSED has steadily introduced numerous standards-based initiatives aimed at raising academic expectations. Most recently, in 2010 NYSED was awarded approximately $700 million in *Race to the Top* (RttT) funds from the United States Department of Education contingent on the State's efforts to 'advance reform' through 1) implementing the Common Core State Standards (CCSS), 2) developing assessments linked to those standards, and 3) improving data systems (www.engageny.org). To date, all initiatives have taken form, and movement toward a national curriculum has begun to swell in strength and sway, affecting the working lives of teachers across the state and the nation.

Reform and What It Means for the Sciences

Although much of the initial implementation energy surrounding the CCSS clearly targets English Language Arts (ELA) and mathematics instruction, the sciences are not untouched, even in the early stages. After all, the full title of New York's *Common Core for English Language Arts* includes the phrase "…*and Literacy in History/Social Studies, Science, and Technical Subjects."* Indeed, these same standards "…specify the **literacy skills and understandings** required for college and career readiness **in multiple disciplines** [**bold** added for emphasis]" (www.corestandards.org/ELA-Literacy). An emphasis on literacy, across disciplines but particularly *within* science classrooms, is perhaps the most obvious new feature of the CCSS for science teachers. And it appears that this emphasis may only grow over time: a recently-released draft of the National Research Council's *Next Generation Science Standards* (2013; www.nextgenscience.org) is explicitly aligned to the CCSS and features a similar emphasis on literacy across disciplines.

This paper seeks to highlight how science teachers in New York State can address, sooner rather than later, some of the literacy expectations found in the CCSS through effective, if not advanced vocabulary instruction. In the process, we highlight current research around disciplinary literacy and approaches to vocabulary instruction potentially overlooked or relatively unknown. In the end, we argue that when it comes to using vocabulary instruction to promote conceptual understanding and literacy in the sciences: *All words may appear equal*, we claim, but (to continue in the Orwellian vein), *some words are more equal than others*.

Why Literacy, Especially Adolescent Literacy?

Literacy plays a critical role in helping society achieve a number of important goals. Literacy's import extends to matters of health, academic success, avoidance of the criminal justice system, social and civic involvement and our nation's survival (Shanahan & Shanahan, 2008). As our world continues to change, so too, have societal expectations for literacy among our youth.

Over the last several decades, literacy achievement in the United States has been a cause for concern leading many to conclude that adolescent literacy, especially, is in a state of crisis (Carnegie Council on Advancing Adolescent Literacy, 2010; Heller & Greenleaf, 2007). Long-term National Assessment of Educational Progress (NAEP) data suggest that grade 8 and grade 12 reading levels have not significantly improved since 1971 – with pluralities scoring at or below-basic, while just 3% score 'advanced' (a percentage unchanged since 1992; see Rampey, Dion, & Donahue, 2009, 3; and Aud *et al.*, 2012, 63). These findings appear confirmed within science fields, as well, where students must attain reasonable proficiency with challenging texts. NAEP 2011 science data for New York State, for example, indicate that just 29% of our 8th graders scored at or above 'proficient' in science, with the average score unchanged since 2009, and lower than the national average (National Center for Education Statistics, 2012, 1).

Reasons for these trends are many, but all point to the need to for more effective and advanced literacy instruction at the secondary level, especially in core academic classes (Ippolito, Steele, & Samson, 2008). What is clear is that far too many students are leaving secondary schools without the kinds and levels of literacy they need to succeed in college and/or the workplace. The good news is that we continue to gain a greater sense of what we can do about it.

Why Disciplinary Literacy and Where Does Vocabulary Fit in?

As students enter middle school, they begin to pursue in-depth study of a variety of subjects. As content demands and sources of information become more complex within a particular discipline, so, too, do the texts students encounter in secondary school classrooms (McConachie & Petrosky, 2010). More formal study of various sciences requires students to engage in more sophisticated and specialized literate practices and what some call *disciplinary literacy* holds as a key idea that "…content knowledge cannot be separated from the language to represent it" (Schleppegrell, 2004, in McConachie & Petrosky, 2010, 4; for a succinct definition of disciplinary literacy, see *ibid,* 11). Overall, the *CCSS for ELA & Literacy* expects students to be strategic consumers and producers of information. Critical to this endeavor is the goal that student abilities to use and create text become increasingly complex and varied over time. So what does that mean in science classrooms? It means that students need instruction that:

- builds more extensive background knowledge;
- helps them acquire many new vocabulary words and language; and
- develops verbal fluency and reasoning.

It would seem that – whatever one's take is on New York's *P-12 Common Core Learning Standards for ELA & Literacy* – this kind of instruction falls to science teachers. If this is their task, what might we suggest they do? We say: Start with vocabulary.

Why Vocabulary?

Vocabulary is both a vehicle for and measure of general verbal ability that underlies all learning. It is therefore strongly correlated to school and life success. The more vocabulary students can effectively use, the more likely they will be successful as learners in school. Likewise, the less vocabulary students can effectively use, the more likely they will struggle in (and subsequently fail or drop out of) school. Who wants that?

While considerable advances have been made in the area of vocabulary theory and research within the last twenty years, classroom approaches to vocabulary instruction have been slow to change, and for the most part, remain grounded in practices that are ineffectual or bring about nominal change at best. Consider using the common approach of *define, memorize, and recall,* for example, to help students learn a new vocabulary word, say *transmutation*. With this approach, students might look the word up (where we might find, for example, "*Nuclear transmutation is the conversion of one chemical element or isotope into another,"* thanks to Wikipedia, 2013), generate study guides or flashcards, and try to remember the words-that-mean-that-other-word in time for the quiz.

And yet, we have all come across students who can memorize definitions but fail to grasp the concept at hand. While memorization is certainly *part* of acquiring vocabulary, it is *not* the same as having an conceptual understanding of it (for a good review, see Farstrup and Samuels, Eds., 2008). Memorizing definitions, while necessary, can be misleading (for us as teachers) and insufficient (for students as learners). *Why?* Such an approach focuses on the surface aspects of a word or concept (the phonemes; the spelling; a definition); it does not summon genuine or nuanced understanding that might be used for future learning. A student could *define, memorize, and recall* the term 'transmutation' without understanding anything about atomic nuclei, or elements, or isotopes, or possible mechanisms by which one might convert into another. This approach to vocabulary leaves students at clear risk of earning an "A" on a quiz while failing to understand an idea and worse, failing to gain future access to deeper and more meaningful learning. If, as the research suggest, that teachers identify vocabulary instruction as a critical instructional component of their classroom practice, it seems reasonable to question why any teacher would continue to invest in this kind of instruction given the low rate of return (Cassidy & Cassidy, 2005/2006). What, then, might be done?

The Importance of Background Knowledge

For one, we suggest holding off on the flashcards if the goal is to promote science literacy and vocabulary development. What we have learned over the past thirty years about science and literacy is that there is also strong and positive relationship between the amount of **background knowledge** students possess and their ability to learn (and remember) new information from texts (Carnine & Carnine, 2004; Willingham, 2007).

In one early reading experiment conducted with junior high school students, for example, Recht and Leslie (1988) found that background knowledge was a more powerful predictor of student learning gains than reading skills. Students they identified as 'poor readers,' but who possessed decent background knowledge about the topic (in this case, about baseball) performed far better on tests than those identified as 'good readers' who had little background knowledge. As summarized by Willingham (2009, 35), "[w]hether they were 'good readers' or 'bad readers' didn't matter nearly as much as what they knew."

Ongoing research on literacy has found that once students have learned to decode text – as virtually all have by the time they take middle- and high-school science courses – their understanding of text is most clearly predicted by background knowledge in that content area (see especially Manzano, 2004; also Alexander, Kulikowich & Schulze, 1994; Alexander, Kulikowich & Jetton, 1994; Cunningham & Stanovich, 1997; Schiefele & Krapp, 1996; Shapiro, 2004; Thompson & Zamboanga, 2004; and Willoughby, Waller, Wood, & MacKinnon, 1993). We even have evidence that background knowledge can help students overcome challenges presented by poor instructional formats (Mayer, 2001) or minimal / 'low-coherence' texts (McNamara, Kintsch, Songer, & Kintsch, 1996). Recent large-scale research on science knowledge and reading skill at the high school level (O'Reilly & McNamara, 2007) concludes (among other things) that:

> In terms of academic achievement, the role of domain [science] knowledge is probably most critical for helping students to interpret and comprehend their textbooks. For instance, some researchers have argued that learners often make more errors on various tasks as a result of missing knowledge, rather than incorrect knowledge.... (163)

In terms of learning from text, background knowledge, then, trumps reading comprehension. Think about this for a second. *Background knowledge trumps reading comprehension.* Students learn the most from text, not when they have the 'best' reading ability, but when they know something about what they are reading. This may be an intuitive point, but it's one that has profound implications for how we should support literacy in our science classrooms.

Making the second largest contribution to variance in comprehension is vocabulary (followed by inference, word reading, and reading comprehension strategies) (Jetton & Shanahan, 2012). Instruction that builds on background knowledge and vocabulary for adolescents, therefore, has the best utility for improving literal and inferential comprehension.

How to Teach Vocabulary and Promote Conceptual Understanding

For teachers who want to help students comprehend science texts better and hence, learn more science), we suggest that they *not* waste time trying to get students to memorize vocabulary in isolation, or by teaching generalized 'literacy strategies.' Rather, **we suggest you teach vocabulary in ways that emphasize helping students acquire and use the language of science and build conceptual understanding**. And we have known this for a long time; almost thirty years ago, Stahl and Fairbanks's (1986) sprawling meta-analysis of vocabulary instruction provided convincing evidence that students who are *directly taught vocabulary* terms understand reading passages significantly better than students who have no prior exposure, or no prior instruction. So – hang on to your hats – we should directly teach science vocabulary terms, in context. This finding has since been amply confirmed by a U.S. Department of Education research synthesis (Butler *et al.*, 2010). Which raises the question: *which vocabulary should we teach*?

The business of choosing vocabulary to teach may be more subtle than it would first appear. The English language has a *lot* of words – Stahl (2005) cites estimates of a 1,000,000+ wordstock, with somewhere in the realm of 45,000-87,000 different words used in k-12 texts (97); such a sprawling lexicon would require a student learning rate of about 3,000 new terms per student per year. In all likelihood, a decent proportion of these terms are necessary for our science courses. So get going!

We clearly can't just give students massive lists, however, and say: *verily, you should memorize these*. Instead, we must deliberately decide what vocabulary we will and will not teach – and the vocabulary we *do* teach should maximize the time and effort returns of ourselves and our students. And it is here that our own content-specific knowledge is critical. As Stahl (2005) points out: "Not every 'hard' word has to be taught. Choosing which words to teach involves teacher judgment, a process in which good teachers are continually engaged." (Stahl, 2005, 101-102). The path here – that of narrowing down which terms to teach – is the first, and perhaps most difficult, aspect of good vocabulary instruction. **We must be selective.**

Fortunately, every science field has *concepts* that students will encounter over and over in our fields, without understanding of which they will struggle. In general, concepts that matter the most recur – and those concepts are the ones that ought to help us generate high-return vocabulary lists. Daniel Willingham summarizes: "Cognitive science leads to the rather obvious conclusion that students must learn the concepts that come up again and again – the unifying ideas of each discipline." (48) In biology, for example, a key concept might be evolution. In chemistry, thermodynamics. The National Research Council's *Next Generation Science Standards* has articulated this as "…*disciplinary core ideas* that focus K–12 science curriculum, instruction and assessments on the most important aspects of science disciplinary content knowledge [italics added for emphasis]."

This is perhaps not groundbreaking: *the vocabulary that we teach should matter*. Given. But there is an additional, second step that we ought to take once we have identified the key concepts in our field(s): once we have identified key concepts, we need to **make explicit the background knowledge** required to understand each key concept, for ourselves, as much as for our students. Such background knowledge – just as much as the key concepts themselves – can and should inform the terms we teach, and when. Making explicit these demands is helpful, because it makes our teaching agenda clear (examples below).

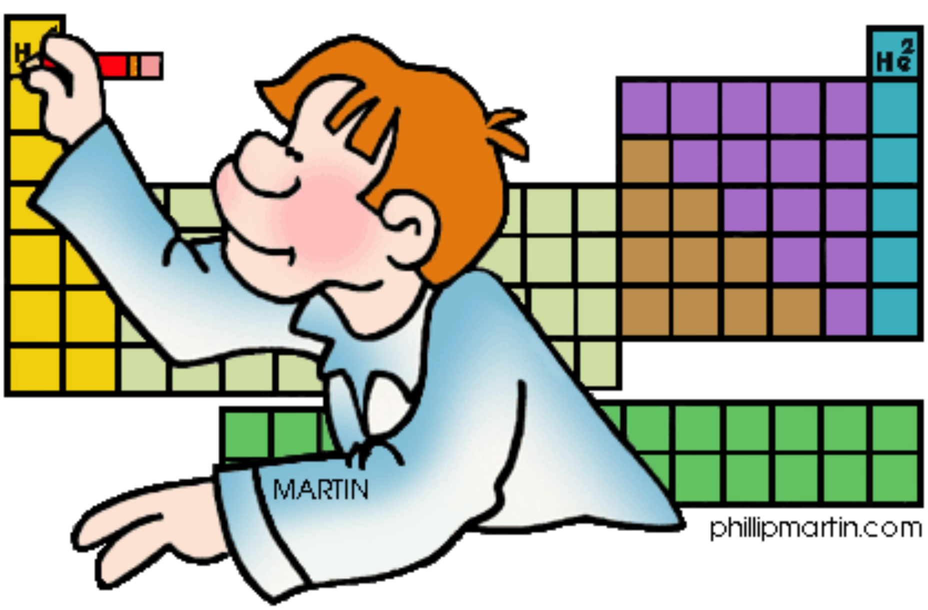
Finally, **sequence and relationships matter**. If and when new ideas or terms require background knowledge, it's important to help students learn the vocabulary *along with* background knowledge that might be spotty or nonexistent. And we must do so at the beginning of and throughout our instruction. Otherwise, the learning our students demonstrate will be limited to either superficial memorization, or by the background knowledge they already possess. We also need to help students understand that list of words in relation to each other and the larger, overarching concept or big idea.

Below are detailed a few examples of the process of teaching new vocabulary in ways that make explicit the background knowledge and conceptual understanding demands involved. Here is one of the authors, describing the introduction of a new term in a recent chemistry class:

Vocabulary Instruction That Promotes Conceptual Understanding: Take One

Ex. 1: Transmutation (n.): *the conversion of one chemical element or isotope into another through a nuclear reaction* (Wikipedia, 2013).

When teaching this word, I try to first identify where students have heard the components of this word before ('*trans-*' and '*-mutation*'); often my students' default strategy with new vocabulary is to latch on to anything they see that appears familiar. And as it turns out, this process is well-grounded in research (see Templeton, Johnston, Bear, & Invernizzi, M., 2009, 103 – though the authors would likely use a more technical description of the process as being a 'generative, word-specific strategy'). Although prefixes, suffixes and phonetic roots are typically taught in English classes to some degree, I have found that many of the word parts relevant to science have been glossed, omitted, or have not been explained thoroughly.



I start with the prefix, '*trans*-.' Many students have learned about geometrical *trans*lations prior to chemistry class; I can take advantage of this by drawing x- and y- axes on the board, and reminding students of what they have learned in geometry. There, students often have learned to translate points (or lines, *etc*.) about the line $y = x$, and when illustrated at the front, it becomes reasonably clear that such points are simply being moved *through* the line. Ergo, *trans = through*. Important idea, and one that can come directly from students.

But we're not done. We then discuss the second part, '*-mutation.*' Students generally have a decent lay understanding of the concept of biological mutations (*thank you science fiction! Also Mr. Snyder the biology teacher down the hall!*). Yet the concept of a biological mutation is not completely helpful here, and can mislead. Part of my direct instruction is to contrast the biological concept (change in genes) with the chemical concept (decay of radioactive isotopes). And it is here, not in teaching a definition, but in situating this new concept within the knowledge my students either have – or have not – mastered, that the work of promoting conceptual understanding is most critical.

To understand the term 'transmutation,' students must learn the word parts – but must *also* have a grasp on a range of foundational ideas, including (at least):

1. How to represent an atom, including mass and charge;
2. Atomic structure (including subatomic particles);
3. The relationships between subatomic particles, mass, and atomic identity;
4. What radiation is, and why it occurs;
5. How to write a chemical reaction; and
6. The concept of a half-life.

The term 'transmutation,' then, is clearly loaded with a variety of key concepts for the study of chemistry – the absence of *any* of which might be fatal to a student's understanding of the term. If, for example, a student does not know that protons are subatomic particles, that they contribute to atomic mass and are key to identity, or that they carry a positive charge, or that they can be given off during radioactive decay, they can memorize **transmutation:** *the conversion of one chemical element or isotope into another through a nuclear reaction* all they want, and it will baffle them still.

Ex. 2: Equilibrium (n.): *a state of dynamic balance in which a chemical reaction and its reverse reaction proceed at equal rates.*

As with 'transmutation,' a good starting point is the prefix '*equi*-' which most students can identify as meaning 'equal.' But here, a generative strategy is less useful than for 'transmutation;' most students have a difficult time understanding what, exactly, is equal in a chemical reaction. Without direct guidance, students risk concluding that equilibrium means ‘equal amounts’ (perhaps the most common conceptual misunderstanding of a chemical equilibrium) – when we’re really concerned with *rates of reaction*. A decent conceptual understanding of the term ‘equilibrium’ comes only with mastery of several background concepts, which I must either pre-assess, remind, or directly teach along with the new term:

1. What a chemical reaction is;
2. How to represent chemical reactions in writing;
3. Directionality of chemical reactions;
4. Laboratory evidence of chemical change;
5. Rates of chemical reactions;
6. Variables that can impact rates (temperature, surface area, concentration, *etc.*); and
7. Some general understanding of thermodynamic principals, particularly conservation of matter and energy transfer.

A significant part of my own direct instruction here is to clarify the concept of *rates of chemical reactions* with students who have seen the term ‘rate’ time and again in different contexts. Most students have a lay understanding of a rate (*e.g.* miles per hour), have developed proficiency at fractions and division, and have been graphing lines and calculating slopes for a few years prior to chemistry class. Hence they are, in theory, quite capable of understanding rates as units-per-some-other-units. Yet again – as with figuring out what to do with student’s *biological* concept of mutation when teaching the chemical sense – there is a distinct new meaning for rates of chemical reactions, and here I must figure out how to situate the new concept within the knowledge my students either have – or have not – mastered.

Vocabulary Instruction That Promotes Conceptual Understanding: Take Two

The second example of effective vocabulary instruction comes from the authors’ co-planning of a lesson in a unit on genetics. For this lesson, we focused on helping students learn individual vocabulary words in relation to the overarching concept of heredity as evident a Punnett square.

A desire to pique student interest around Punnett squares led us to discover "Mr. Lee's Genetics Rap" video available on-line. (See http://www.youtube.com/watch?v=_IOIx__UJ5g). Once we examined all of the words in the lyrics, we realized that if the goal of the lesson was to build students' understanding of Punnett squares, all of the vocabulary words in the lyrics were not equal. Related? Yes. Essential to an introductory lesson on *Punnett squares*? Not so much. For instance, although the words found in the rap (e.g., *asexual*, *fertilization, DNA, and chromosomes)* are important to the study of genetics in general, some words were not critical to understanding a Punnett square. After some discussion, we narrowed the list to seven, key words: *genes, alleles, dominant, recessive, homozygous, heterozygous, Punnett Square.* We then found an on-line resource that would allow us to gauge student learning in an engaging way. Afterall, what adolescent doesn't like Sponge Bob, Square Pants®? (See Appendix B for "Bikini Bottom Genetics" a la Sponge Bob.) This resource prompted us to add three more words to the list, specifically *traits, phenotype,* and *genotype*. (Appendix A shows what our prioritized vocabulary list for Mr. Lee's Genetics Rap" looks like.)

Where we ended up as teachers is not where we started our students, however. At the core of instruction, we wanted to provide students with multiple and varied opportunities to confirm, expand, and contradict what they already knew so that we could foster an accurate and richer understanding of principles important to heredity. We couldn't do that without finding out what they already knew. To do that, we opened the lesson with the question "When you hear or see the word *genetics*, what comes to mind?" This question allowed us to assess students' background knowledge and make links between what they knew and the definition of genetics we would provide. As they listened to "Mr. Lee's Genetics Rap" two times, students were to highlight any words (found in the printed lyrics) they thought were related to the concept of genetics. Students highlighted most, if not almost all of the same words we did. That being said, although students highlighted words like homozygous and heterozygous, many struggled pronouncing them. Anticipating that this might be the case, we asked students to underline words we identified as critical to learning about *Punnett squares*. As we went through the list, we were able to model and provide them further practice with pronunciation.

Students then provided a definition for each of the words that we asked them to highlight, plus three additional words: t*raits, phenotype,* and *genotype*. Most students could define a few of the words, but most, if not all, reported feeling unsure about their definitions. At this point, we asked students to check their definitions with what we then provided. Once we discussed these definitions, we moved on to discussion about a Punnett square, guided practice (see Appendix B), and an exit slip that asked student to apply what they learned with the following question in mind: "Using the cartoon…how is it possible for Nidorans to NOT have horns?"(See Appendix C for exit slip.)

In the end, once we matched our students to our instructional purposes, we employed a number of multi-modal vocabulary strategies aimed at helping students gain disciplinary language and conceptual knowledge around genetics. In other lessons, this same rap was repeatedly revisited but with a focus on the vocabulary important to new (but related) concepts or a review of what had been learned thus far. As such, what began as a way to intrigue students and help students learn vocabulary and key disciplinary concepts, eventually led us to consider the importance of asking students to re-read a text more than once, each time with a changed purpose or focus. As a result, we found that the less-is-more approach was not only strategic and simple, but powerful.

Conclusion

We have, hopefully, highlighted the idea that the recent wave of reforms in New York schools is changing – and will continue to change – what's expected of New York State's science teachers. In particular, the Common Core State Standards (along with the *Next Generation Science Standards*) will for the foreseeable future require science teachers to help develop student's scientific literacy skills. What is clear to us is that all students benefit from learning science when disciplinary language and learning are intricately intertwined with background knowledge.

This is good news, at least as far as we understand it. First, we have argued that the right and proper role of science teachers across New York State in helping students improve literacy skills is *teaching content knowledge*. And second, we have suggested that vocabulary instruction 1) selectively and strategically builds on and expands background knowledge; 2) is layered; and 3) promotes conceptual knowledge by making visible the relationships among individual words to big ideas or overarching concepts is one of the most productive approaches to building disciplinary literacy and knowledge in the sciences you can use. In essence, we have argued that we can promote science literacy skills by teaching content knowledge.

This, then, is no paradigm shift. Surely we can respond to education reform demands, and still do what we love best; we can grow too many plants, we can keep too many aquariums, we can crash things into each other or set them on fire. We just have to be deliberate about what our students know and do not, and what we rely on when teaching them new vocabulary. This is literacy instruction, and it is what we need to do in science classrooms across New York State.

APPENDIX A

Mr. Lee's Genetics Rap Lyrics

Resource: http://www.youtube.com/watch?v=_IOIx__UJ5g&feature=related

Chorus
It may not make sense to ya'll
But once I finish singing this song you'll see
You'll be singing it in the hall
Listen up and learn about your genes.

Maybe you know how to draw
Or you sing a song better than Tim McGraw
Or you grow to be seven feet tall
Whatever it's all about your genes.

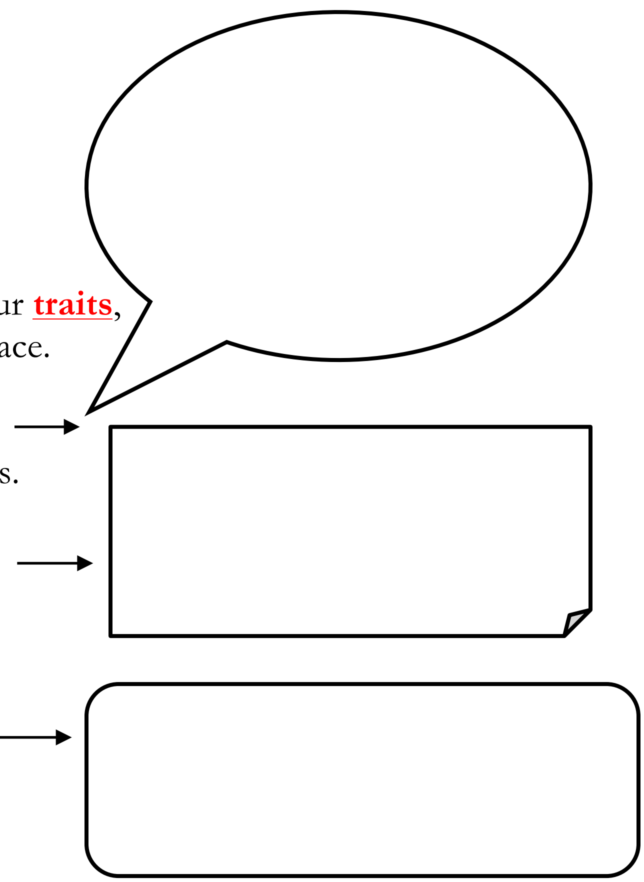
Last name Lee,
First name Mr.
I made this song on Windows 7
Boy I'm not Vista.

Started off talking
But then it got so boring that,
Students always sleeping
And they won't stop snoring.

I decided I would rhyme about genes,
Not the kind you buyin' at the mall with Christine.
The **genes** I'm talking 'bout they controllin' all your **traits**,
From the color of your skin to the shape of your face.

Genes have different versions that we call **alleles**,
They come in pairs of two boy they just like wheels.
Represent on paper write down two T's,
Uppercase **dominant** like Kobe dropping three's.

Small t means allele is **recessive**,
Say that at a party it will be impressive.
What you been doing at your school well gee,
I'm mastering science with my teacher Mr. Lee.



Chorus

Ever ever Mr. Lee is in the building,
Everybody here hey hi how you doin'.
Let's talk about the different types of reproduction,
Over this bass, beat, and percussion.

Asexual is done by bacteria,
You never find those in the cafeteria.
And all of them have the same genes as one parent,
That make them identical, did you hear that?

But most animals reproduce the other way,
They get genes from both parents like a holiday.
Create variation with the parent sex cells,
Fertilization and a zygote sperm plus egg spells

And I know that that's some big words,
Might think if you say em you'll be soundin' like a bunch of nerds.
If both parents pass on the same allele it's **homozygous**,
If they different well I guess it's **heterozygous**.

I wonder if my kid will have straight hair,
I don't know let me find out on my **Punnett square**.
The DNA and genes all coiled up in chromosomes,
Look like X's when you text your boo over the phone.

Like Beyonce where they are where they at,
They balled up in the nucleus, baby that's a fact.

Chorus

Additional Vocabulary

Traits:

Phenotype:

Genotype:

APPENDIX B

Bikini Bottom Genetics Name ____________________________

Scientists at Bikini Bottoms have been investigating the genetic makeup of the organisms in this community. Use the information provided and your knowledge of genetics to answer each question.

1. For each genotype below, indicate whether it is a heterozygous (He) OR homozygous (Ho).

TT _____ Bb _____ DD _____ Ff _____ tt _____ dd _____

Dd _____ ff _____ Tt _____ bb _____ BB _____ FF _____

Which of the genotypes in #1 would be considered purebred? ______________________________

Which of the genotypes in #1 would be hybrids? ____

2. Determine the phenotype for each genotype using the information provided about SpongeBob.

Yellow body color is dominant to blue.

YY _______________ Yy _______________ yy _______________

Square shape is dominant to round.

SS _______________ Ss _______________ ss _______________

3. For each phenotype, give the genotypes that are possible for Patrick.

A tall head (T) is dominant to short (t).

Tall = ______________ Short = ______________

Pink body color (P) is dominant to yellow (p).

Pink body = ____________ Yellow body = ________________

4. SpongeBob SquarePants recently met SpongeSusie Roundpants at a dance. SpongeBob is heterozygous for his square shape, but SpongeSusie is round. Create a Punnett square to show the possibilities that would result if SpongeBob and SpongeSusie had children. HINT: Read question #2!

A. List the possible genotypes and phenotypes for their children.

B. What are the chances of a child with a square shape? ____ out of ____ or ____%

C. What are the chances of a child with a round shape? ____ out of ____ or ____%

5. Patrick met Patti at the dance. Both of them are heterozygous for their pink body color, which is dominant over a yellow body color. Create a Punnett square to show the possibilities that would result if Patrick and Patti had children. HINT: Read question #3!

A. List the possible genotypes and phenotypes for their children.

B. What are the chances of a child with a pink body? ____ out of ____ or ____%

C. What are the chances of a child with a yellow body? ____ out of ____ or ____%

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6. Everyone in Squidward's family has light blue skin, which is the dominant trait for body color in his hometown of Squid Valley. His family brags that they are a "purebred" line. He recently married a nice girl who has light green skin, which is a recessive trait. Create a Punnett square to show the possibilities that would result if Squidward and his new bride had children. Use B to represent the dominant gene and b to represent the recessive gene.

A. List the possible genotypes and phenotypes for their children.

B. What are the chances of a child with light blue skin? ____%

C. What are the chances of a child with light green skin? ____%

D. Would Squidward's children still be considered purebreds? Explain!

7. Assume that one of Squidward's sons, who is heterozygous for the light blue body color, married a girl that was also heterozygous. Create a Punnett square to show the possibilities that would result if they had children.

A. List the possible genotypes and phenotypes for their children.

B. What are the chances of a child with light blue skin? ____%

C. What are the chances of a child with light green skin? ____%

8. Mr. Krabbs and his wife recently had a Lil' Krabby, but it has not been a happy occasion for them. Mrs. Krabbs has been upset since she first saw her new baby who had short eyeballs. She claims that the hospital goofed and mixed up her baby with someone else's baby. Mr. Krabbs is homozygous for his tall eyeballs, while his wife is heterozygous for her tall eyeballs. Some members of her family have short eyes, which is the recessive trait. Create a Punnett square using T for the dominant gene and t for the recessive one.

A. List the possible genotypes and phenotypes for their children.

B. Did the hospital make a mistake? Explain your answer.

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Bikini Bottom Genetics

Answer Key

1. Ho He He Ho Ho He He Ho Ho Ho Ho Ho

Ho	He	Ho	He	Ho	Ho
He	Ho	He	Ho	Ho	Ho

Purebreds - TT, DD, BB, FF, ff, dd, bb, tt
Hybrids - Dd, Bb, Ff, Tt

2.

Yellow body	Yellow body	Blue body
Square shape	Square shape	Round shape

3. Tall - TT or Tt Short - tt
   Pink - PP or Pp Yellow – pp

4.

	s	s
S	Ss	Ss
s	ss	ss

A. SS - square shape, Ss - square shape, and ss - round shape
B. 2 out of 4 or 50%
C. 2 out of 4 or 50%

NOTE: Some of your students may feel that the roundpants gene should be the dominant trait as SpongeBob's TV parents are both roundpants. However, these are only his parents on the TV show and his real parents are both heterozygous for squarepants.

5.

	P	p
P	PP	Pp
p	Pp	pp

A. PP - pink body, Pp - pink body, and pp - yellow body
B. 3 out of 4 or 75%
C. 1 out of 4 or 25%

6.

	b	b
B	Bb	Bb
B	Bb	Bb

A. Bb - light blue skin
B. 100%
C. 0%
D. Squidward's children would not be considered purebred, since each would have a gene pair made up of a dominant gene and a recessive gene.

7.

	T	t
T	TT	Tt
T	TT	Tt

A. TT - tall eyeballs or Tt - tall eyeballs
B. The hospital must have made a mistake, since the genotype "tt" would not be possible based on the genotypes of Mr. and Mrs. Krabbs.
NOTE: Students may come up with other possible scenarios, such as Mr. Krabbs not really a homozygous tall-eyed crab or a mutation. A few of my students suggested that Mr. Krabbs might not be the father!

NOTE: Some of your students may comment that Mr. Krabbs was married to a whale. However, this was only for the TV show and he is happily married to a beautiful crab in real life. (Ok, so it's not "real" life!)

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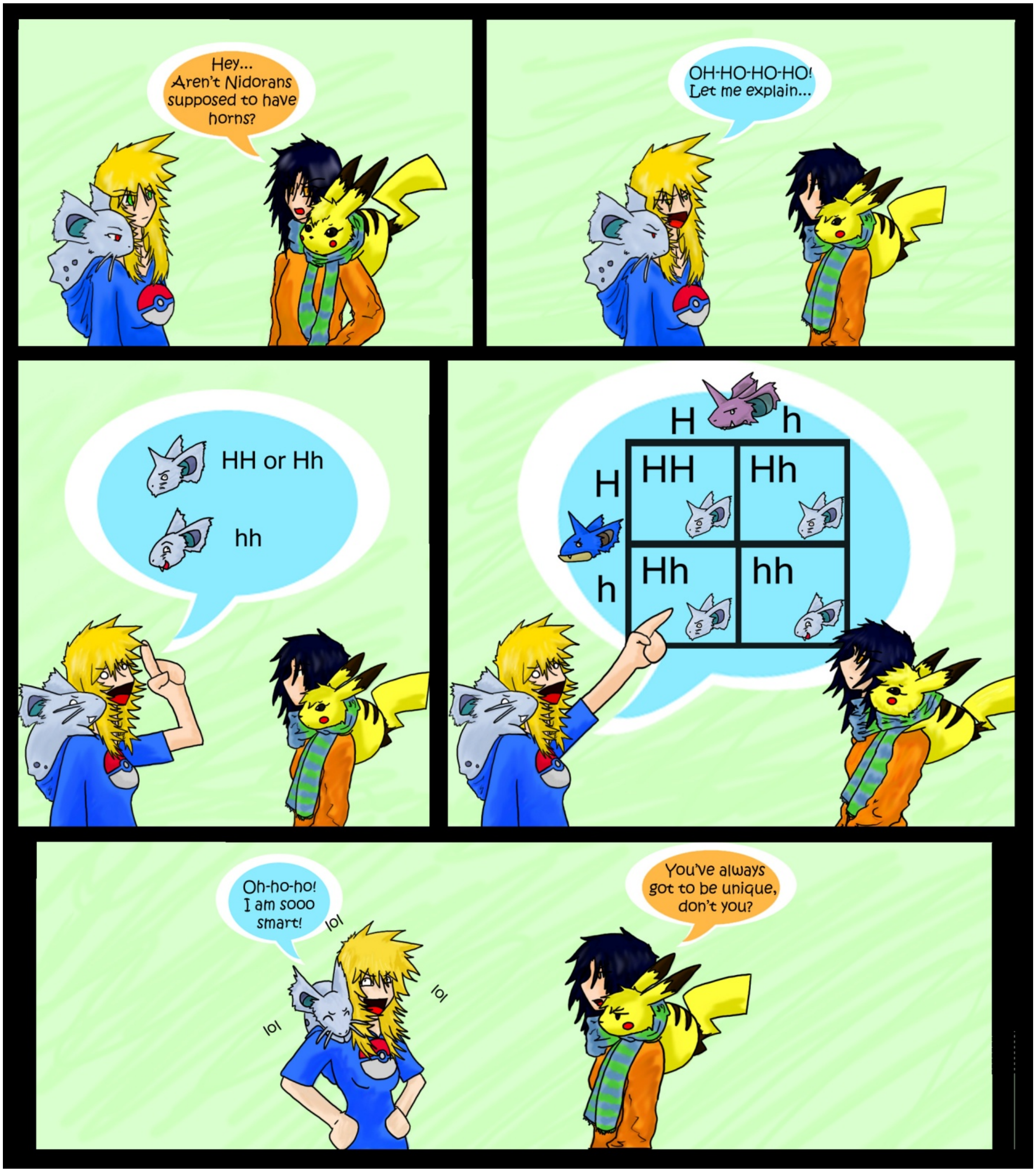
APPENDIX C



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Opening Up the Lab:
Guided Inquiry in Laboratory Experiences

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Introduction: "Inquiry" is fast becoming a formalized tenet of science education across the country. Opportunities to foster student inquiry are formally encouraged in the Next Generation Science Standards, The College Board's Science Standards for College Success, and the redesigned curricula of all AP-level science courses. With the increasing emphasis, it can become very easy for a teacher to get overwhelmed with just how to go about bringing inquiry opportunities to students in a way that is manageable, safe, and that provides for genuine experiences that advance the concepts of a particular curriculum in a meaningful way. Provided herein are some strategies for increasing opportunities for guided student inquiry within the context of laboratory experience in the honors chemistry curriculum at Deer Park High School, in Deer Park, NY.

Levels of inquiry and learner considerations:
In "The nature of scientific enquiry" (1972), Marshall Herron proposes a methodology for identifying the amount of inquiry present in a particular laboratory activity. More recently, Bianchi and Bell (2008) identify four major levels of inquiry. These levels move from confirmation (where learners are provided with a question, and a procedure and are directed how to use the latter to verify a particular answer to the former) through structured inquiry (where learners are given a question, and a procedure, but are tasked with developing their own explanation) into guided inquiry (where learners are given a question, and asked to develop a procedure and explanation), and open inquiry (where learners are asked to develop a question, a procedure, and an explanation). As the levels of inquiry are considered sequentially, the amount of autonomy and responsibility of the learner increases. It is proposed that the greater the level of inquiry in a particular activity, the more meaningful the understanding that learners receive from the activity.

When determining how best to approach increasing the amount of inquiry offered to learners in a particular educational setting, there are a variety of factors that must be considered. The familiarity of learners with inquiry learning, the abilities of learner populations, and structural constraints on the learning process (*e.g.* scheduling, resources), all factor into determinations of what level of inquiry is most appropriate for a particular lab activity in a particular course (or even section). Instructors must be careful to ensure that the experiences that they are offering their students are appropriate for the circumstances.

Methodology: What follows is a description of an approach to increasing the amount of inquiry on offer in the Honors Chemistry curriculum of Deer Park High School in Deer Park Union Free School District (DPUFSD). It was determined that students at the honors level were not being provided with laboratory experiences that moved beyond the structured inquiry level of investigation. After consultation among the instructors, a mode of laboratory investigation that drew more heavily on the guided inquiry mode was developed. This mode (herein termed "inquiry labs") would supplement more traditional, confirmational and structured activities, supplanting some, but leaving others in place where warranted by factors such as student safety, technique training, etc. Many resources were consulted during the development of this instructional mode, but "Inquiry-Based Experiments in Chemistry" (2000) by Valerie Lechtanski was particularly useful in illustrating the level of rigor in inquiry investigations that high school students could reasonably be expected to approach.

When beginning an inquiry-lab, students are presented with an organizer handout that delineates the purpose of the experiment, presents some background information on the specific subject of the investigation, and explicitly addresses safety considerations related to the particulars of the experiment. The purpose of the experiment is always presented in the form of a question. Here are several of the questions that are used to guide our inquiry labs:

- Is density an intrinsic or extrinsic property of matter?
- How can you separate the components of a mixture of sand, salt, and water?
- How can the heat of fusion of ice be experimentally determined?
- How can the bonds that hold a substance together be determined?
- How does changing temperature affect the reaction of Alka-Seltzer and water?
- How much water is incorporated into the structure of a hydrate?
- How can the pH of an unknown solution be determined?

The instructor leads a whole-group discussion of these aspects of the investigation, and takes the opportunity to demonstrate proper operation of all equipment, and reinforce safety aspects of the lab, cleanup procedures, and any other administrative issues related to the lab.

Once this discussion is concluded, students begin developing the procedure that their group will follow to address the purpose of the experiment. It is established that no group can begin their procedure until it is presented to the instructor for final approval. Students are only allowed to work with the other students in their group to develop the procedure that the group will follow. Once a lab group has developed a procedure to the point where they are in agreement that it will address the purpose of the lab, one member of the group shows the procedure to the instructor. If final approval is granted, the group begins their experiment. If final approval is withheld, the group addresses any procedural shortcomings and then resubmits their procedure for instructor approval.

After the experimentation has concluded, the instructor addresses any whole group items that may be required (*e.g.* collection of group data). The guidelines for the final report for the experiment are also discussed. In most cases, students will compose a report that contains the following sections: Introduction (purpose and hypothesis), Methodology (materials and procedure used), Results (data, graphs, figures, calculations) and Discussion (conclusion, error analysis and any answers to particular discussion questions). Students then work to independently develop a formal lab report according to specific guidelines.

Discussion: The inquiry lab approach has been utilized by the DPUFSD Honors chemistry classes for three years. In that time, various kinks in the system were addressed and the process has changed somewhat from its original inception. The major difficulty that instructors encounter when working with students in the inquiry setting is the lack of experience that students have with this kind of laboratory investigation. This is mostly a function of the fact that they have never been expected to develop their own protocols, collect their own data, and synthesize their own, independently-generated answer to a laboratory question. This issue dissipates as the year progresses, but the first few experiments can be very difficult for students. To counteract student acclimatization, the first inquiry lab experiences are very concrete, and require very little in the way of special techniques or equipment. In this way, students are able to focus more on the process of the inquiry lab experience.

Another crucially important part of the process for instructors is the understanding that in the inquiry setting, instructors are expected to act in a mentoring capacity, available to help students crystallize their own thinking, but not to tell students what to do or how to do it. This can be a challenge for instructors, particularly if they are used to working from a more directive approach. It is very easy to look at a student generated protocol and determine how it will fail to address the question it has been designed to address. If instructors carelessly short-circuit the inquiry cycle by passing judgment prior to students running their protocol, opportunities for student learning can be severely curtailed. To deal with this issue, instructors may wish to assume a posture where if an issue is not safety related, it will not be addressed (in which case instructors may find it best to inform students of this aspect of the process prior to beginning a particular inquiry lab), or relate to students in an interrogative style, asking questions about what students are doing to help them evoke their own conceptions and address their own difficulties.

Timing of inquiry lab activities is also a major instructional consideration. Inquiry labs will take longer than more confirmational, "cookbook-style" activities. At the same time, the time that students spend developing a protocol, running it, re-running it when necessary, collecting data, and analyzing it is foundational for the scientific process, and as such it has been our experience that any loss of instructional time is recouped by the learning that is done in the inquiry lab setting.

Other administrative considerations should also be considered. How will instructors collect lab reports? In our program, these issues are determined by the instructor in concert with the students. Originally, all experiential lab work was collected in a lab notebook, and a formal report was then generated on succeeding pages in the same lab notebook. For the past two years, we have used the lab notebook in the lab setting, and have required students to submit electronic lab reports through the district Google Apps portal.

Concluding remarks:

It is not hyperbole to say that inquiry-focused pedagogy is going to be with the science teacher community of New York State for a long time to come. The laboratory setting provides instructors with an easily accessible forum to allow students to develop their own protocols for collecting data and answering questions. The inquiry lab style described above is one possible structure that instructors can employ to allow students to operate in more inquiry-focused laboratory modes. By having students take more responsibility for the design and execution of protocols to formulate their own answers to questions, the skills of a scientist and the learning of a particular body of scientific knowledge are reinforced and expanded. Hopefully other teachers will find this kind of experience as rewarding for their students as we have for ours.

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Resources:

http://goo.gl/NfXUy- Public Chemistry Materials

http://goo.gl/9pVMR- Chemistry Lab Documents. Administrative section includes many of the handouts and templates mentioned in the article.

http://dpchem.wikispaces.com- Chemistry Course Wiki

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David Knuffke teaches science to children in Deer Park, NY. He teaches AP Biology and Chemistry. He is the moderator of the AP Biology Teacher Community for the College Board, and maintains mrknuffke.net, where he gives it all away for free. In 2012, he was the recipient of the High School Science Teacher of The Year award from the Suffolk County Science Teachers Association, and the Kim Foglia AP Biology Service Award from the National Association of Biology Teachers.

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A Hands-On Investigation of Electric Circuits Using a Light Bulb

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Abstract: This article describes an activity that introduced students to the scientific process using a novel curriculum examining a household item: a 3-way incandescent light bulb. I built upon standard introductory exercises involving simple DC circuits with batteries and miniature light bulbs. Standard activities have merit in exposing students to ideas of a closed circuit, current flow and resistance, but they often fail to fully invoke the scientific process. Using 3-way bulbs, I extended these experiments to draw testable hypotheses from my students. Allowing my students to explore 3-way bulbs turned my students into scientists doing inquiry.

Introduction: The study of electricity can be very challenging to students. Many students initially possess ideas about the flow of electric current in simple DC battery and bulb circuits that are highly inconsistent with a physicist's views (Henry & Jabot 2007; McDermott & Shaffer 1992; Borges, Tecnico, & Gilbert, 1999). Other studies have been conducted specific to students' ideas of potential difference (Liegeois, Chasseigne, Papin & Mullet 2003) and resistance (Liegeois, Mullet, & Mullet, 2002). It is a common mistake in instruction to assume students have some basic knowledge of simple electric circuits (Arons, 1997). A study by McDermott and Shaffer (1992) revealed that many students had no observational or experiential base that they could use as a foundation for constructing the formal concepts of introductory electricity. McDermott and Shaffer's survey of a large calculus-based physics class found 60% of students lacked precious experience with simple DC circuits. In fact, only about 15% indicated that they had some familiarity with batteries and bulbs. Students' lack of hands on experience leads to several deficiencies including an inability to apply formal concepts to an electric circuit, an inability to use and interpret formal representations of an electric circuit, and an inability to reason qualitatively about the behavior of an electric circuit.

The literature shows traditional lecture style teaching often has little impact on students' preconceived ideas (Prakash 2010; McDermott & Shaffer, 1992). As teachers, we know all too well how many of our students enter our classroom with little knowledge of topics "covered" in a previous class. Our students may be passing exams without truly understanding the material by memorizing content with little context to its proper application (Lujan & DiCarlo, 2006). Many students succumb to memorization when studying electricity, often because the opportunity to experiment is not sufficiently granted during instruction.

The activity described in this paper expands on standard battery and bulb activities described thoroughly by Evans (1978), McDermott & Shaffer (1992), Arons (1997) and others. The 3-way bulb investigation offers hands-on time for students to see and think about circuits in real life applications. The activity is designed to be conducted with all levels of high school or even middle school students, ranging from a recommended minimum of 80 minutes to 120 minutes or more, depending on the ability of the students and the depth of study desired. It is best run all in one day if possible.

Table 1: **Electricity and Scientific Inquiry Skills from the NYS Physics Core Curriculum**
Standard 1: Analysis, Inquiry, and Design
Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.
Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.
Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.
Standard 7: Interdisciplinary Problem Solving
Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision-making, design, and inquiry into phenomena.
STANDARD 4: The Physical Setting
4.1n A circuit is a closed path in which a current* can exist. (*use conventional current)

Traditional Teaching:

"Public understanding of science is appalling. The major contributor to society's stunning ignorance of science has been our own educational system" (Volpe, 1984, p.433). Three decades ago, Volpe was sounding the alarm – a wake-up call to educators to get our students to "actively know," not just "passively believe." Traditional teaching often involves a "sage on the stage" lecture-oriented classroom. The teacher tells students what he or she knows and the students are left to memorize as much as possible. Even lucid lectures from experienced and knowledgeable teachers often fail to develop within students the critical thinking, problem solving, and communication skills we strive to instill. Lectures expose students to content, but exposure is not sufficient for learning. Research indicates that students forget much of the factual information they memorize. Furthermore, after a short time, students who received high grades know no more that students who received low grades (DiCarlo, 2009). Passive reception of information is very limited and short lived. We must allow our students to actively process new information (Lujan & DiCarlo, 2005).

Active Learning:

In recent years, numerous studies have reported on the merits of active learning over so called traditional teaching. How can teachers create an environment where students are more active in their own learning? Michael, (2006, p. 160) offers this definition from the *Greenwood Dictionary of Education:*

> "Active Learning: …The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving."

An active learning environment in the classroom lifts our students above the role of passive "regurgitator" and turns them into scientists who must gather information, think and solve problems – in short, construct working models based on observations they make and data they collect. C*onstructivism* (Freedman, 1998 cited in İpek and Çalık 2008) forces students to link new learning to prior knowledge, often confronting misconceptions head on (Michael, 2006, p. 160).

Why should we bring active learning into our classrooms? Where is the evidence that active learning works better than traditional teaching methods? Using, the Force Concept Inventory (FCI), a valuable assessment tool for the classroom teacher, Richard Hake performed a comparison of learning outcomes from 14 traditional courses (2084 students) and 48 courses using "interactive-engagement" (active learning) techniques (4458 students). The results showed students in the interactive-engagement courses outperformed students in the traditional courses on the FCI assessment by 2 standard deviations (Michael, 2006, p. 162).

In a side-by-side comparison of a first year introductory electricity and magnetism course at the University of British Columbia, researchers compared 2 sections taught with contrasting instructional methods. In a 1-week period, class A was taught using traditional lecture style instruction by an experienced and motivated faculty member with high student evaluations. Class B was taught using constructivist ideas designed to get the students "thinking scientifically." The results were striking – with class B performing more than twice as well on a 12-question test administered at the end of the week (Deslauriers, Schelew, & Wieman, 2011).

In another side-by-side comparison, Burrowes (2003) compared learning outcomes in two sections of the same biology course taught by the same teacher. One section was taught in the traditional teacher-centered manner, whereas the other section was taught in a manner that was based on constructivist ideas. The results of this experiment were striking: the mean exam scores of the experimental group were significantly higher than those of the control group, and students in the experimental group did better on questions that specifically tested their ability to think like a scientist (Burrowes, 2003).

Applying Active Learning: Lighting the Way

If we expect our students to use knowledge to solve problems, we must provide them with opportunities to practice problem solving and receive feedback about their performance (Michael, 2006, p. 161). This is best accomplished by restructuring our class-time to provide more opportunities for students to be engaged in actively doing science. Certainly, some topics lend themselves more readily to an active learning approach. Direct current electricity is a subject rich in the opportunity for reasoning, for the development of models and theories, for the design of crucial experiments, and for free exploration. "If the students are to realize the benefits of this opportunity, they must be left to their own devices much of the time" (Evans, 1978, p. 16). We must be mindful that most students require guidance in their investigations to arrive at desired learning outcomes. Arons (1997 p.199) suggested initial suggestions and leading questions, not "cookbook instructions" that disrupt inquiry.

Electric Circuits – An Introductory Activity:

Evans (1978) outlined detailed activities involving various arrangements of batteries, bulbs and wire. "As elementary as these tasks may seem, they are essential. Most of the students have no idea about way the various wires inside a light bulb are connected. Lacking this understanding, how secure can they be in their understanding of 'circuit'?" (Evans, 1978, p. 17).

My students included general and Regents level physics classes consisting of a mix of 11th and 12th graders. They typically had very limited exposure to electricity in previous classes. Some have had brief and seemingly unconnected hands on experience with batteries and bulbs in 4th grade while others did not. I conducted the following 40-minute activity prior to the 3-way bulb activity to give my students background knowledge of what a complete circuit entails and how a light bulb is wired inside. Those that had previous experience typically fare little or no better than those who had none.

1. Give the students a worksheet with 10 hypothetical setups involving a battery, bulb, and 1 or 2 wires (see appendix A). I ask students to predict which of the 10 setups will light the bulb and which will not. They are to circle Y or N next to 'prediction.' Allow 2-3 minutes for this task.

2. Towards the end of the 2-3 minutes, ask them to count the total number of 'yeses' and write that number in the upper right corner of the sheet. As I wander around the room, I can quickly see that most papers have the wrong number in the upper corner. Typically only one or two (if any) out of the entire class correctly predict that only 2 of the setups will work.

3. Allow the students a few minutes to discuss their choices with a partner and check for agreement on predictions. If both partners agree on a yes or no, they may move on. If they disagree, they should explain their reasoning to their partner and try to convince the other person to change their mind. Listen carefully to their conversations to get an idea of where they are starting out. Ultimately, they may agree to disagree and keep their differing predictions.

4. Next, give the students a battery, bulb, and 2 wires of 6-8" in length. It is best to use relatively new alkaline batteries. Some of the 10 setups are short circuits and will get warm to the touch (I warn them as I pass out materials that some setups might get warm). This is important for students to make note of for later discussion. I allow about 10 minutes of experimentation, and instruct students to circle Y or N next to 'observation' for the setups that actually work. This allows me to wander around the room and verify each group is correct in their findings.

5. I then ask students to write a sentence or two outlining what conditions are necessary for the bulb to light. Most students indicate something to the effect of both sides of the battery must be touched and the side and bottom of the bulb must be touched.

6. Next, ask students what the inside of the bulb must look like behind the threads. Have them predict and draw their ideas on the blank light bulb picture (see appendix B - Top). I then give them a minute or two to discuss with their partner while I pass around clear household (120V) bulbs that have been specially prepared so as to be able to clearly see inside by grinding away some of the metal threaded area (see figure 1). The goal is for students to see one wire connects to the side of the bulb (threads) and one wire connects to the tip (base). I close the first day having students draw a complete circuit including a battery, wires, and bulb (see Appendix B – bottom). If time permits, I ask the class if it matters whether the current enters the side and exits the bottom of the bulb or vice versa. I lead them to realize that either way works fine (the filament doesn't care which way the current flows) however it is safer for current to enter the bottom and exit the side. At 120 V (household voltage), the hot wire is turned on or off by the switch and contacts the bulb on the bottom, while the threaded side of the bulb connects to the neutral. At this stage I don't discriminate between alternating and direct current.

<u>Inquiry with a 3-Way Bulb:</u>

At this point, students should understand a complete circuit is required for electric current to flow. The activity described here offers students the challenge of applying basic circuit concepts to a novel, real world application; a 3-way incandescent bulb. Students must formulate a theory about the inner workings of a 3-way bulb and provide supporting evidence based on their observations and experiments. Students must use prior knowledge and reason qualitatively about the behavior of electric circuits by examining evidence to construct a working theory. There is a heavy emphasis on active learning techniques.

1. Introduction – How do 3-way bulbs work? (8-10 minutes)
    a. Pass out 3-way bulb activity worksheet (appendix C) and experiment log (appendix D).
    b. Begin lesson with a 3-way lamp in the front of the room. Demonstrate the 4 possibilities: off, low, medium, high.
    c. Challenge students to form a hypothesis about how the 3-way bulb is wired inside without making any more observations. Encourage testable

hypothesis. Allow 3-5 minutes for students to form a hypothesis on their own. They should record a written hypothesis in the box provided on the top of their experiment log. Encourage drawings or diagrams.

2. Rules of the challenge (5 minutes)
    a. Similar to real life, they will be on a budget. Each group of two to three students will receive a fictional grant of $5000. They will use this grant to pay for various experiments with the 3-way bulb.
    b. Students must design experiments (within their budget) that serve to support or disprove elements of their hypothesis and document these experiments in their experiment log (appendix D).
    c. The one experiment that students cannot afford is to break open a 3-way bulb. I tell them that in the "real world," some experiments are either too expensive to conduct within budget or simply not possible with current technology. Breaking open the bulb fits into this category.
    d. Students must NOT look up information specific to 3-way bulbs in print or on the internet.
    e. Students can earn more grant money by writing their experimental observations down and submitting to *Electrician's Digest*, a fictional scholarly journal within the classroom for sharing of information amongst the groups. These submissions are shared publicly within the classroom on either a lab table or bulletin board.

3. Ask the students what experiments they could perform to test their hypothesis.
    a. At this stage, I emphasize to students that science is a creative endeavor, and that constructing models and explanations about phenomena in nature requires human creativity and imagination (Goldberg, Robinson, & Otero, 2007, p. 55). These models can then be tested and evaluated based on experimental evidence.
    b. Students should design specific experiments to test various elements of their hypotheses. Example experiments are listed in appendix F, along with their associated "cost."

4. Students perform experiments to test hypothesis. This is the core of the activity, lasting anywhere from 40 to 80 minutes.
    a. When students have designed an experiment and are ready to perform it, deduct an appropriate amount from their budget.
    b. Example "costs" are listed in appendix F. I usually tell them they have 5 minutes for each experiment. I let them police themselves on time.
    c. If students desire to do experiments outside the realm of experiments discussed in the table, use your judgment accordingly. My rule of thumb is that experiments based on observation are cheaper than experiments that require action or energy.
    d. Students must complete an experiment log for each experiment they perform. Students accept or reject their current hypothesis based on experimental evidence or research through Electricians Digest. I usually require a minimum of 3 experiment logs filled out per group.

5. Ultimately, the lesson culminates in a white-board session (MacIsaac) lasting 20-30 minutes or more where students share their findings with the class. During presentations, others can comment with similar findings, concerns, or divergent ideas. My goal is always to encourage student discourse and play the role of facilitator.

<u>How a 3-way Bulb Works:</u>
An incandescent 3-way bulb provides 3 levels of brightness by the use of two filaments within the bulb (see figure 1). A low illumination setting is achieved by lighting a high resistance (low current) filament. Medium illumination is achieved by lighting a lower resistance (more current) filament. Higher illumination is achieved by lighting both filaments simultaneously.

Figure 2 shows the bottom of the bulb contains two metal connections, one leading to each filament. The threaded side of the bulb connects to the neutral wire. Figure 3 shows a regular socket (left) vs. a 3-way socket (right). Both sockets have a brass flap that contacts the center of the bottom of the bulb. The 3-way socket contains an extra connector that touches the extra metal ring on the bottom of the 3-way bulb.

The switch inside a 3-way socket (figure 4) contains a rotating disc that is ¾ metal and ¼ plastic insulator. Each click of switch rotates the center disc 90^{o}. When the plastic fourth contacts the incoming "hot" wire from the socket, the bulb is off. The first click rotates the plastic quadrant to the low resistance filament, leaving it off and connecting the hot wire to the high resistance filament. The second click rotates the plastic quadrant to the high resistance filament, turning it off and the low resistance filament on. The third click rotates the plastic piece out of the way, so that the three metal quadrants connect the hot wire to both filaments.

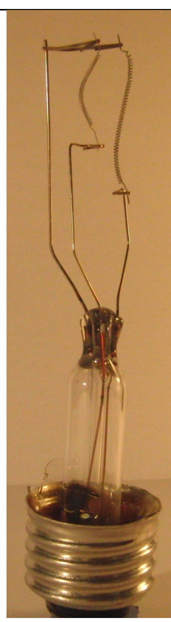
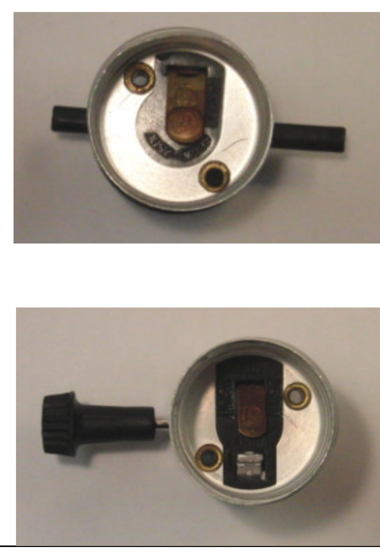
Figure 1	**Figure 2**	**Figure 3**
		

Figure 4

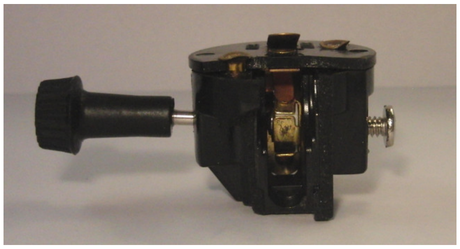


Figure 5

Figure 6

3-Way Bulb Activity: Discussion, Modifications and Extensions

At the onset, many interesting and plausible hypothesis emerge amongst the class. The most common initial hypothesis is that there are 3 filaments contained within the bulb. I always ask students to clearly indicate how 3 filaments offer 3 distinct levels of brightness; for within the "3 filament" theory there are two distinct variations.

Some students believe the first click of the switch lights one filament, the second click lights an additional filament, and the third click lights three filaments at once. A similar theory is that the first click lights one filament, the second click lights a second, brighter filament, and the third click lights a third, brightest filament in a one-at-a-time fashion. Both of these theories have merit and can only be changed by careful investigation of the bottom of the 3-way bulb and the 3-way lamp socket (there are only 2 inputs to the bulb).

Another common initial theory amongst students is that there are 3 different resistors in the 3-way lamp socket that allow 3 different amounts of current into the bulb. This theory suggests an ordinary light bulb would work in a three-way lamp. While plausible, this theory is quickly debunked by investigation of the 3-way bulb or socket, or testing of a regular bulb in a 3-way lamp.

Some students quickly deplete their budget on several experiments and fail to note significant features of a 3-way bulb or socket. These students often stand by an incorrect theory. Out of money and still not sure how the bulb works inside, these students often congregate around the electricians digest, waiting for information from other groups experiments. I encourage them to read as much information from others as possible to try to support or disprove their hypothesis.

Some students reach wrong conclusions from observations during various experiments. I have seen some students think that the two connections on the bottom of the 3-way bulb and the treaded side of the bulb provide three ways for electricity to get in, "proving" a three-filament model. These mistakes usually come out during whiteboarding sessions through rich dialog between students. Two or more groups may observe the same thing and infer different meaning from the same observation. Usually, the class reaches a correct conclusion during the resulting discourse.

In some instances, I have provided a mix of 30/70/100 W bulbs (figure 5) and 50/100/150 W bulbs (figure 6). Some clever students pick up on the fact that the maximum wattage of the 3-way bulb is the sum of the first two. Students typically only look at one bulb experimentally but often read through the Electrician's Digest that others have observed different wattages on the bulb. This observation provides evidence supporting two filaments within the bulb that add together to produce the highest level of illumination (power). 50/100/150 W bulbs seem to offer less definitive information about the number of filaments within the bulb because a 50 W filament and a 100 W filament add to make 150 W or three separate 50 W filaments add to make 50 W, 100 W and 150 W. Instructors may choose to use all the same bulb or intentionally mix in some of each.

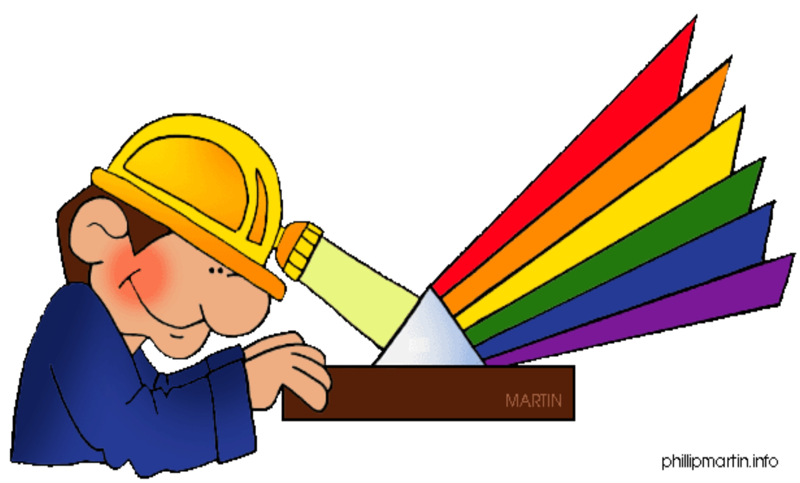
I recommend using bulbs that are heavily frosted to prevent seeing inside. Some students attempt to hold the bulbs up to the lights or windows to see inside. I quickly protest such behavior and insist they examine the exterior of the bulb only.

The 3-way bulb activity can be extended to include discussion of the resistance of each filament and the current through each filament, the electrical energy and power consumed by each filament, and the parallel configuration of the two filaments.

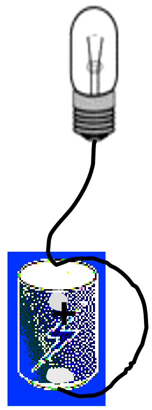
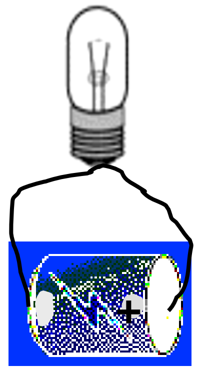
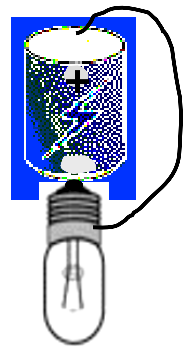
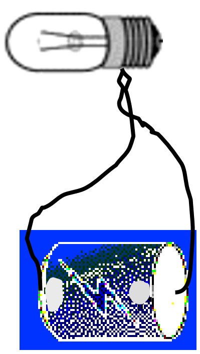
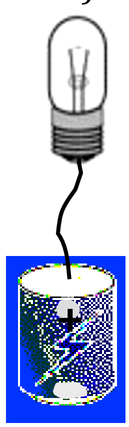
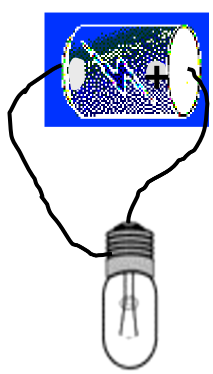
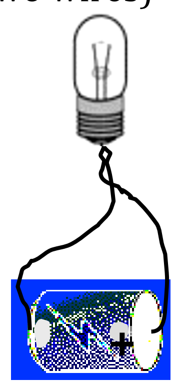
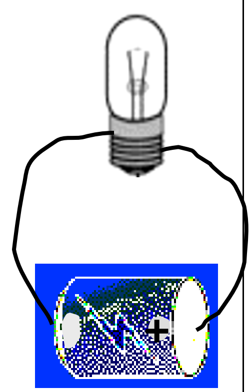
The intricate detail of the 3-way switch is fascinating to some students and beyond the grasp of others. I typically direct the more advanced students in the class who may finish early to figure out the details of the switch.

Conclusion:
I recommend the 3-way bulb activity for teachers looking for a unique opportunity to allow their students to assume the role of scientist. You will find many 'difficult to engage' students open up and participate much more than usual. Having students work together in a small group encourages discourse associated with planning what experiments to perform and the conclusions drawn from those experiments.

Acknowledgements: This paper is submitted in partial fulfillment of the requirements for PHY690: Master's Project at Buffalo State College under the guidance of Dr. Dan MacIsaac.

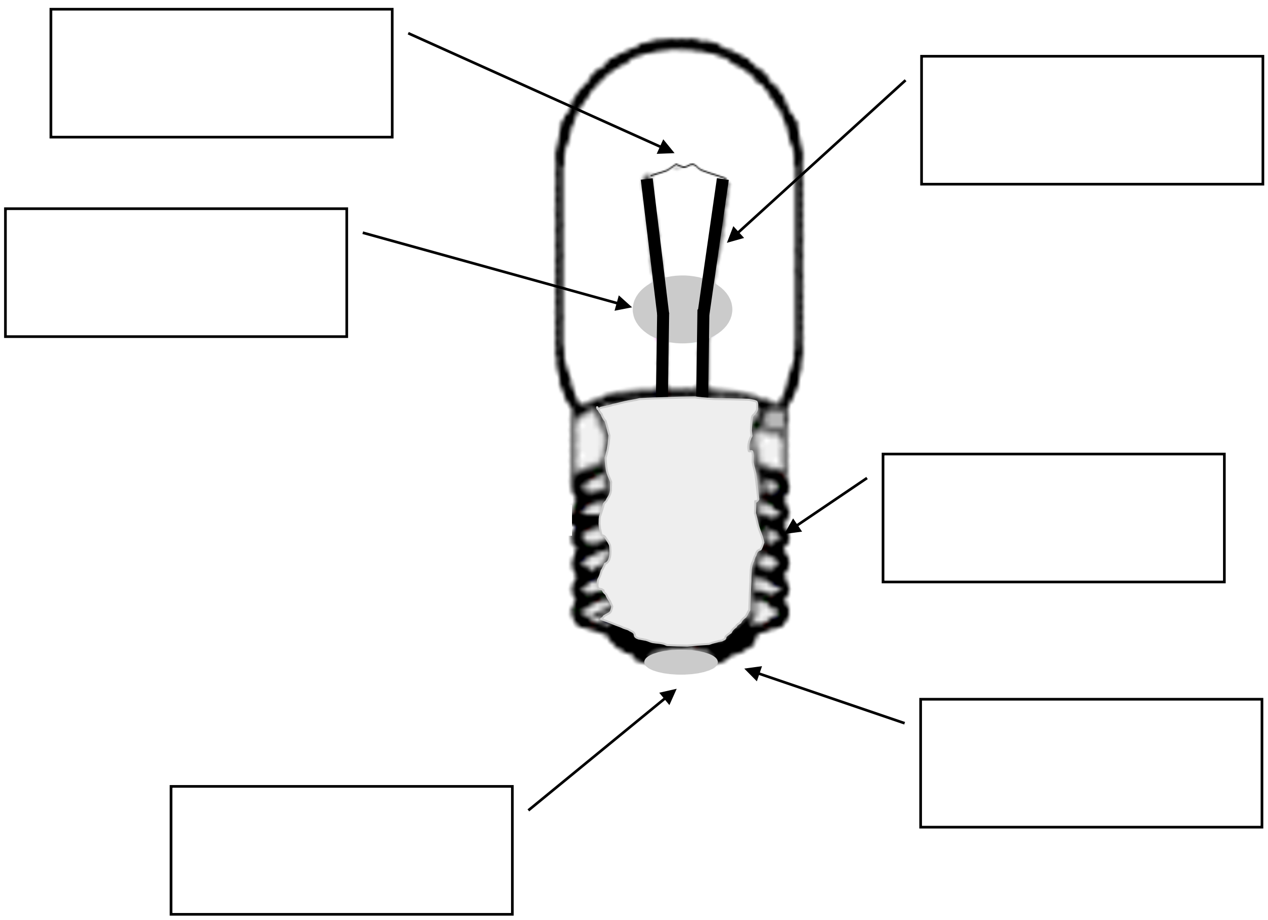


Appendix A: Batteries and Bulbs Student Worksheet (Heller & McCullough, 2011).

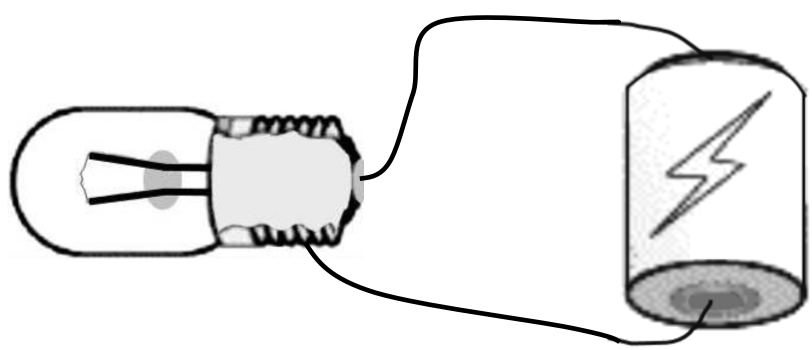
1 (No wires)  Prediction: Y or N Observation: Y or N	2 (One wire)  Prediction: Y or N Observation: Y or N	3 (One wire)  Prediction: Y or N Observation: Y or N	4 (One wire)  Prediction: Y or N Observation: Y or N	5 (One wire)  Prediction: Y or N Observation: Y or N
6 (Two wires)  Prediction: Y or N Observation: Y or N	7 (One wire)  Prediction: Y or N Observation: Y or N	8 (Two wires)  Prediction: Y or N Observation: Y or N	9 (Two wires)  Prediction: Y or N Observation: Y or N	10 (Two wires)  Prediction: Y or N Observation: Y or N

Appendix B – Batteries and Bulbs Student Worksheet p.2 (Heller & McCullough, 2011).

Label all of the parts of a light bulb. Also write if the part is an insulator or a conductor.



In the following diagram use a colored pencil, crayon, or marker to carefully follow the path of conductors from one side of the battery to the other:



Appendix C: 3-Way Bulb Activity Sheet p.1

Name ________________________ Date _______________ Period _____

Purpose: You must develop and test a hypothesis about how a 3-way bulb works. Your goal is to develop a theory backed by evidence about the inner wiring of the bulb.

Introduction: Design and then perform experiments as necessary to test your hypothesis. You must pay to perform each desired experiment. Simpler "observational" experiments are cheaper while more complex experiments are more expensive. To further your abilities of scientific deduction, **you may NOT break open a 3-way bulb for any reason.** The internet or reference books are also strictly prohibited. In this spirit of conducting "real" science where the "right answer" is not yet known, do NOT cheat!

Requirements:

- Develop a hypothesis about how a 3-way bulb operates. Record your initial hypothesis in the box provided.
- Design the experiments necessary to test your hypothesis. (Most likely experiments will be observational in nature.) Describe your experiment in the box provided on the experiment log provided.
- Describe in as much detail as possible your observations and conclusions from each experiment performed.
- In the final box, indicate whether the evidence supports your current hypothesis or suggests formulating a new and different hypothesis.
- Electricians Digest: You may submit your findings to the Electrician's Digest journal. The journal is a collection of experimental results that will be spread out on a lab table for all to see. Quality submissions will be rewarded with a $500 payment.
- **Fictional operating budget = $5,000**
- You will work in groups of two.

Getting Started: For example, your first experiment could be to observe a 3-way bulb. Explain the experiment on your "Experimental Log" sheet and then get a price quote and permission from your teacher. The amount of time you have to perform the experiment may be limited, so work fast and record observations on paper to be analyzed after the experiment. Think of any additional experiments you would like to perform. Some may not be possible due to cost or equipment considerations, but this is very true in the real world as well.

Appendix D: Experiment Log that students complete for each experiment done.

Experiment Log Names:

Current Hypothesis	
Experiment Description	
Observations / Drawings	
Conclusion	
Supports current hypothesis or suggests a new hypothesis?	

Appendix E: Submission form for Electrician's Digest

Names:

Experiment Description	**Observations / Drawings**	**Conclusions**

Appendix F: Recommended experimental "costs"

Fictional Operating Budget = $5,000

Experiments	Cost
Look at a regular bulb	1000
Look at a 3 way bulb	1500
Look in a regular lamp with bulb removed	1000
Look in a 3-way lamp with bulb removed	1500
Plug in and test a regular bulb	1000
Plug in and test a 3-way bulb (keep the shade on, otherwise filaments are visible)	2000
Look at a 3 way switch (Attempted cut-away of inside the switch. Pieces were removed in an attempt to see inside the switch mechanism.)	2000
Using a multi-meter in conjunction with any other experiment. (appropriate for more advanced classes)	500
Plug in and test a 3-way lamp with a regular bulb installed (shade on)	2500
Plug in and test a regular lamp with a 3-way bulb installed (shade on)	2500
Payment for journal submissions	500

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A Program for Talented High School Science Students

Marvin Druger
Syracuse University, Syracuse, NY

Many years ago, I interviewed the late Nobel prize-winning physicist Isidor Rabi of Columbia University on my radio interview program on WAER-FM 88.3 (*Druger's Zoo*). We discussed the value of providing special science programs for gifted students. I said, "Many people believe that such programs are unnecessary, since these talented students will succeed anyhow." He replied, "No, We need special programs for talented students. Otherwise, instead of becoming bright scientists, they could become bright gangsters." I thought about his remark and became convinced that we do need special programs to enrich scientific talent among our brightest students. Science for all is a worthy goal, but we should not ignore the need for special programs for the brightest youngsters.

For several years, I have been conducting a *Saturday Frontiers of Science Program for Talented Students in the Syracuse Area.* The program involves a series of ten Saturday science sessions (9:00 A.M. – Noon), at Syracuse University, spaced throughout the academic year.

The sessions are taught by science faculty, graduate students and high school teachers and include a variety of science topics that go beyond what is usually taught in high school. Each session has a laboratory component. The 2012-2013 program includes sessions on *Electricity, Magnetism and Superconductivity; Earth Sciences; Introduction to Engineering; Modern Drosophila Genetics; Molecular Biology; Food Science; Science Book Archives; The World of Vision; Energy; and Lasers and Applications of Light*.

The program is under the auspices of the Department of Science Teaching. Schools pay a fee of $650 per student but, since I want to reach as many students as possible, a participating school can send an additional student free for every two paid for. The fee is used to provide an honorarium of $150 to each presenter, hire a course assistant, provide breakfast snacks, purchase supplies and hire a part-time secretary. I do not receive any pay, and my wife serves as the part-time secretary. She only gets paid if there are funds remaining at the end of the program.

An important feature of the program is that there is no application form and I do not select the participants. Each participating school is asked to select as participants the students who they believe will benefit most from the program. Some parents who heard about the program have said, "I'd like to pay for my child to attend the program." My response is that "We only accept fees from the schools, not directly from parents." So, financial arrangements are in the hands of the schools, thus relieving me of that concern.

Parents are invited to participate in the final session on Lasers and Applications of Light. At that session, certificates of participation are awarded. A letter of commendation for each participant and a program agenda is sent to the school principals to include in the students' file.

I am describing this program because I believe it can serve as a model for similar programs elsewhere. The program essentially runs on its own. All the director has to do is to solicit appropriate presenters, hire a graduate assistant and a part-time secretary, remind students about each session, and attend to any problems or concerns. My experience is that scientists are very willing to help. They seem to enjoy working with these bright high school students. One year, I thought we would not raise enough money to run the program. I told this to the presenters and they were willing to conduct their session without pay. Fortunately, we did raise enough money that year, after all.

Students seem to like the program and I thoroughly enjoy seeing these bright science students from different schools interact with each other. In school, they do not often get opportunities to meet and interact with other bright students who really like science. Parents get a taste of the program by attending the final session.

It's nice to get grants to run such programs, but I believe they can be run by using a bit of determination, ingenuity and good will. Big-time funding is not necessary IF you really want to develop such a program. Try it and see.

About the Author: Marvin Druger is professor emeritus of Biology and Science Education at Syracuse University, and Laura J. and L. Douglas Meredith Professor for Teaching Excellence. He earned his undergraduate degree at Brooklyn College, and his master's and Ph.D. degrees from Columbia University. He taught introductory biology for about 55 years and was chair of the Department of Science Teaching for about 21 years. For many years, he supervised the teaching of his biology course by high school teachers to seniors for college credit as part of the Syracuse University Project Advance program. He served as president of the National Science Teachers Association (NSTA), the Association for Science Teacher Education (ASTE), and twice president of the Society for College Science Teachers (SCST). He is the recipient of the Robert Carleton Award from NSTA and the Honorary Emeritus Member Award from ASTE – the highest awards bestowed by these international science education organizations. He served as a program officer and headed the Networks Program at the National Science Foundation in the mid-1980's. He served as chair and as secretary of the Education Section (Q) of the American Association for the Advancement of Science (AAAS). He has a radio program on WAER-FM 88.3 (*Science on the Radio*) that is designed to enhance the scientific literacy of the general public. He organizes and directs a Saturday science enrichment program for talented high school students in the Syracuse area. He has contributed to science education in countless ways during his long career, and he continues to do so.

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Submission Guidelines

The Science Teachers Bulletin welcomes articles about science and science education. If you wish to submit an article for publication, please prepare the following:

1) Double-spaced manuscript (in Microsoft Word format) with figure, tables, photos or other images separated from the main body of the text. Permission for image/photo use may be required.

2) References (if used) at the end of the text using an appropriate reference format.

3) An autobiographical sketch including your background, email, telephone number and address.

For additional information or if you have any questions, please contact:

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