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In today’s complex world, teaching young adults about being Green, from an educational standpoint, is not a difficult endeavor. The need to conserve, reduce, recycle and sustain is increasingly apparent with dwindling resources coupled with the increase in need for space, healthy food, and clean water and air. The necessities of making our world, our environment and our schools more sustainable are not just the right thing to do, it is a moral imperative and it can be done. Sustainability is loosely defined as our capacity to endure. In ecology, sustainability describes how biological systems remain diverse and productive over time. Long-lived and healthy wetlands and forests are examples of sustainable biological systems. For humans, sustainability is the potential for long-term maintenance of well being, which has environmental, economic, and social dimensions. School leaders can contribute significantly to sustainability by creating opportunities to not only educate students, but to model the implementation of sustainability strategies through place based learning opportunities.

Schools can play a major role in incorporating the concept of sustainability into the curricula and instruction. Young adults see their world changing at a fast pace and see their world shrinking as we enter an age of fostering global empathy. They see the need to work together and the ultimate priority to save and sustain our resources and our world. Students really want to make a difference in their world and it is easy to capture their interest in improving their world they are inheriting from the adults. One way to pursue these needs is through Place-Based Education. Students naturally understand their environment and have an innate interest in affecting their world around them. That natural motivation to impact their own environment makes becoming a green school that much easier. “Place-Based Education has the potential to foster students’ connection to place and creates vibrant partnerships between schools and communities. It boosts student achievement and improves environmental, social and economic vitality. In short, place based education helps students learn to take care of their world by understanding where they live and taking action in their own backyards and communities.” (Place Based Education Evaluation Collaborative, 2007) Not helpful? You can block www.promiseofplace.org results when you’re signed in to search. www.promiseofplace.org

As a former principal who has returned to the classroom, I have learned that in order to become a Green School, educators and school leaders must tap into interests and motivations of students and in doing so, provide the relevance that students crave today. In the pursuit of sustainability, conservation, and the greening of a school, students willingly become participants in their learning, become enthusiastic about their world environment and become motivated about doing something that makes a difference. “Place-Based Education boosts students’ engagement, academic achievement, and sense of personal efficacy as stewards of their local environment and community. It also can re-energize teachers.” (http://www.promiseofplace.org, 2011)
At our school, getting students to do the work to promote a sustainable environment has led to activities that inspire students to not only participate but to become active participants of several projects. For example, our students have worked on efforts to recycle paper and plastic in school, process recycled materials, build vegetable and butterfly gardens, construct a nature trail, remove invasive plant species, complete pond studies, plant native species, conduct water quality testing and experiment with alternative energy sources. Creating these activities required minimal groundwork in terms of fostering interest and by making these activities available during school, after school and on field trips, students do not feel these initiatives are being forced on them. In fact the activities are naturally supported by students who see a new way of learning, problem solving and discovering. The lines between classroom activities and projects that students are interested in become blurry. Students recognize the real-world application that being green affords and this allows teachers to encourage rigor and greater problem solving skills through action. However, it is not always smooth sailing and there are barriers to sustainability.

In order to create sustainability learning opportunities our school had to concentrate on being flexible enough to alter the teaching schedule, to incorporate field trips and adequate curricular flexibility in terms of scope and sequence of content. Another barrier included finding appropriate funding and resources. One must be creative, perseverant, and goal-oriented to keep the momentum of a project on track. The teacher and students must stay focused on key objectives and a project will continue to reap rewards for the students, the teacher, and the school. Any special initiative takes extra time and preparation, which requires being organized, being persistent about developing a collaborative plan. Lastly it is important to gather student input and feedback on each project. Student input and interest will help keep the energy and enthusiasm necessary for completing tasks and building on ideas. This endeavor of greening a school is replicable given space and resources. Much of what we at our school have accomplished resulted from grant funding and obtaining district permission for what we aspired to do. Writing grants is easy to do and there are a host of granters ready and willing to accept proposals. In planning, it is imperative to consider how the project will benefit students, the district and the community. Forming partnerships is also important. Many community colleges and universities are willing to partner with schools on projects that promote place-based education and sustainability. According to the Rural School and Community Trust Report, Place-Based Learning and the partnerships that can be formed provide a structured, focused means for higher education institutions to impact and change lives of vulnerable youth. (Engaged Institutions: Impacting the Lives of Vulnerable Youth Through Place Based Learning, 2003). Nurturing a groundswell of support from the community, district leaders, and district board members is also crucial. Where content objectives work in concert with district initiatives and community outreach, principals will find the most fertile ground for potential success. Harnessing this framework for support is what will make projects sustainable, replicable and lasting.

By pursuing green school status and projects that build on sustainability measures, teachers can exact change in the school and the surrounding learning environment, but most importantly, in the minds of the learners we are charged with preparing for the complex future that awaits them. First, it is helpful to encourage teachers who are entrepreneurial and creative in their approach to teaching. Teachers should try to find new ways of bringing content to students, including out-of-classroom experiences, field trips and partnerships. Also, tapping in to different modes of instruction that have a lasting effect on student interests and motivation
should be the focus of any school pursuing green school status.
At our school, students helped with writing grants for funding and recycle bins, developed a nature trail and butterfly garden celebration, recycled 3500 cubic meters of paper and 3000 cubic meters of plastic, were awarded county recycling recognition awards, achieved green school status three years in a row and were invited to complete water quality tests in a river polluted with oil spillage. None of these activities were necessarily part of our established curriculum, but they have had a huge impact on student engagement and interest.

So, in conclusion, some tips for educators include looking around the school and making observations of potential problem solving opportunities that exist already. These opportunities include finding ways to utilize resources that already exist and can serve a greater benefit such as unused technology in the school building, new ways to build social capital such as developing a relationship with nearby colleges for support and partnership, building support teams or mentor programs and clubs, or locating new and unused resources such as available land for scientific use and study. Each of these activities provides potential resources that promote inquiry based, problem solving applications that engage students to be critical thinkers and good team members. Whatever you may find, using current resources and student energies may be the missing ingredient that can transform learning and significantly change classroom and school culture. These existing resources may require flexibility, but they come at no cost to a school or district and students can recognize real world issues and gain experience being the change in the world they desire.

REFERENCES
India has roughly three times as many people as the U.S. but only educates about two thirds of them, based on literacy rates. (The US has a 98% literacy rate compared to India’s 65%.) So, the advantage due to size is diminished -- to about double the number of educated students. However, after 9th grade, the top two thirds of the class in India are put in the ‘math-science stream’ and the other third are placed in the ‘commerce’ stream. Those math-science students get math, biology, chemistry and physics every year.

I am currently spending a semester in Chennai, India, through the Fulbright Teacher Exchange Program. Indian educational practices differ immensely from our U.S. classrooms, and I have learned a great deal about education and culture. I am quite convinced that the U.S. is in a losing race with India to educate students in science and math, but the reason requires some explanation.

On first glance, the Indian school system is not impressive. I can only speak to my experience and the reports of the other Fulbright Exchange teachers. My K-12 school is for the children of civil and military employees, called a Kendriya Vidyalaya. Approximately 1,000 of these K.V. schools are scattered throughout India. They serve middle and working class families, who are rather mobile as central government workers. The curriculums are standardized so that frequent moves are less disruptive on the children’s educations.

Teachers do not create lesson plans here in the way U.S. teachers do. Mostly, the teacher arrives in class and writes notes from the book on the board and students copy them into their elaborate notebooks. Copying a diagram from the text is considered a pretty good lesson. The principal at this school is encouraging teachers to bring activities into the classroom, but with little success. For my middle school class, I took two plastic bottles and put holes around the bottom to show that air pressure prevents the water from coming out when the lid is on. I set up the other with holes vertically, to show that the water pressure is greater at greater depths. I offered the demonstration to a colleague, but she said she did not need it because she had brought a model of lungs in last chapter. The teachers often use the materials I make, but they clearly do not use teacher-made lessons generally. For quizzes, teachers dictate the questions or write them on the board, and students copy the questions and write answers. Teachers tell me they make up the quiz questions during class.

In defense of the teachers, the facilities are severely lacking. The chemistry lab has about 12 rubber stoppers, nearly all with holes. There are no droppers and no pipette bulbs. (The book has a nice clear picture of how to mouth pipette.) The lab has no safety
goggles; not a single pair is in the whole lab. The school (for 1,000 students) has a single LCD projector. The Internet is available on only a few computers in the computer lab. Students are not permitted to use calculators; they use logbooks. The electricity in the building is frequently out. Classes have between 40 and 45 students each. Classrooms have benches with writing surfaces — a sort of elongated desk. Three students sit at each bench of less than four feet. They are literally shoulder-to-shoulder. No provision is made for LD, CI or EI students. Students with disabilities are present in the classroom — often unable to grasp the material and determined to disrupt the class. Students with minor physical disabilities are present, but no special accommodation is made.

The textbooks have not been carefully proof-read or fact-checked. The chemistry book explains, “Glass is an extremely viscous liquid. It is so viscous that many of its properties resemble solids. However, property of flow of glass can be experienced by measuring the thickness of windowpanes of old buildings.” Also, the book includes a correct explanation of significant figures, but the sample problems are not properly rounded in the remainder of the book. In states of matter, a problem incorrectly uses the heat of vaporization for a problem about melting.

The procedure for making photocopies is long. No paper is kept in the school’s single printer, and the computer teacher has to be tracked down to get a couple sheets to print a test. After printing, I take the original to the department head, who is a teacher and is often unavailable. She has to accompany me to the exam room, where the paper is kept. She gets out the ledger where the paper consumption is recorded. She writes down 70 sheets for a test while I count the blank copy papers. Next, I take the original and the paper to the vice-principal, who is also a busy person. He has to initial the original to show his approval for the copies. Then, I find one of the office staff because teachers do not use the copier. The staff member will make the copies. Also, tests are be reused and everything is double sided. Students write questions and answers on the test paper. Most teachers don’t make copies during the normal course of teaching. All notes are written on chalkboards or dictated. Students have extremely high stamina for writing.

Indian law bans corporal punishment in schools. However, in practice, it is quite common. My son, who is attending the school where I teach, reported that a female teacher hit a little first grade girl very hard over something the child was writing in her notebook. I saw an administrator hit a student on the side of the head repeatedly for being late to school on a day when the rain was torrential. Many people were late that day, including teachers, waiting for the rain to let up a little. He hit a number of students hard on their backs and shoulders for the same infraction. I could hear him shouting at them from the end of the hall. My son reports that students are hit with rulers (metal or wood) for wrong answers and misbehavior. Or, the teachers jab students in the stomach with the ruler. He said that all of his teachers have hit students at one time or another. One teacher explained to me why they hit students. She said that teachers tell students how to behave repeatedly and when they still do not listen “we have no choice but to beat them.”

Another day, the principal said at assembly that the students were “stupid monkeys” when addressing grades 6-12. Teachers commonly tell students they are stupid or lazy. Screaming at students is the standard discipline technique. This country is clearly not into the ‘self-esteem building’ that has become crucial in US education.

In explaining all this, I think some might be inclined to think that the lack of corporal punishment is the cause of the ills in the US educational system. Actually, many Indian students excel in spite of the poor educational methodology. The key, I am convinced,
to the success of Indian students is cultural. Culture is like air; it is hard to perceive until it changes. The bottom line here is: the student is responsible for their own learning and their own futures. In the US, the student expects the teacher to work harder to “teach.” In India, the solution to not understanding is to study more. I am continually amazed that U.S. students balk at the suggestion that they should study their texts to assist them in understanding. My U.S. students expect all information to be delivered in much the way we feed toddlers with a spoon. I must not include anything on the test that was not thoroughly explained in class. The US students feel it is my responsibility to explain repeatedly until they understand. Indian students believe they need to study until they understand. At the high school level, teachers may not complete all the required chapters. Students are expected to study remaining chapters on their own. And they do. Indian students study hard. Students as young as 6th grade are expected to study for a day (6-8 hours) for a single exam. Middle school students commonly do 3 hours of studying in a night. The difference in learning rate is tremendous. Students really understand what is happening in class. I focus on the hardest problems and explain them in depth. The basics are already understood because the students STUDY. I think the biggest change in my teaching style as a result of this experience will be to actively shift the responsibility for studying onto the student. As it is not natural in our culture, I think I need to directly teach it.

Self-discipline is stressed as the prerequisite to academic success here. At morning assembly, students stand in neat rows in the schoolyard. Quite a bit of time is spent making sure the students are in proper formation, and the assembly can last for 45 minutes. Announcements, prayers, a pledge of allegiance, birthday announcements, short motivational readings and the singing of the national anthem are completed daily. The temperature is often over 90 degrees, even in the morning, and students are sometimes standing in the sun. One day, the principal was berating the students about the lack of self-discipline demonstrated by their poor performance at assembly. He told them they were fidgeting and not in straight lines. The assembly had already run about 40 minutes, and then a seventh grade boy passed out and fell over onto the dirt. Teachers rushed to help him and carried him inside, but the principal’s response was that even the boy’s inability to maintain attention was an example of poor practice of self-discipline. As hard as this is for people in our culture to understand, I can see that a deep sense of personal responsibility is ingrained. One teacher said, “We think that if we teach self-discipline well enough, the rest will follow naturally.”

In the U.S. we value efficiency tremendously. We want to use every minute of classroom time, we want students to move quickly from one place to another, we do not want to ‘waste’ time by having students copy questions before writing answers. Even the pledge of allegiance becomes too much of an imposition on our school day in the upper grades. In India, efficiency is less important than respect, proper behavior or self-discipline. These value differences have advantages and drawbacks.

Why does this difference exist? This is purely speculation on my part, but I think that decades of prosperity have removed the link between work and survival. In India, the poor are easily identified because they are short and frighteningly thin. That image,
of poor children and poor adults, is not part of our psyche in the U.S. The poor do not starve and we have gotten lazy. Entitlement has inserted itself into our culture. For better or worse, I think that cultural fault will resolve itself as our country loses its place as #1 economy in the world. As we slip, so will our standard of living and our social safety net. The poor may become thin in the US as well. I am deeply upset by the weakening of our social services, and I think a country as wealthy as ours is obliged to help its poorest citizens. However, our wealth over the past several generations has impacted our culture.

I dissolved Styrofoam in acetone and got an audible gasp from my 11th grade class. They were really amazed. Teaching students who are not embarrassed to be ‘into’ school is a wonderful change. The culture here is one of excellence. The top students are most respected by both peers and faculty. The value is on high achievement. Low performers feel very bad about their abilities. India is such a contrast to the US. Apathy is not a way of life here. Students are really pleased to be recognized by the teacher for their high scores on tests or for good answers in class. They really want to do well. They find satisfaction in learning well.

In the US because many students feel that academic praise lowers their status among peers and doing badly makes them look cool. What a rude shock our society is going to get over the next few decades as US students enter academia and the job market with Indian students to find how pampered and lazy they appear by comparison. People in India commonly work six days per week, too. Market forces are not kind to those with anemic skills and weak work ethics. After a few generations of privilege, our children have forgotten that prosperity must be earned.

I followed the Styrofoam dissolving with flame tests; a salt solution is mixed with ethanol and lit. I used copper (green flame), potassium (lavender flame) and strontium (red flame). They were clearly delighted by that one too. The entire class was appreciative and amazed. What would it take for US students to find internal motivation like that?

I am teaching an 11th grade chemistry class that incorporates topics like Molecular Orbital Theory, equilibria of weak acids and bases, thermodynamics, redox and organic chemistry which are only taught at this depth in our AP Chemistry classes. How many of our high school students take the AP Chemistry Exam? Fewer than 125,000 students nationwide. But, that is not the highest level that the math-science student in India will see. In the 12th grade, they get further study – in depth on drug chemistry, coordination chemistry, organic chemistry; topics that I have never taught in the US, and, I am embarrassed to admit, I only vaguely remember from my own college days.

And, chemistry is not the only advantage the math-science students have. They also get three years of physics and three years of biology in high school. They take 2 years of calculus, too. They spend 4 hours and 40 minutes per week in each science class – which is a little less than our students. But, that does not offset the advantage by much.

Only highly specialized programs in the U.S. would even be able to offer this depth to high school students. And it is standard preparation in India for two-thirds of their
high school students, which is double the size of our entire student body.

I understand that the US has prided itself on a well-rounded education. The math-science students in India will not study history or art, although their study of English continues throughout high school. However, students from India and students from the U.S. arrive at the same universities and compete for the same spots in medical school and graduate programs.

Also, U.S. schools are active places. Teachers include inquiry learning, critical thinking skills and creative thought is purposefully encouraged. Indian students are very much rote learners. When a question from the book asked how many transitions were possible when an electron moves from the 5th quantum level to the first, I drew the levels and showed students how to count the transitions. A student raised her hand and said the answer was obtained by using a formula, which she knew by heart and could write on the board. This moment illustrated a clear advantage of teaching that requires understanding versus rote learning.

The cultural emphasis on self-discipline and responsibility for learning, coupled with an intense program at the high school level (in spite of poor teaching methods) make Indian students much more competitive than U.S. students in the long run. Although our students have the edge in thinking skills, the sheer volume of knowledge that Indian students command makes them very attractive. Thinking ability only takes us so far if we lack something to think about.

Each year, about 70 teachers accept year-long or semester exchanges through the Fulbright Teacher Exchange Program. Science teachers exchange with the U.K., Hungary, the Czech Republic, Switzerland and India. For more information: http://www.fulbrightteacherexchange.org/

A blog of my exchange can be found at: http://zitzelberger.blogspot.com/
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ACTIVE LEARNING STRATEGIES IN SCIENCE
BY JAMES T. MCDONALD, PROFESSOR OF SCIENCE EDUCATION AND DIRECTOR OF THE CENTRAL MICHIGAN GEMS EDUCATION CENTER

INTRODUCTION
Recent efforts to improve science education in U.S. college and K-12 classrooms have focused on the role of active learning in promoting acquisition and retention of knowledge as well as critical thinking, deep and enduring understanding, and oral and written communication skills. A number of studies have provided evidence that active learning in the classroom enhances student performance, deep conceptual understanding, and long-term retention (Dinan, 2002; Freeman et al., 2007; Handlesman et al., 2004; Knight & Wood, 2005; O’Sullivan & Copper, 2003; Prince, 2004; Prince & Felder, 2006; Smith et al., 2005). In addition, interactive activities such as problems, cases, role-play exercises, debates, and inquiry-based investigative labs, encourage students to gather and synthesize information to practice application and analysis. These activities are essential for improving critical reasoning abilities, as several recent studies have documented (Camill, 2006; Chaplin, 2009; Chaplin & Manske, 2005; Herreid, 2004; Prince & Felder, 2006). Many studies have described a variety of successful methods of introducing students to the primary research literature, and most studies have documented the impact these exercises have on improving science literacy, critical thinking, and/or understanding of the scientific process in their students (Brill & Yarden, 2003; Houde, 2000; Jacques-Frick et al., 2009). Working in collaborative project teams on a complex problem or a journal club presentation of primary literature has also been shown to enhance critical thinking and deep conceptual understanding, as students share information and stimulate each other to greater insights (Gokhale, 1995; Henderson & Buisin, 2000).

WHAT IS ACTIVE LEARNING?
Active learning has a powerful impact on student learning. How? Student achievement increases through mastery of science and math content as a result of this technique. Students also develop improved problem solving, communication, and higher order thinking skills.

Before discussing the benefits of active learning, I need to establish a definition for this teaching technique. “Students participate in teaching and learning beyond simply listening to lectures or witnessing demonstrations concerning science or math concepts.”

FOUR PRINCIPLES: BASICS OF ACTIVE LEARNING
Four basic principles guide this teaching technique and stipulate that:

- Learning is by nature an active process
- Students learn in different ways
- Students learning by doing
- Use of higher order thinking skills by analyzing, synthesizing, and evaluating (Bloom’s Taxonomy or Bloom’s Revised Taxonomy) scientific or mathematic problems and findings

BENEFITS FOR STUDENTS: ADVANTAGES FOR PARTICIPATING IN LESSONS
The advantages for student participation are grounded in the use of higher order thinking skills, as students are more:

Focused – students are more attentive in class when they participate. Why? Few students actually listen to teacher lectures or
demonstrations of how to solve math problems or explanations of science concepts – passive learning. However, their attention and focus are increased when students:

- Question the importance of specific procedures for solving a math problem or data collection techniques in a scientific investigation.
- Use the language of math or science as they communicate using correct terminology for explanations, asking questions, and responding to questions. This helps them link terms with definitions.
- Connect concepts and link big ideas in science or math during open class discussions.
- Are more likely to complete homework or other assignments when they understand that the teacher will ask questions, using random student selection, regarding these assignments.

Engaged – achieved though stimulating student interest by causing conflict with their prior knowledge and experiences, along with assessing their understanding. This can be achieved as you ask higher order thinking open-ended questions, for example:

- How does ... affect ...?
- What causes ...?
- What are the differences (or similarities) between ...?
- Why is ... important?
- How does ... relate to what we have learned before about ...?
- Explain why you agree or disagree about ...?

PRODUCTIVE QUESTIONS

One way to get students of any age to be more active in science is through the asking of questions with the purpose of getting them to use process skills in their science investigations. Process skills are sometimes the forgotten part of preparing to teach a science lesson to children. Process skills are an important part of science instruction because it helps children to practice using the skills that will make them successful in doing active science (Rezba, Sprague, Fiel, Okey, & Jaus, 1995). The Inquiry portion of the Michigan Science Content Expectations (Michigan Department of Education, 2007) contains the process skills that are important for students to learn in order to develop the habits necessary to do science actively.

One of the most useful strategies that I use in my elementary science methods class is to have students design their very first lesson that is built on asking productive questions (Harlen, 2001). This Questions Lab takes a science activity such as sink/float or Oobleck in a kindergarten or first grade class. Students create 12 productive questions, two of each type, and ask them during the lesson. The lesson is not a full lesson but is the first three parts (Engage, Explore, and Explain) of a 5E Lesson (Bybee, et al, 2006). Students learn that there is a right time to ask a question, that it pays to have the questions written down, and that spontaneous follow-up questions are needed. Teachers and student both need to practice asking and answering questions.

Children, even at a very young age, formulate theories and ideas for just about everything, and these ideas play a role in the learning experience. Through the use of appropriate questions at the right time, teachers can elicit these ideas and facilitate the learning process in a meaningful way. Questions that assist teachers with gaining information about children's concepts and ideas and at the same time promote the formation of children's understanding are productive questions (Harlen, 2001). Productive questions promote science as a way of doing and encourage activity while constructing knowledge. The answers generated by productive questions are derived from first-hand experiences involving practical actions with materials. In addition, productive questions encourage an awareness of the possibility of more than one correct answer to the question. Children
answer on their own developmental levels and the teacher views achievement as what is learned through the process of arriving at the answer. All children have success answering productive questions.

Unproductive questions promote science as information and derive answers from secondary sources by talking and reading. Questions that do not promote children’s thinking ask about knowledge of words, or repetition of words given earlier by the teacher or found in a book. Verbally fluent children who have confidence and proficiency with words most typically achieve success in answering unproductive questions with the correct end product (right answer). Often times, unproductive questions require a simple yes or no answer.

1) Attention-Focusing Questions:
The simplest form of productive questions is the straightforward “Have you seen?” or “What do you notice?” type of question. These questions are indispensable for fixing children’s attention on using their senses and for encouraging children (Harlen, 2001) to use the science process skills of observing and communicating during the exploration phase of an investigation or experiment. Additional examples of attention-focusing productive question starters are: “What are they doing....?” and “How does it feel/ sound/look?”

2) Measuring and Counting Questions:
Quantitative questions encourage sharper observations and communications (Harlen, 2001). Carefully phrased measuring and counting questions help children organize their thinking and unify similar concepts or ideas through the use of grouping or sets. Children use the science process skills of measuring and classifying as they check accuracy and use new instruments. Examples of measuring and counting questions include: “How many...?”; “How often...?”, “How long...?”, and “How much...?”.

3) Comparison Questions:
Comparison questions ask children to identify number relationships, develop concepts of alike and different, quantify the number of ways things are alike or different, and describe how things fit together (Harlen, 2001). The science processes of observing, measuring, classifying, and communicating are used by children as they answer comparison questions. Comparison question starters include: “How do...fit together?”, “How are... different?”; “In how many ways are...alike?”, and “In how many ways do...differ?”

4) Action Questions:
Action questions involve children in the science process skills of predicting, investigating, and experimenting (Harlen, 2001). Finding the answers to “What happens if...?” and “What would happen if you...?” engages children during the process of inquiry to discover an answer through investigation and experimentation. Asking children to make predictions about the outcomes of investigations or experiments stimulates thinking about variables, hypotheses, and conclusions affecting the investigation before it begins.

5) Problem-Posing Questions:
“Can you find a way to...?” and “Can you figure out how to...?” questions pose problems to children and encourage children to devise methods for testing hypotheses and formulating conclusions (Harlen, 2001). When answering problem-posing questions, children do science as they utilize the science process skills to discover the answer to the question. Before asking problem-posing questions, children need exploration time to provide time to discover the materials, possibilities, and impossibilities.

6) Reasoning Questions:
In science, the question, “How does this work?” can be very intimidating to children. Encouraging children to think about how things work or questioning children about
how something happens, requires the use of productive reasoning questions (Harlen, 2001). Answering reasoning questions engages children in the science process skills of interpreting data, defining operationally, evaluating, and formulating conclusions. “What are some reasons to explain...” and “How would you explain...” are examples of reasoning questions that invite children to answer without fear of being wrong. Asking why? in science can also be intimidating. A carefully timed, “Why do you think?” question can be an appropriate productive reasoning question.

Productive questions offer children opportunities to use the science process skills to discover multiple answers to questions posed by the teacher. Children ascertain that there is often more than one answer to questions. More importantly, these questions cannot be answered by using a simple yes or no response. Productive questions require children to apply attention, focus, measuring or counting, comparison, action, problem solving, or reasoning before responding. Meaningful science inquiry begins as children ask themselves or their classmates questions about the circumstances of their lives and the events of their classroom environment.

CONCLUSION

Active learning is important in science because it engages students through first-hand investigation. There are a variety of teaching strategies and techniques that can be used with students of any age. A variety of activities are important and some may be more useful for your teaching situation than others. Introducing students to primary research literature is important for older students because it exposes them to the nature of science and how science is done. Asking questions is also an important part of getting students actively engaged in doing science. Productive questions (Harlen, 2001) is one way, but not the only way, to ask questions. Using a variety of process skills will engage students with science phenomena in a way that will increase science literacy and confidence in wanting to do science in the future.

REFERENCES


Introduction
This case study examines children’s prior knowledge and understandings of substances. The motivation behind the work leading up to this study originates from our experiences teaching this concept to both adults and children. We have become increasingly aware that the vast majority of students in our experience did not have a meaningful understanding of the concept of substance, although this concept is usually taught in grade school and is central to an understanding of chemistry. This concern led us to reflect on the gap between what was being taught and what was being learned. A constructivist view of learning asserts that the student makes sense of what is taught by incorporating new ideas into current thinking based on his/her experience. We began to wonder how prior knowledge of the concept of substances or related terms plays a role in the learning process as stu-
sents attempt to grasp this concept. Thus, the following questions are raised and serve as the basis of this research.

1. What is children’s prior knowledge of substances?
2. How do children’s prior knowledge and understandings of substances compare and interact with the scientific view?

From the scientific viewpoint, a substance is a specific type of matter with an identity conferred by its properties (color, melting point, boiling point, etc.). According to the National Science Education Standards (NRC, 1996), students in grades K-4 should "develop an understanding of properties of objects and materials." (p. 123); students in grades 5-8 should “observe and measure characteristic properties, such as boiling and melting points, solubility, and simple chemical changes of pure substances, and use those properties to distinguish and separate one substance from another.” (p. 149) Vogelezang (1987) argued that a means of identifying “a substance” is a prerequisite for appreciating chemical change. Johnson (2000) interpreted this argument further by stating that “one can hardly recognize what is a change of substance if one does not have an idea of what ‘a substance’ is, in the first place.” (p. 719) Although the importance of this concept is emphasized in the National Science Education Standards and by the science education community, Stavridou and Solomonidou (1989) claim that the concept of substance remains uncertain for pupils.

In addition to the studies that focus on children’s conceptions of substances, researchers have investigated how students at different grade levels understand the nature of matter, a broader related concept. In Nakhleh and Samarapungavan’s (1999) study of elementary school children’s beliefs about matter, fifteen children aged 7-10 expressed ideas about states of matter, phase changes and dissolving. They observed children’s inconsistent and incomplete beliefs concerning a variety of substances from continuous solids to particulate solids, liquids, and gases. Later, the same researchers examined middle school students’ developing understanding of the nature of matter as well as comparing their ideas to those of elementary schools students (Nakhleh, Samarapungavan, & Saglam, 2005). They found that, unlike elementary school students, most of the middle school students interviewed knew that matter was composed of atoms and molecules; however, they were unable to apply this knowledge to consistently explain material properties or processes. These researchers further suggested that these middle school students’ fragmented ideas about matter result from their “difficulty in assimilating the microscopic level scientific knowledge acquired through formal instruction into their initial macroscopic knowledge frameworks.” (p. 581)

Research on undergraduate students’ understanding of the concepts of element, compound, and mixture indicates that many students perceived the concepts of atom and element as being interchangeable. A similar result was found with the associated concepts of molecule and compound (Ramette & Haworth, 2006; Stains & Talanquer, 2006, 2007; Taber, 2001). In addition, undergraduate students were found to lack of conceptual differentiation between compound and mixture (Stains & Talanquer, 2007).

This preliminary case study has implications for the teaching and learning of substances, particularly in the elementary classroom. We hope that this study of children’s prior knowledge and understanding of substances will encourage science educators to rethink the way they approach chemistry education in order to help students achieve the intended conceptual development.
Method

The researcher randomly selected four participants (pupil A, E, J, and M) from a Saturday science program offered at a Midwestern university for children in grades K-8. Pupils A and E were 9 years old and in the 4th grade and pupils J and M were 10 years old and 5th graders. In addition, pupils A and J are female; pupils E and M are male. In order to gather information that addresses the above research questions, each participant was interviewed on one or two occasions with the length of each interview ranging from 30-60 minutes. Two basic types of interviewing were adopted in this research: protocol and elicitation interviews. Protocol interviews use a list of questions developed in advance of the interview; elicitation interviews use some type of “prop” (e.g. a quote, object, photograph, etc.) presented along with questions.

During the first interview, the four pupils were first asked what they know about four words (substance, element, compound, and mixture) and then were given a brief description of substance from the scientific viewpoint. They were simply told the following information without any further explanation or instruction:

A substance is only one thing and has only one set of properties, such as one boiling, freezing and melting point, one color and so on. A substance is either an element or a compound; an element cannot be broken down into a simpler type of matter by either physical or chemical means; a compound can be broken down into a simpler type of matter (elements) by chemical means. If it is more than one thing and has more than one set of properties, it is a mixture.

In order to find out how these pupils make sense of the scientific view of substance that was provided to them, they were asked to carefully observe eight objects (rock, margarine, banana, carrot, iron nail, aluminum nail, salt, sugar) with regard to their properties such as color, texture, and melting behavior, to determine if each of these object is a substance, and to provide justification for their decisions (see Appendix A for a full list of interview questions).

During the second interview, pupils A and E were interviewed again, this time together. They were asked to define the same four words they had been asked about in the first interview. Then a game activity which applies the concept attainment model of teaching (Joyce, Weil, & Calhoun, 2000) was used to further probe how the children develop their understanding of the concept of substance. Eleven positive and negative exemplars of substances were listed in a chart (see Appendix B) and the pupils were asked to examine these exemplars and discover what the positive exemplars have in common that they do not share with the negative exemplars. Then the interviewer presented them with several new exemplars and asked the children whether these were positive or negative based on their previous conclusions. The researcher also asked them to provide any additional positive exemplars that they could think of. All interviews were taped and later transcribed. Multi-layered analysis of the interview transcripts was conducted individually as well as collaboratively, using member-checking to increase “trustworthiness” (Mishler, 1990, as cited in LaBoskey, 2004, p. 817). Qualitative data analysis involved iterative analysis and revision of the coding scheme (Miles & Huberman, 1994). Emergent themes and patterns were then identified in the coded data.

Results and Discussion

The analysis is composed of three main sections. In the first section, we explored the different facets of four pupils’ prior knowledge of substances. In the second section, we examined how pupils’ prior knowledge of substances interacted with the scientific view of substances provided to them in the first interview. Finally, in the last
section, we analyzed how pupils’ new ideas about substances developed throughout the concept attainment activity in the second interview. It should be noted that because the pupils were interviewed as a pair in the second interview it was sometimes difficult to separate their responses.

Different Facets of Pupils’ Prior knowledge of Substances
In the first interview, the four pupils were asked individually what they know about an element, a compound, and a mixture. Then they were asked to name examples of elements, compounds, and mixtures. The following responses of each pupil revealed their varied prior knowledge of substances.

Pupil E.
Pupil E’s prior knowledge of substances was both scientific and non-scientific. “Elements are usually gases and usually clear. Air, oxygen, hydrogen, and carbon dioxide are elements. Compounds are usually liquids. Some solids are compound. Some compounds have elements in them,” he said. His perceptions of elements and compounds seem to be related to the different states of matter. He mentioned that he had heard of these terms from the first week Saturday science class and from his parents, so he might also have learned examples of each from these sources. From the few examples he knew, he could possibly figure out what they have in common, and used that to define each term. For example, he knew oxygen and hydrogen are elements and both of them are gases and clear, from this he concluded that elements are usually gases and usually clear.

In contrast with his view of elements and compounds, his prior knowledge of mixtures is more scientific. He stated, “Mix things together, like water and salt, to make salt water; that would be a mixture. Mixtures can be in the solid, liquid, or gas states.” People usually have experience in seeing, using or making a mixture. Additionally, “mixture” is a much more common term used in daily life than “element” or “compound.” As a result, it is not surprising that pupil E’s prior knowledge of mixtures is more in keeping with the scientific view.

Pupil A.
Pupil A was unfamiliar with all three terms and unable to define them. This reflects that children may not naturally have a concept of substance. This result is consistent with Johnson’s (2000).

Pupil M.
Pupil M had little prior knowledge of substances. He thought elements, compounds and mixtures are perhaps different effects. “Like sometimes blow up and other times like boil,” he said, “Fire, water are elements;” “If put elements together, they are compounds.” Although not scientific, pupil M’s thoughts about elements and compounds seems to coincide with the pre-Socratic philosopher, Empedocles’s. Empedocles posited, “the sempiternal (everlasting) existence of a fixed mass of what were later termed the four elements— earth, air, fire, and water—in a state of swirling motion. . . . The exact nature of a compound turns on the ‘ratio of the mixture’ of the four elements within it (blood, for example, being 1:1:1:1).” (Robinson, 1999)

Pupil J.
Pupil J’s prior knowledge of substances is another form of non-scientific understanding. She stated, “I think a substance is something that is living. I’m not really sure. I felt more that a thing that you make into, like food, is more a substance. Both plant and animal can be substances.” She further expressed her thoughts on elements, compounds and mixtures. “An element is pretty much the thing is natural. I always think the element is rock. I think a compound is let you add a mixture and another mixture, and then put pressure on it. A mixture could be clay, drinks of blenders of apple and cranberry juice mix together. A compound is more like a gas. A mountain is an element,” she added.
Pupil J thought that substances are living things, including plants and animals. She viewed an element as the thing that is natural, a rock or mountain, and a compound as a gas or mixtures with added pressure. Her responses indicate that she had some prior knowledge about each of these terms; however, like pupil E, her prior knowledge of mixtures is more scientific.

Interaction of Pupils’ Prior knowledge of Substances with the Scientific View
After the pupils responded individually regarding what they know about each term and named some of each in the beginning of the first interview, the researcher provided them with a brief description of what substances are from the scientific viewpoint. They were then asked to carefully observe the properties of eight objects presented and determine if each of these objects is a substance. The following analysis of their responses to these objects focuses on how their prior knowledge interacted with the introduced scientific view.

Pupil E.
When Pupil E was asked to determine whether salt and the iron nail are substances, he said:

It [salt] is probably one thing. If you are talking about one grain of salt, it would have only one boiling, freezing, and melting points. It is same color. . . . It [iron nail] is not a substance. It has more than one boiling point and freezing point. . . . It has only one melting point. . . . It is a substance because it has only one color.

Pupil E had greater prior knowledge of substances than the other pupils in the study. His response to salt suggests that he interpreted “one thing” in terms of composition as “one grain of salt” in terms of quantity. Thus, he considered one grain of salt is a substance. For the iron nail, his contradictory response suggests that he could not fully make sense of the statement “a substance has only one set of properties.” It is possible that he was struggling with the concept of substance because he didn’t understand what boiling/freezing/melting points are. In addition, he still held his prior beliefs about substances. For example, he maintained that “an element is a gas.”

Pupil A.
Pupil A did not have any apparent previous knowledge of the substance concepts. After the brief introduction of the scientific view, she developed some understanding of substances, as reflected in her responses to the rock and salt:

It [rock] has more than one color. The color is a substance. . . . That’s a substance, and that’s only one thing because just one rock. . . . I see more than one color. It is not a substance. It’s more than one thing…It [salt] is a non-substance…many little cubes.

Pupil A observed the varied colors of the rock and determined that it is not a substance because of this quality. However, she also thought the rock was a substance because it is just one rock. Like Pupil E, Pupil A confused “one thing” (composition) with “one object” (quantity). She classified salt as a non-substance for the same reason (many little cubes). When the researcher asked her to consider only one cube of salt, she replied, “It is a substance because there is only one and only one color.” In addition, she thought the color itself was a substance. In a study by Sanmarti, Izquierdo & Watson (1995), this tendency of children to “substantiate” properties such as color and sweetness was also noted.

Pupil M.
Pupil M had little knowledge about substances beforehand. After the brief introduction of the scientific view, he observed what happens to sugar being heated and stated, “It [sugar] is more than one thing [a non-substance] because it melted and changed color [to black] after heating.” He
thought that the change of the color and state implies that sugar has more than one set of properties, and therefore it is a non-substance. This suggests that his developing understanding of this concept is that sugar still maintains its identity even though it has turned into a black thing after heating. He was not aware that the state is not a property and color change is due to the decomposition of sugar to other substances. Given that he had only been provided with a brief introduction to substances before responding to questions about the eight presented objects, pupil M’s limited understanding of substances hardly helps him develop any ideas about what a change of substance is. These findings are consistent with those of earlier studies (Johnson, 2000; Vogelezang, 1987).

Pupil J.
Like pupil E, pupil J had greater prior knowledge of substances than the other two pupils did, although many of her views were not scientific. After the brief introduction of the concept of substance, she interpreted “a substance has only one boiling and one freezing point” as “anything that [sic] can be frozen, also can be [sic] boiled.” When she was asked to classify salt, she replied “Everything can be a non-substance and a substance too. It [salt] doesn’t have boiling, freezing points, but it is all white.” Her response reveals that she could not envision a material, such as salt, as able to exist in different physical states.

Pupils’ New Ideas about Substances Developed in the Second Interview
Pupils A and E together played the game which applied the concept attainment model of teaching (Joyce et al., 2000) in the second interview. They identified what the eleven positive exemplars (substances) have in common that they do not share with the eleven negative exemplars (non-substances) and made some inferences regarding what the positive exemplars are. Their inferences are discussed below to illustrate how these pupils’ new ideas about substances developed throughout the concept attainment activity.

Inference #1: “The examples in the yes category are all chemicals. And in the no category they are not chemicals.”

They came up with this inference in no time. However, they abandoned this inference soon after I asked them to provide their reasoning. Pupil A commended that “actually, they’re [both the positive and negative examples] all chemicals.”

Inference #2: “Maybe one of them is substance and the other is mixture.”

They made this inference, but they thought some exemplars were listed in the wrong category, such as salt. What follows is our discussion about salt.

I (interviewer): Which one is a substance and which one is a mixture?
E and A: These [in the NO category] are the mixtures and these [in the YES category] are the substances.
A: Well, salt is made up of two. Chlorine and...
I: Do you think salt is a substance?
A: Salt is made up of two chemicals.
I: What are the two chemicals?
A: Chlorine and... I can’t remember the other one. Something I leaned in my science class last year.
I: You learned in the Saturday science class?
A: No, in school.
I: So is salt a substance or non-substance?
A: Non-substance.
E: It should be in the other group.

For them, salt is not a substance in its own right, but a mixture where chlorine and something else still persist. It is difficult for pupils to accept that one substance plus one substance can equal one substance because it seems not to obey laws of conservation. In order to differentiate mixtures from compounds, they need to entertain the idea of a chemical change; that is, a substance can change into other substance(s).
In addition, they thought wood should be a substance “unless you count any bugs [that] are stuffed somewhere in the wood.” A similar response was also found in their discussion about water:

I: Why do you think water is a substance?
A: Because it is only one.
I: Only one what?
A: I guess only one chemical.
E: Well, only one freezing point.
I: Anything else?
A: Well, if it is pure water, it is a substance because there is nothing else in it. If a pinch of chlorine in it, then it is not a substance.
E: It is a mixture.

The reasoning that the pupils used was mainly in terms of the history of the sample. If nothing is added to it (chlorine in water) or gets in (bugs in wood), it is said to be pure or a substance. Pupil E also suggested that water is a substance because it has only one freezing point.

*Inference #3: “Maybe elements and compounds.”*

Their puzzlement over the classification of salt and wood prompted pupil E to give up the second inference. He then came up with this third inference.

I: Do you want to take a look at the list again and tell me more.
E: Maybe elements and compounds.
I: Which category is element and which one is compound?
E: I don’t know. Well, the thing is that I can’t really remember what a compound is.

After probed further, Pupil E responded as follows.

E: This one [the no category] should be a compound, and this one [the yes category] should be an element as you know the gravel has to be a compound. It doesn’t, it’s not solid.
I: Gravel is not solid?
E: Yes, because it’s rocks. Oh, sorry, that’s solid. I don’t know.

Pupil E reasoning behind the third inference referred back to his prior knowledge about elements and compounds. That is, whether it is an element or a compound depends on its physical phase.

Pupil A then joined the discussion after I provided them with more examples in both categories.

I: Now I have ice in the yes category, and 7-up in the no category.
A: Well, I think 7-up is a mixture.
I: How about ice?
A: Ice is a substance, because it is made of water.
I: Ok. I have gold in the yes, and 14 K gold in the no.
A: Well, I think 14 K gold; it is partly gold and partly not gold. And gold is all gold.
I: Ok. So what does that tell you?
In the yes, we have mercury, and in the no, we have jam.
A: Well, like mercury is an element.
I: How about jam?
A: I guess jam is an element too. You could mix them.
I: So if something can be mixed, that would be an element?
A: Yes.
I: How about mercury? Why do you think it is an element?
A: Because you can mix it with something. But aluminum foil and chocolate you can’t really mix them.

Pupil A had no prior knowledge of substances in the beginning of the first interview. After the brief introduction to the concept of substance, she interpreted a substance as one thing in terms of quantity rather than composition. During the second interview pupil A’s successful classification of ice, 7-up, gold, and 14 K gold into substances or
mixtures indicates that she has developed a more scientific understanding of substances and mixtures. However, her newly developed understanding of elements, which is evident in the discussion about mercury, jam, aluminum foil, and chocolate, is still non-scientific.

Inference #4: “The yes category is something that you need for one of the ones in the no.”

Pupils A and E came up with this fourth inference after they discussed some more pairs of positive and negative exemplars (e.g. charcoal and wood, lead and coins, graphite and pencil, carbon dioxide and coke, oxygen and air). They discovered that these pairs of exemplars seem to have some kind of relationship. For example, pupil A commented that, “You have carbon dioxide in the coke to make it;” and pupil E explained that, “Actually oxygen is there in the air.” I reminded them of the fact that the examples in the yes category definitely share something in common; however, each pair of positive and negative exemplars that were given do not necessarily have any relationship between them, such as iron nail and margarine, a pair of examples that I provided them with earlier. Meanwhile, pupil E seemed to be a little confused. When asked, he responded, “I’m thinking, just too hard.” Pupil A concurred with him immediately and said: “Yes, really challenging!”

When they could not come up with any new inferences, I announced the correct answer. Both pupils A and E were surprised to learn that all the examples in the yes category are substances. They explained why some exemplars in the yes category cannot be substances in the following discussion.

I: Let’s go back to these examples and tell me which ones you think might not be in the right category?
A: Maybe lime.
I: What else?
A: Some water, because chlorine is in it.
I: Anything else?
E: Gold necklace. Might be something else in it. It’s not just like [it can] be taken in the air. It has to be kind of strings or something, and those strings, it might have gold color, but it is not made of gold.
I: Anything else?
E: No.
I: After I told you that the yes category is substance, were you surprised?
A and E: Yes.
A: Because some of them are made up of two. Chlorine and something else.
I: So you think salt is made of two chemicals, and it seems to be strange that it is still a substance.
A: Yes.
I: Anything else?
A: No.
I: How about lime? Why do you think it is not a substance?
A: It doesn’t seem like a substance.
There got to be something in the lime.

These discussions during the second interview show us that their understanding about substance was approaching the scientific view through the process of assimilation and accommodation. For example, they could successfully classify some, but not all, examples into substances or mixtures according to whether there is something else in them. However, some of their non-scientific prior knowledge remained unchanged (e.g. an element is a gas) and/or developed into other mixed conceptions (e.g. salt is not a substance for it is made of two chemicals; an element is something that can be mixed).
Conclusion/Implication

Our research suggests that the children’s prior knowledge of substances take several forms:

1. No prior knowledge, like pupil A, who had no ideas for any of the four terms.
2. Little prior knowledge, like pupil M. He thought elements, compounds and mixtures are perhaps different effects, such as blowing up and boiling. He gave fire and water as examples of elements and explained compounds are elements that are put together.
3. Some prior knowledge, like pupil E and J. Pupil E differentiates elements and compounds according to the states of matter (elements are usually gases; compounds are usually liquids); pupil J used living and natural as the criteria for classifying substances (e.g., plants and animals) and elements (e.g., rock and mountain), respectively. She thought a compound is a gas or mixtures with added pressure. Their prior knowledge of elements, compounds and substances are primarily non-scientific, but they had a more scientific understanding of mixtures.

After a brief introduction to the concept of substance, it was observed that the children developed new understanding of substances. However, given their different prior knowledge, the concept of substance has multiple meanings for them. All pupils did not fully make sense of the statement “a substance has only one set of properties.” Pupils A, E and J though anything can be a substance and a non-substance depending on which property they observed. For example, Pupil E determined that the iron nail is not a substance for it has more than one boiling point and freezing point. He then added that it is a substance because it has only one color and one melting point. Pupil M observed what happens to sugar being heated and thought that the change of the color and state implies that sugar has more than one set of properties and thus is more than one thing (a non-substance).

By simply providing a brief description of substances, pupils A and E interpreted “one thing” in the statement, “a substance is only one thing.” as “one object.” As a result, they concluded that salt is a substance only when one grain is considered and rock is a substance because there is only one rock. The other unique interpretations of the scientific view of substances made by the pupils during the first interview include:

- Pupil J interpreted “a substance has only one boiling and one freezing point” as “anything that [sic] can be frozen, also can be [sic] boiled.”
- Pupil A substantialized properties. She thought color is a substance.

Pupils’ new ideas about substances developed throughout the concept attainment activity during the second interview were reflected in the four inferences they made and in the associated discussions. The pupils came up with the right answer (objects in the yes category are substances and those in the no category are mixtures) as soon as they made their second inference, but they thought some exemplars were listed in the wrong category and gave up this particular inference. They successfully classified some examples (e.g., ice, 7-up, gold, 14 K gold, and water) into substances or mixtures according to whether there is something else in them. For example, they explained how pure water is a substance because there is nothing else in it but will be a mixture if a pinch of chlorine is in it. Pupil E also added that water is a substance because it has only one freezing point. However, they were puzzled over the classification of salt and wood. They thought wood is a substance unless bugs get in the wood and salt cannot be a substance for it is made up of two chemicals. Their successful classification of some objects into substance or mixtures indicates that they have developed a more scientific understanding of substances and mixtures. However,
some of their non-scientific prior knowledge about elements and compounds remained unchanged (e.g. elements are usually gases and compounds are usually liquids) and/or developed into other mixed conceptions (e.g. salt is not a substance for it is made of two chemicals; an element is something that can be mixed).

Taber (2001) suggested that “learners’ conceptions can vary on a range of dimensions - such as complexity, consistency, context-dependence etc.” (p. 44) The findings of this research may help science instructors appreciate how unique each pupil’s prior knowledge of substances is and how their thinking might differ from and interact with the scientific view of substances. It may also assist instructors to identify which ideas pupils feel confused about or struggle with (e.g. one set of properties, melting/freezing/boiling points, differentiation of mixtures from compounds, and “one thing” in terms of composition vs. quantity). This knowledge would in turn help science instructors plan more effective lessons to overcome students’ barriers to further learning and to build upon their acceptable “intermediate conceptions” to ultimately comprehend the concept of substance (Taber, 2001).

REFERENCES


Appendix A

INTERVIEW QUESTIONS FOR THE FIRST INTERVIEW
MATERIALS: ROCK, MARGARINE, BANANA, CARROT, IRON NAIL, ALUMINUM NAIL, SALT, SUGAR

1. What do you know about an element, a compound, a mixture, and a substance? Can you name some elements, compounds, mixtures and substances? (After they answer this question, provide a brief description for each of the four terms. Tell them if it is only one thing and has only one set of properties, such as boiling point and melting point, it is either an element or a compound. Introduce to them the difference between an element and a compound. Element and compound together are called ‘substance’. This term ‘substance’ used in the science world is different from that used in our daily life. If it is more than one thing and has more than one set of properties, it’s a mixture. Give them some examples for each category.)

2. (Ask them to take a look at the rock.) Do you think it is one thing or more than one thing? (If they say one thing, ask them it is an element or a compound?) How could you tell? Is there any test you think would help you answer this question? (If they have no idea, suggest that heating might be an option. Have them try to heat the rock and see what happens. Ask them if there are some other tests they can do.) (For carrot, I may also suggest them squeezing it and see what happens. After they finish testing, ask them again rock is one thing or more than one thing? How could they tell?)

3. (Ask them to take a look at margarine.) Do you think it is one thing or more than one thing? (If they say one thing, ask them it is an element or a compound?) How could you tell? (They might suggest cutting them into small pieces. If they don’t, I may suggest them doing so.) Is there any test you think would help you answer this question? (If they have no idea, suggest that heating might be an option. Have them try to heat the carrot or banana and see what happens. Ask them if there are some other tests they can do.) (For carrot, I may also suggest them squeezing it and see what happens. After they finish testing, ask them again carrot/banana is one thing or more than one thing? How could they tell?)

4. (Ask them to take a look at the carrot/banana.) Do you think it is one thing or more than one thing? (If they say one thing, ask them it is an element or a compound?) How could you tell? (They might suggest cutting them into small pieces. If they don’t, I may suggest them doing so.) Is there any test you think would help you answer this question? (If they have no idea, suggest that heating might be an option. Have them try to heat the carrot or banana and see what happens. Ask them if there are some other tests they can do.) (For carrot, I may also suggest them squeezing it and see what happens. After they finish testing, ask them again carrot/banana is one thing or more than one thing? How could they tell?)

5. (Ask them to take a look at salt.) What is salt made of? Do you think it is one thing or more than one thing? (If they say one thing, ask them it is an element or a compound?) How could you tell? (If they have no idea, suggest that heating might be an option. Have them heat margarine in the test tube gently (or hot water bath). After margarine separate into different layers, ask them again margarine is one thing or more than one thing? How could they tell?)
Have them try to heat salt and see what happens. Ask them if there are some other tests they can do. After they finish testing, ask them again salt is one thing or more than one thing? How could they tell?

7. (Ask them to take a look at sugar.) Do you think it is one thing or more than one thing? (If they say one thing, ask them it is an element or a compound?) How could you tell? Is there any test you think would help you answer this question? (If they have no idea, suggest that heating might be an option. Have them try to heat sugar and see what happens.) Does sugar stay the same before and after heating? What’s the ‘black stuff’? What happens to sugar when it is heated? Please tell me again if sugar is one thing or more than one thing? How could you tell?

### Appendix B

**Positive and Negative Exemplars for the Concept Attainment Model Activity Used in the Second Interview**

<table>
<thead>
<tr>
<th>Positive exemplars (Yes)</th>
<th>Negative exemplars (No)</th>
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<tbody>
<tr>
<td>Iron nail</td>
<td>Margarine</td>
</tr>
<tr>
<td>Sugar</td>
<td>Carrot</td>
</tr>
<tr>
<td>Salt</td>
<td>Rock</td>
</tr>
<tr>
<td>Water</td>
<td>Juice</td>
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<tr>
<td>Oxygen</td>
<td>Air</td>
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<tr>
<td>Carbon dioxide</td>
<td>Coke</td>
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<tr>
<td>Mercury</td>
<td>Jam</td>
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<tr>
<td>Aluminum foil</td>
<td>Chocolate</td>
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<tr>
<td>Diamond</td>
<td>Gravel</td>
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<tr>
<td>Graphite</td>
<td>Pencil</td>
</tr>
<tr>
<td>Charcoal</td>
<td>Wood</td>
</tr>
</tbody>
</table>
Shadows are a common occurrence in our lives. We see them both inside and outside: sometimes we use the shadows on a sundial to tell the time of day and sometimes we use our fingers to make shadow images to amuse ourselves and others. The importance of shadows can be seen in the science we teach elementary children. Understanding light and the formation of shadows is a key component in learning about lunar phases and the changing position and size of shadows as the sun changes position in the sky during the day or from season to season. The need for elementary students to have accurate knowledge of shadows and their formation is noted in the National Science Education Standards (NSES) (National Research Council, 1996). According to the Grade Level Content Expectations (GLCEs), third grade students should learn that "Shadows result from light not being able to pass through an object" (Michigan Department of Education, 2009, p. 35).

Children's thoughts and ideas about light and shadows have been explored and some misconceptions have been reported. For example, Feher and Rice (1988) reported on the concepts of shadow formation held by children aged 8 to 14 years. They found that students believe shadows are formed when light acts on an object and shadows are formed when light is blocked or deflected. They also reported that some children believed that shadows are reflections of an object or that shadows are images of the object. Guesne (1985) found that most of the 10 and 11 year old children in his study considered shadows to be reflections of objects. Other student misconceptions relate to the location and size of a shadow. For example, some students do not realize that shadows appear on the side of an object opposite the light source and that the length of a shadow depends on the angle the light source makes with the surface. A common misconception relating to the location of the light source and the position of the shadow occurs when students and adults alike believe that lunar phases are caused by the earth's shadow. These alternative conceptions pose potential problems for students in their future learning as described by Brickhouse (1994), and Ravanis, Zacharos and Vellopoulou (2010).

Barrow (2007) described how third grade students investigated formation of shadows. He suggested that this shadow study could be conducted at intervals throughout the school year so that students could observe how shadow lengths change as the sun's position in the sky changes. Vincent and Cassel's article (2011) describes just such a study. In their research, fifth grade students conducted an investigation into the length of their shadows at various times during the school year. These students observed the changing lengths of the shadows and postulated reasons for the change. Neither of these articles described students' prior understanding of shadows.

During the course of an action research project conducted by pre-service elementary teachers in a third grade classroom, an assessment method was developed to probe student understanding of shadows. The information gleaned from that assessment was surprising and provided direction for development of 5E inquiry lesson plans targeted towards improving student knowledge. This paper describes the third graders’ conceptions of shadows and the benefits of pre-assessing students. Pre-assessment
The pre-service teachers researched light and shadows to determine known elementary student conceptions of light and shadows and used these alternative conceptions to design a pre-assessment. The assessment was administered as a series of five questions and two drawings to 26 students in a third grade classroom in the Detroit metropolitan area. Five questions about shadows including: "What is a shadow?", "How are shadows created", "Do shadows have a color? Why or why not?", "Do all objects have a shadow? Why or why not?", and "Do shadows change? How?", were given to prompt student recall of what they knew about shadows. In addition, the third graders were given two pictures of a sun and a flagpole with the American flag, and asked to draw shadows of the flag and flagpole. In Picture A, the sun was to the left of the flagpole about 45o above the horizon. In Picture B, the sun was to the right of the flagpole about 60o above the horizon. The pre-assessment took less than 30 minutes to administer.

RESULTS OF PRE-ASSESSMENT

Student responses to the five questions posed for the K part of the K-W-L chart and the drawings revealed several non-scientific conceptions and lack of knowledge. In examining all the responses to each question, we noted that not one student indicated that sources of light other than the sun could create shadows. In response to "what is a shadow?", 7 students clearly grasped the concept that sunlight was needed to create a shadow. An example of this is the student who wrote "A shadow is like when it's a sunny day, you stand in the sun and you see your shadow." Four students described it as a dark spot. Six students described shadows as copies of themselves: one student wrote "it is a reflection of yourself" and another wrote "it is yourself but on ground." One student wrote "light can't get past" which suggests to us that this student understands that shadows are formed by objects that block the passage of light. Thus, this student has mastered the third grade content knowledge about shadows contained in the GLCEs.

When asked how shadows are created, 17 students wrote sunlight or by the sun. One student wrote "by the sun and you" and one student wrote 'by everything." The student who had mastered the content knowledge in the above paragraph elaborated on his/her understanding by writing "when light cannot get through something." Of interest was the student who wrote "sun shining when you move." Answers to later questions described below reveal that at least three students believed that movement of an object was necessary for a shadow to form.

Almost all of the students (79%) felt that shadows were black in color. Some students did not specify a color. Other students said that shadows were brown or "just the ground" and one student said that shadows were white. Two students said that shadows did not have color. The one student described above as mastering the third grade content knowledge wrote "no light can reach past something" which we interpreted to mean that shadows do not have a color.

The question, "does everything have a shadow", elicited varied and interesting responses. The third graders were evenly divided between correct and incorrect responses. These students also possessed the conception noted by Feher and Rice (1988) that the sun creates the shadow. Some students answering yes provided reasons that were not scientifically correct. An example is the student who wrote "yes because everything has a color". Some students who answered no provided correct responses. For example, one student wrote that light does not have a shadow and three noted that the sun does not shine on everything. Other students who answered no displayed a variety of incorrect conceptions including the need for things to move to create a shadow (3 students); that small things do not have shadows (2 students); and that when it is dark you won't be able to see the
shadow (1 student). This last student appears to believe that shadows are always present but cannot always be seen.

Finally, in response to the question about whether shadows move, most students (17) agreed that shadows move. Six of these were correct in saying that when you move, your shadow also moves. One student was quite specific in writing that a tall person would have a bigger shadow than a dog. One student wrote “no – maybe yes if you change clothes”. Five students said that shadows do not change at all, one student answered no because you don’t change. One student correctly stated that if there was no sun, there would be no shadows. It was not surprising that none of the students knew that the length of a shadow can change depending on the position of the light.

We were particularly intrigued by the drawings of shadows in Pictures A and B. We analyzed the drawings in terms of where the shadow was in relationship to the sun, if the shadows touched the flagpole correctly (that is, the shadow pole began at the base of the flagpole), if the shadow contained details such as stars and stripes, and if the shadow was completely on the ground. Table 1 is a compilation of the analyses of the drawings. Figure 1 illustrates one student’s drawing showing the flag as a separate entity with the detail of stars and stripes. The drawings of shadows demonstrated that the third graders had difficulty in correctly relating the size of the shadow in relation to the position of the light source (the sun in Pictures A and B) as 20 (76.9%) drew the shadow in Picture A about the same height as the object and 15 (57.7%) drew the shadow the same height as the object in Picture B. The number of third grade students who drew details in shadows was surprising. More than two-thirds of these students drew the flag and flagpole in Picture A (slightly fewer for Picture B) as a separate image not touching the flagpole and containing stars and stripes. The image was vertical – in other words, the students drew the shadow as an object removed from the source. Feher and Rice (1988) reported that fewer than half of the students in their study had the conception that shadows are reflections or images of an object. It is possible that the students in our urban third grade classroom have limited experience in observing shadows in an outdoor setting or they may simply not have had prior experiences in school with observing or drawing shadows. The students may also have encountered difficulty in drawing. This latter point is suggested by the low numbers of students who drew the shadows completely or partially on the ground. Of those who drew the shadows partially on the ground, all drew the pole on the ground with the flag in the air.

<table>
<thead>
<tr>
<th></th>
<th>Pre-assessment results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
</tr>
<tr>
<td></td>
<td>Picture A</td>
</tr>
<tr>
<td>Stars and stripes detail present</td>
<td>18 (69.2%)</td>
</tr>
<tr>
<td>Shadow placement relative to sun</td>
<td>8 (30.8%)</td>
</tr>
<tr>
<td>Shadow correctly touching flagpole</td>
<td>7 (26.9%)</td>
</tr>
<tr>
<td>Shadow completely on the ground</td>
<td>4 (15.4%)</td>
</tr>
<tr>
<td>Shadow partly on ground</td>
<td>3 (11.5%)</td>
</tr>
</tbody>
</table>

TABLE 1. DRAWING PRE-ASSESSMENT RESULTS (N = 26)
DISCUSSION
The diversity of the third grade students’ understanding of shadows indicates that a single lesson that focuses on the GLCE, i.e., that shadows arise when light cannot pass through an object, would not address all of the misunderstandings observed in our third grade class or reported in the literature. A series of lessons that could be taught outdoors appear to be needed. For example, lessons asking students to discover the relationship of the shadow to the object casting the shadow could have students drawing various playground equipment and their shadows. Teachers would need to stress careful attention to the location of the shadow and how it relates to the object. Students could be asked to describe the relationship between the shadow cast by another student and what the student was wearing. An inquiry question might be “if you only saw the shadow of a student wearing a jacket, could you tell which jacket a student was wearing?” A discussion on the differences between what the students can see and what the shadows show could follow to help students understand that the shadow is an outline of the object, not a copy of the whole object. It may be difficult for students who can see the entire object to understand that not all that they can see would be seen in the shadow. Another outdoor activity could begin to address issues such as the length of a shadow depending on the position of the sun. This concept may be more difficult for third grade students to grasp but an activity that has students measuring the length of a shadow at various times during the school day would be a good start for latter lessons on the relationship between shadow length and direction with the position of the sun in the sky. This activity would also show students that shadows can change even if the object remains still. All of these activities conducted outside would also help students to understand that shadows are an absence of light and would address the GLCE by showing students that shadows are created when light cannot pass through an object.

CONCLUSIONS
The data from a pre-assessment of student knowledge about shadows reveals that third grade students have a wide variety of alternative conceptions about shadows. The third grade students in this study shared some of the non-scientific conceptions reported by others. The presence of these misunderstandings strongly indicates that a lesson that focuses only on the fact that shadows are formed when light is blocked by an opaque object would not address all of the misunderstandings or alternative conceptions that were held by our typical third grade students. If a pre-assessment was not conducted, teachers would not know what alternative ideas students had and thus they
would not be creating lessons and activities that would focus on what the students need to further their understandings.

REFERENCES

Use of Lewis Structures of Organic Compounds to Improve the Transfer of General Chemistry Concepts to Higher Level Science Courses

By: Kendra R. Evans, Assistant Professor of Chemistry and Mark Benvenuto, Professor of Chemistry University of Detroit Mercy

Introduction

General chemistry courses serve as an early opportunity to introduce a variety of chemical concepts that students are likely to encounter in higher level science and engineering courses. Though many general chemistry students are able to grasp the principles covered in the course while enrolled, their understanding and recollection of the concepts is often lost in the gap between general chemistry and other courses for which retention of the understanding is crucial. Material covered in general chemistry courses includes molecular structures, which are typically introduced using Lewis structures. The ability to construct proper Lewis structures is necessary to determine molecular shape. Understanding of molecular shape and related concepts is crucial in a number of higher level courses, including but not limited to molecular biology, biochemistry, and organic chemistry. Because of the prevalence of organic compounds in these disciplines, we assert that it is beneficial to introduce Lewis structures of simple organic functional groups as molecular shapes in general chemistry. We emphasized the geometries of the organic functional groups, carboxylic acids and aldehydes, to improve student learning of molecular shapes and to strengthen the link between general chemistry and other science disciplines.

Method

Lewis structures were introduced in the first semester of a two-semester general chemistry sequence. To emphasize the importance of Lewis structures in the second semester of general chemistry, students were exposed to numerous examples of concepts in which an organic Lewis structure was incorporated into the problem or understanding of the concept. To further highlight Lewis structures and to evaluate student learning, a test question was posed on each weekly quiz in which students were asked to draw the Lewis structure of an organic compound that had been discussed in an earlier class.

Points of connection

Historically, the molecules selected for introduction of molecular geometry in general chemistry are inorganic compounds. However, the molecules of interest in fields such as organic chemistry, molecular biology, and biochemistry are largely carbon-based compounds. It was our premise that encouraging the application of such general chemistry concepts to organic compounds would improve the retention of and transfer of the general chemistry material to higher level courses. In addition to presenting Lewis structures of inorganic compounds, as has long been traditional in general chemistry courses and texts,(1,2) we chose to introduce the Lewis structures of carboxylic acids and aldehydes; these two functional group compounds were highlighted because they are highly reactive and consequently are the focus of many chemical and biochemical reactions covered in...
other courses. The structures of two example molecules are illustrated in Figure 1; the structure of acetic acid, a carboxylic acid, is illustrated in Figure 1A, and the structure of propanal, an aldehyde, is illustrated in Figure 1B. Once students were able to truly visualize the geometries of the organic molecules, the shapes were used to introduce further chemical concepts such as intermolecular forces of attraction, trends in physical properties, kinetics and chemical equilibria, and thermodynamics.

Figure 1: Molecular structures of A) acetic acid and B) propanal.

![Molecular structures of acetic acid and propanal.](image_url)

These organic molecules were also used to demonstrate the 3-dimensional nature of molecules. Each molecule contains at least one tetrahedral carbon atom and at least one trigonal planar carbon atom. The varying geometry provided a tool for demonstrating how geometry can affect the reactivity of molecules.

Intermolecular forces of attraction describe the types of attractive forces molecules may have for one another. The types of intermolecular forces a molecule exhibits dictate several chemical and physical properties of the overall compound. Construction of the proper Lewis structures for molecules is thus crucial for successful prediction of the types of intermolecular forces the molecules may exhibit. Organic compounds such as carboxylic acids and aldehydes are helpful for demonstrating how molecular structures determine the types and strengths of intermolecular forces of attraction. Once students comprehend intermolecular forces of attraction, the strengths and properties of various attractive forces can be compared to covalent and ionic bonds. Furthermore, molecular geometry and intermolecular forces of attraction dictate trends in properties such as boiling and melting points, vapor pressures, and viscosities. Acetic acid and propanal are both made only of carbon, hydrogen and oxygen, yet acetic acid’s boiling point is nearly 70 °C higher. (3) While presenting the Lewis structures of the compounds, we highlighted the hydrogen covalently bonded to the oxygen in acetic acid, compared that hydrogen atom to the most acidic hydrogen atom on propanal, and used the structures to facilitate a discussion of hydrogen bonding, other intermolecular forces of attraction, and several physical properties.

Kinetics and chemical equilibria are arguably the least well-understood concepts in general chemistry courses. Such a lack of understanding is unfortunate because kinetics and equilibria play important roles in the reactivity of compounds, and the reactivity of the compounds is what makes molecules important in applications. We compared the ionization reactions alongside the Lewis structures of acetic acid and propanal to those of hydrochloric acid and water can help to illustrate the reactivity of the molecules as acids. The ionization reaction of all four molecules and a comparison of the molecules’ acidity are included in Table 1. Typically, general chemistry curriculum focuses largely on \( K_a \) (the reaction’s equilibrium constant), and \( pK_a \) is only introduced as a mathematical manipulation of
for use in the Henderson-Hasselbalch equation. However, outside of general chemistry, especially in organic chemistry, the acidity of a compound is usually described by its $pK_a$. We introduced $pK_a$, discussed conceptually how it relates to $K_a$, and explained how it is used to describe acidity. Doing so consumed very little time but strengthened the acidity lesson in general chemistry.

Table 1. A comparison of the acidity of four molecules.

<table>
<thead>
<tr>
<th>Acid</th>
<th>Ionization Reaction</th>
<th>$K_a$</th>
<th>$pK_a$</th>
<th>Strength of Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric Acid</td>
<td>$\text{HCl(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(aq) + \text{C}_2\text{H}_3\text{O}_2^-(aq)$</td>
<td>$1 \times 10^8$</td>
<td>-8.0</td>
<td>Strong</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>$\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(aq) + \text{C}_2\text{H}_3\text{O}_2^-(aq)$</td>
<td>$1.8 \times 10^6$</td>
<td>4.75</td>
<td>Weak</td>
</tr>
<tr>
<td>Water</td>
<td>$\text{H}_2\text{O(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq)$</td>
<td>$2 \times 10^{-16}$</td>
<td>15.7</td>
<td>Weak</td>
</tr>
<tr>
<td>Propanal</td>
<td>$\text{HC}_3\text{H}_5\text{O(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(aq) + \text{C}_3\text{H}_5\text{O}^-(aq)$</td>
<td>$1 \times 10^{-17}$</td>
<td>-17</td>
<td>Weak</td>
</tr>
</tbody>
</table>

Chemical equilibrium is the foundation to chemical thermodynamics, as is illustrated in Equation 1. Gibb’s Free Energy, the branch of thermodynamics that describes a reaction’s spontaneity, is directly proportional to the reaction’s equilibrium constant, $K$.

$$\Delta G = -RT \ln K \quad \text{Equation 1}$$

Thus, the higher the $K$ value, the lower the $\Delta G$, and therefore, the more spontaneous the reaction. Propanal’s ionization reaction has an extremely low $K_a$, and thus, propanal is not likely to ionize.

Additionally, because molecules such as acetic acid and propanal have multiple hydrogen atoms, their Lewis structures helped illustrate the difference in acidity of the various hydrogen atoms. For example, the hydrogen connected to the oxygen on acetic acid has a much higher $pK_a$ than the other hydrogen atoms on the molecule; this served as an opportunity to discuss electronegativity and its role in acidity.

As described, several sections of second-semester general chemistry allowed for repeated exposure of the Lewis structures of carboxylic acids and aldehydes to students. We believe that the repeated exposure resulted in enhanced learning of general chemistry topics and led to improved transfer of the concepts to higher level courses.

**Collaboration with Organic Chemistry Instructors**

The majority of general chemistry students who continue in their originally-intended track proceed directly to organic chemistry. Thus, one important aspect of using Lewis structures throughout the second semester of general chemistry to improve transfer of general chemistry concepts is maintaining open lines of communication with the faculty members who are and will be teaching organic chemistry. With awareness of the organic chemistry curriculum and its sequence, general chemistry instructors are able to integrate small pieces of organic chemistry into the normal sequence of general chemistry.
Assessment of Student Learning
Assessment of the methods described above can begin with in-class exams or quizzes. While four exams per semester is a common testing structure for university general chemistry courses, more frequent assessment may be beneficial; we chose to administer more frequent quizzes or exams to test student learning. Weekly or biweekly quizzes, even with simple questions, are excellent opportunities for asking students to recall more frequently the basic concepts and to demonstrate their understanding of those concepts in multiple general chemistry topics. For example, the same two molecules, acetic acid and propanal, can be used throughout the second semester of general chemistry to assess student learning in several topics of general chemistry, including intermolecular forces of attraction, trends in physical properties, chemical equilibria and acid/base chemistry, and thermodynamics. However, to ultimately judge the success of the described methods for student learning, it must be formally evaluated in higher level courses.

When the Method Fails
Invariably, there will be some student answers that make a faculty member wonder just what the student was thinking when he or she drew a particular Lewis structure. For example, after acetic acid had been used in numerous examples, after the Lewis structure of it had been presented in front of students on the board several times, and after students were asked to provide the best possible Lewis structure of the chemical on multiple quizzes or exams, it was difficult to understand how a student arrived at the structure that is redrawn in Figure 2.

![Figure 2. A representation of an imaginative, student-drawn Lewis structure of acetic acid.](image)

One can assume answers like that in Figure 2 were the result of one or more of the following factors: poor study prior to the test, the student’s absence on the days the material was presented, and/or overall student apathy for the subject. Because of responses like that shown in Figure 2, and because in-class testing provided only a short-term glimpse of student learning, it has been difficult to truly assess student learning by general chemistry testing alone. Again, true assessment may only be performed by following students to higher level courses.

Conclusion
The simple fact that students are exposed to small doses of organic chemistry on a repeated basis prior to formal study of the subject leads us to believe they are better prepared
for the class. As a result of the methods described above, students certainly have been more thoroughly exposed to Lewis structures and likely have grasped the three-dimensionality of carbon’s tetrahedral arrangement, have learned how a proton dissociates from an organic acid, and have related the reactivity of various acids to their molecular structure. We assert that the repeated exposure to Lewis structures of organic compounds results in improved transfer of general chemistry topics to higher level courses. It remains difficult, though, to fully gauge student learning simply from test scores.

References:


My experience as a Science Educator in Michigan includes teaching grades Kindergarten through College, and leading Teacher Workshops. In these, I have found a number of my Outdoor Science Activities to work especially well with both students and teachers. I am happy to share some of these with you. I have used many of these as Inquiry-Based Science Learning Labs, rather than as “Cookbook” Labs. Here are my favorites:
Physics of Sledding to Bunny Bundles: Lloyd’s Backpack of Outdoor Science Activities
By Lloyd Hilger-Hanover-Horton Schools, Horton Michigan

My experience as a Science Educator in Michigan includes teaching grades Kindergarten through College, and leading Teacher Workshops. In these, I have found a number of my Outdoor Science Activities to work especially well with both students and teachers. I am happy to share some of these with you. I have used many of these as Inquiry-Based Science Learning Labs, rather than as “Cookbook” Labs. Here are my favorites:

The Physics of Sledding:
I developed this activity in my first “real” teaching job. This was at a K through 8 private school that had 22 students and 4 teachers. This gave us a wide range of sled riders. We weighed and recorded the weight for each participant and for each sled. We then went to the hill and determined the start and finish line, and then measured the distance of the sled run. Each participant made several runs with one or more sleds. We recorded the weights of each sled-plus-participant, and the lengths of time for each sled run that was made. We calculated the speed of each sled run (using distance and time), and we compared these sled-run speeds to sled-plus-participant weights by making a graph of this data. As we analyzed the graph data, we found that each sled-plus-participant had an optimum weight that resulted in the fastest sled-run speed. We also observed that too little weight resulted in a person’s sled bouncing off the snow surface, and too much weight had the person’s sled dragging slowly across the snow.

Snow Archaeology:
This activity requires fairly deep, unchanged snow. We use a shovel to create a smooth plane-surface that cuts down deep into the natural layers of a snow bank. Participants use measuring instruments and work to discover answers to the following questions:

1. How deep is the snow bank?
2. How many layers does it have?
3. How thick is each layer?
4. What are the temperatures of each layer?
5. What are the snowflake types that are found at each layer?

The Physics of Skiing:
This activity requires a hill with un-tracked snow. I instructed the skiers that the “push off” (the amount of force on the ski poles needed, to get a skier started going down the hill) had to be the same amount of force each time, for each ski run. Likewise I instructed the skiers for each time, for each ski run, that their body position also had to be the same,
in order for the “push off” to be successful. Most importantly, I instructed the skiers that
tones they got their ski run started, that they were not to stop the run while it was going,
but that they were to allow the run to continue until the ski run “stopped itself naturally.”
Each skier made a set of ski runs, and recorded the “natural” distance each run went. We
graphed the distance data for each skier’s set of runs. When we analyzed the data, the first
thing we noticed was that with each succeeding ski run, the same skier traveled a farther
distance. Through additional discussion, skiers attempted to explain why this is so. Eventu-
ally they understood that every time a ski run was made, due to increased compression of
the snow by the weight of skiers, the snow changed, becoming smoother and wetter (in-
creased moisture content), which meant the snow was providing less and less friction each
time, and so, with each successive ski run, the same skier will naturally travel faster and
farther (a greater distance) each time.

**Microclimates:**
I ran a workshop for Science Teachers about Inquiry-Based Science Education, as applied to
the study of Microclimates. I gave each Teacher Group a TI-84 Plus Silver Calculator and a
Vernier Easy-Temp Probe. Then, I instructed them to design their own outdoor science lab :
they were to decide how they were going to use the equipment I gave them, to decide
which types of other equipment they would want to use, and
also to decide how they were going to use their equipment to locate Microclimates in
outdoor settings. I gave them some basic instruction on how to use the Vernier Probe : that
they need to insert or remove the Probe by using the metal part, rather than the handle-
like structure. (These probes can break if they are not used properly.) Some Teacher Groups
decided to add Meter Sticks to their list of equipment. As the Teacher Groups explored just
outside of a building, they found extreme changes of ground temperatures as they moved a
relatively short distance away from the building and/or concrete.

**Catch & Release Insect Survey Lab:**

**Question:** How do the types of insects living in a Lawn Environment, compare with the
types of insects living in a Field Environment (natural, uncultivated terrain) ?

**Procedure:**

**Day 1:**
- Students form small Student Groups, and within their Groups, they will discuss
  which ways they believe they can find the answer to this question.
- They will then share their ideas with the Entire Class.
  Students will also use resources to become familiar with the Orders of Insects that
  they are likely to find when they go outdoors.

**Day 2:**
- Each Student Group will take a Sweep Net and a Data Sheet (see below) outdoors
  where both a Lawn environment and a Field environment are accessible to them.
- They will take 12 minutes to sweep, observe, count, and release the insects that
  they find in the Lawn Environment.
- They will repeat that same process for 12 minutes in the Field Environment (which
  has taller grass than a Lawn Environment has.)
- Each student will copy their Group’s data onto their Individual data sheets.
• Each student will then make a Double Bar Graph for their Group’s data.
• Each student will then also make a Double Bar Graph for the Entire Class’ data.

**Day 3:**
• Each Class will compare their Graphs with other Classes’ Graphs.
• Students will then write a conclusion about what they have learned.

### Data Sheet : Catch & Release Insect Survey Lab

<table>
<thead>
<tr>
<th>Order (of Insect)</th>
<th># In Lawn</th>
<th># In Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleoptera (Beetles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera (Flies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepidoptera (Butterflies, Skippers, &amp; Moths)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odonata (Dragonflies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthoptera (Crickets &amp; Grasshoppers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phasmida (Walking Sticks)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dermaptera (Earwigs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dictyoptera (Cockroaches &amp; Mantids)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Bunny Bundles :
This is a winter activity. Students find different types of woody-plant twigs and wrap them into bundles. They identify rabbit tracks in the snow, and then they place these bundles on the paths that the rabbits were using. The next day, they check to see which woody-plant bundles were chewed on the most. This provides the students with clues as to which types of woody plants appear to be most preferred by the local rabbits.

### About the Author
Lloyd Hilger is Science Department Chair for Hanover-Horton Schools, in Horton, Michigan. He is a strong proponent of Inquiry-Based Science Learning. He has been a frequent presenter at MSTA Annual Conferences. In 2005, Mr. Hilger was named Sole Finalist in the MSTA Science Teacher of The Year Awards (Middle School.) He currently teaches High-School-Level Earth Science to Eighth Graders, and Seventh Grade Science. He also runs Science Learning Camps in Northern Michigan.
No Fourth Grader Left Inside

I knew that I had made the right decision to arrange this field trip after the students had walked past the fox den and observed a small hole near the base of a fallen tree. The sign read “What do you think lives in this Den?” and a fourth grade student answered confidently “A Deer!” I was disappointed that students have so little experience in the woods and outdoors, but proud that I was taking steps to get students outside and energized to do more work to make outdoor learning a possibility.

As a Science Specialist for my district I teach around 950 students, I travel to our 3 elementary schools to do hands on experiments and investigations. I only see students for 1 hour once every two weeks but enjoy the chance to bring many cool and exciting things for them to experience.

With the rigorous curriculum I didn’t take students outside very often but always wanted to give our urban students more time outdoors so I applied for grants and looked for a local place to take a field trip. I called my field trip “No Fourth Grader Left Inside” and it was funded by a Michigan Water Works Association grant. I was able to take all our 170 district Fourth graders to a local park where science stations were set up for a half day learning experience. Our district provided the bussing to the park which was about 10 minutes from our school.

I set up 7 stations throughout the park and students were able to spend a couple hours rotating in small groups through all the stations, each station was staffed with a volunteer helper to guide the activity and I made sure their were enough supplies so each student could have their own equipment.

Some activities that students did were water quality testing, we tested water in the stream for dissolved oxygen, pH, and Nitrates and also used an Enviroscape model to show how water can be polluted by fertilizers and pesticides.

Student wore big rubber boots and carried a net into the creek to investigate aquatic organisms. We had guide books and dish tubs for student to observe and identify what they found.

Hula hoops were used in a plot study station for students to compare what the number and types of plants that live in a grassy area compared to in the woods. They also used digital thermometers to record temperatures and had a mini lesson on decomposers.

A leaf observation identification station also included making prints with SunPrint paper. Students were able to make stops at a bird watching station and use binoculars and an Identiflyer bird call. They stopped in the apple orchard and used Brock microscopes to observe things they found and made a stop in a grassland station and used butterfly
nets to capture and observe insects. I borrowed animal skins from a local taxidermist which helped students see the different fur thickness and types from many North American and African mammals.

I loved seeing the students enjoying the outdoors and feeling like scientists! I was also pleasantly surprised that the students who I was most worried about taking on a field trip were not troublesome but flourished that day. I am currently planning to move the location of our trip and make it a whole day of activities instead of a half day.

This year I am working on adding a geology station where students will find and break rocks, a soil composition station, a decomposers station, an animal tracking station, a station to practice using GPS and compasses, and natural resources and Native American tools station. Finally an animal homes station so we can explore what really lives in a den!

Thanks to all my district administration, teachers, parent chaperones, volunteers who staffed the stations and to my grant providers for making this experience possible!

Lynnea Roon
Science Specialist
Kelloggsville Public Schools
A Study of Vehicle Exhaust
By: Tom Green-Knabusch Math/Science Center

This unit was developed under a NASA Climate Change grant awarded to Wayne RESA and Eastern Michigan University. The outcome of this two-year grant is for students and teachers to have a working understanding of the science behind global climate change and its relationship to human activity, in particular its relationship to changes on multiple scales through NASA data products and models. See the ICCARS (Investigating Climate Change and Remote Sensing) website. http://www.resa.net/climatechange

Introduction
“Over the past 200 years, deforestation and the burning of fossil fuels such as coal and oil have caused the concentration of heat-trapping “greenhouse gases” to increase significantly in our atmosphere. These gases prevent heat from escaping to space, somewhat like the glass panels of a greenhouse. The levels of these gases are increasing at a faster rate than at any time in hundreds of thousands of years. If human activities continue to release greenhouse gases at or above the current rate, we will continue to increase average temperatures around the globe. Increases in global temperatures will most likely change our planet’s climate in ways that will have significant long-term effects on people and the environment. Transportation sources emit greenhouse gases that contribute to climate change. In 2008, transportation sources contributed approximately 27 percent of total U.S. greenhouse gas emissions. Transportation is also the fastest-growing source of U.S. greenhouse gas emissions, accounting for 47 percent of the net increase in total U.S. emissions since 1990, and is the largest end-use source of CO2, which is the most prevalent greenhouse gas.” (EPA 2010, 2)

Calculating the CO2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO2 (m.w. 44) to the molecular weight of carbon (m.w.12): 44/12. For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains un-oxidized.) Gasoline carbon content per gallon: 2,421 grams, gasoline is approximately 87% carbon (US Department of Energy, 6). Diesel carbon content per gallon: 2,778 grams (EPA 2010, 3).

CO2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams = 8.8 kg/gallon = 19.4 pounds/gallon

CO2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) = 10,084 grams = 10.1 kg/gallon = 22.2 pounds/gallon

Preliminary Investigation
1. All students list their vehicle (or parents), year, make, model, transmission, 2WD or 4WD and type of fuel on the board and the approximate number of miles the vehicle is driven in the last year.

2. Working with a partner, each team chooses their vehicle (two total).

3. Three criteria initially will be researched on each vehicle (or for vehicles before 2000 only fuel economy can be found). (EPA 2010, 4 & 5). The students can use
a search engine and put in Green Vehicle EPA to find this information. Please record on the table supplied, the information from number 1 above and the three criteria you will be researching, only fuel economy for vehicles prior to 2000.

a. **Air pollution Score:** This score reflects vehicle tailpipe emissions that contribute to local and regional air pollution, creating problems such as smog, haze, and health issues. Vehicles that score a 10 are the cleanest, meaning they emit none of these types of pollutants. Emission standards are for the major pollutants in vehicle exhaust: 1) NMOG, NMHC, or THC—types of carbon-containing compounds, including hydrocarbons, 2) NOx—Oxides of Nitrogen, which combine with hydrocarbons to create smog, 3) PM—Particulate Matter, tiny particles of solid matter that lodge in the lungs and deposit on buildings, 4) CO—Carbon Monoxide, a colorless, odorless, poisonous gas, 5) HCHO—Formaldehyde, a lung irritant and carcinogen.

b. **Fuel Economy:** The fuel economy values provide EPA miles per gallon (mpg), city and highway estimates for each car and light truck. Combined fuel economy = 1 / [(0.55/City fuel economy) + (0.45/Highway fuel economy)]

   For example, if City = 20 mpg and Highway = 30 mpg, the Combined example = 1 / [(0.55/20) + (0.45/30)] = 23.5 mpg

   Please use this way of calculating and list combined fuel economy along with highway and city.

c. **Greenhouse Score:** This score reflects emissions of carbon dioxide (CO2) and other greenhouse gases. The score reflects a vehicle’s tailpipe greenhouse gas emissions. A vehicle’s CO2 emissions are based on the carbon content of the fuel used and the fuel economy of your engine. In addition to CO2, the GHG score includes the tailpipe greenhouse gas emissions of methane (CH4) and nitrous oxide (N2O), are largely dependent on a vehicle’s emission control technology and the miles traveled.

d. For each vehicle, calculate how much CO2 would be produced if the vehicles traveled 12,000 miles last year (use either metric or English units). Use the combined miles per gallon in the calculation. Now calculate this using the actual miles driven.

4. Example using a 2006 4WD Toyota Matrix, gas.
   a. Air Pollution Score: 2
   b. Fuel Economy: 22 City/ 29 Highway/ 25 Combined
   c. Greenhouse Score: 7
   d. 12000/25 x 19.4 lbs/gallon = 9312 lbs
      12000/25 x 8.8 kg/gallon = 4224 kg

      Actual driving
      6000 miles
      6000/25 x 19.4 = 4656 lbs
      6000/25 x 8.8 = 2112 kg
5. Share these results with the rest of the class

<table>
<thead>
<tr>
<th>Air Pollution Score</th>
<th>Fuel Economy</th>
<th>Greenhouse Score</th>
<th>CO₂ produced per 12,000 miles</th>
<th>CO₂ actually produced in a year (number of miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

Data Table - Vehicle Description

<table>
<thead>
<tr>
<th>Air Pollution Score</th>
<th>Fuel Economy</th>
<th>Greenhouse Score</th>
<th>CO₂ produced per 12,000 miles</th>
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</table>

Vehicle Description

Investigation

Objectives

In this investigation, you will

1. Compare Air Pollution scores, Fuel Economy and Greenhouse scores among various vehicles.
2. Use a CO₂ Gas Sensor to measure the amount of carbon dioxide found in the exhaust of 2 vehicles.
3. Measure the length of time it takes to inflate a large garbage bag (40-45 gallon bag) and the size of a balloon after it is attached to the vehicle’s exhaust for five seconds.
4. Compare vehicle CO₂ results and inflation rates and compare these results with your preliminary investigation on the classes’ vehicles.
5. Discuss how we can reduce our carbon footprint concerning how and what we drive.
Materials

TI-Nspire handheld
Dataquest App
Lab Cradle
Vernier CO2 Gas Sensor
Manila Folder
10-20 Gallon Trash Bag
Duct tape
Ruler
Vehicle
Stopwatch
Helium Quality 12 inch balloon

Procedures

1. Turn on the calculator. Connect the CO2 Gas Sensor to CH 1 of the lab cradle. Select the high setting (on the sensor 0-100,000 ppm) the and the temperature sensor.
2. If Dataquest doesn’t open automatically, click on the Dataquest icon, to open the app
3. Go to Menu>Experiment> Collection Mode > Selected Events.
   ![Screen shot of the Dataquest app interface]
4. For the name use exhaust and units are ppm.
5. Let the sensor reading stabilize, if the reading is outside the range of 200-600 ppm, reset the sensor by using a pencil to press in the cal hole on the side of the sensor. When the light flashes you will notice it is reset.

6. Go outside to the vehicle you will be testing. Turn on the vehicle and let it run for 1 minute. Once the vehicle has been running (make sure it is in park (automatic) or neutral (stick shifts) and put the emergency brake on, hold the CO2 Respirator Chamber to the tailpipe and collect exhaust for 5 seconds, when complete immediately put a cap on the Chamber. Take the Chamber inside if that is where your sensor and interface is.

7. Uncap the Chamber and immediately put the probe in the chamber. Click the start button, wait till the CO2 readings stabilize and then click the keep button which will start data collection for 10 seconds. This is automatically put in your table in Dataquest. Press keep once more and if both readings are close record this.
8. Take a manila folder outside to your vehicle’s exhaust pipe and wrap it around the tailpipe, tape the folder to create a cylinder a little larger than the tailpipe. Duct tape both end securely. Attaching a 40-45 gallon trash bag to the folder. Tape it to the folder. Take this to your vehicle’s exhaust pipe, make sure the car has been running for at least one minute, attach the folder and bag to the tailpipe, have your partner with a stopwatch record the time it takes to inflate the bag.

9. Inflating a balloon.
   a. Create a cone with a manila folder. Go out to the vehicle you are testing and put the large end of the cone over the exhaust pipe so it fits snugly and duct tape it closed. Now attach a Helium Quality 12 inch balloon to the small end of the folder and attach with duct tape. Make sure there will be no leaks.

   b. Turn the vehicle on and let run for 1 minute. Attach the funnel to the exhaust tailpipe, make sure it fits tight and the second it starts too inflate have someone time it for 5 seconds. Remove and twist the balloon stem to seal.
c. Measure the circumference of the balloon at its largest spot. Record all data in the table below.

8. Get a copy of all your classmates’ results (see example data sheet) in order to answer the questions below.

Data

<table>
<thead>
<tr>
<th>Vehicle Make and Model</th>
<th>CO2 Exhaust ppm</th>
<th>Inflation time (secs)</th>
<th>Inflation Circumference (cm)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

Questions

From yours and your classmates research:

1. Compare Foreign vehicles to US produced vehicles in all 3 EPA categories, combined mpg, air pollution score and greenhouse score. Is there a difference, please discuss the results. Hint: You could use a 2-sample T test. If there is a difference why do you think this is?

2. Compare vehicles built before 2004 to vehicles built from 2004 and later in all 3 EPA categories, combined mpg, air pollution score and greenhouse score. Is there a difference, please discuss the results. Hint: You could use a 2-sample T test. If there is a difference why do you think this is?

3. Compare combined mpg to Air pollution score for all vehicles (2000 and later). Compare combined mpg to greenhouse score. Hint: Try a scatter plot and then a linear regression, look at the correlation coefficient. Is there a correlation? Why or why not?

4. What are your conclusions concerning the amount of CO2 generated by an individual’s vehicle. List 4 ways an individual could lessen this amount and give a reason for each of your answers.
5. Is there a relationship between CO2 emissions that you measured and any of the data previously gathered?

6. Is there a relationship between inflation time and balloon circumference size that you measured and any of the data previously gathered?

7. Calculate for your vehicle and your partners how much NOx, CO, NHOG and PM generated per year by these vehicles (only if 2000 or later).

8. Using just your vehicle, summarize any other findings (data) relevant to exhaust emissions.

9. On measuring exhaust from your vehicle (bag inflation time, balloon circumference and respiration chamber CO2 amount), what could be sources of error?

**Suggested Report**

Introduction: What is the main theme of this investigation?

Data: List all data used in this investigation.

Questions: Answer the above Questions

Conclusion: What have you learned from the investigation?

**References (all from EPA)**

3. http://www.epa.gov/oms/climate/420f05001.htm#1
5. http://www.epa.gov/greenvehicles/Index.do?jsessionid=b9e0e65638e211eb3e30192284292c32dc95047138d0da21b7ec1f36414271e2

**Teacher Section**

The CO2 sensor will not function if Relative Humidity is over 95%. The results may not necessarily be accurate because of this, but the reason to do this is for students to realize the vast amount of this Greenhouse gas that is generated by our vehicles. The inflation times and balloon inflation size if done to the same level of inflation or time may be a better measure to compare different vehicles. But they also have problems also, for example tailpipe sealing is a variable as is the timing.

It may be of interest to put a Relative Humidity sensor by the tailpipe to give the students an idea of the amount of water vapor created when hydrocarbons are burnt.
"For Every" Speak: 
A Cognitive Approach to Teaching 
Dimensional Analysis
By: Gary G. Abud-Grosse
Pointe North High School

According to Piaget, proportional reasoning is an essential cognitive function that indicates 
the formal operational stage of cognitive development (Santrock, 2008). The ability to 
think in an abstract fashion, as is associated with the formal operational stage of cognition, 
is necessary to the successful study of chemistry (Lythcott, 1990). Beyond the concrete 
properties of matter and the directly observable features of chemical change, the study of 
chemistry includes abstract (and sometimes nebulous) concepts. Some of these topics are 
quantitative in nature, such as dimensional analysis, stoichiometry, and equilibrium, requiring sound mathematical talent to successfully master them. Often, students struggle with 
the chemistry when their math ability, especially their proportional reasoning, is under-
developed (Lythcott, 1990). Students can become easily intimidated and discouraged by a 
struggle with chemistry that is in reality a fledgling ability with mathematical reasoning. If 
teachers of chemistry do not address the disparity with math ability in students’ chemistry 
performance, a struggle with the content for many students will be inevitable and meaningful learning will not take place in the chemistry classroom (Krajcik & Haney, 1987).

Arons (1996) describes that proportional reasoning is a fundamental skill that students need 
in order to be successful in any science discipline. Demonstrating successful proportional 
reasoning ability is a telltale sign of good scientific thinking. To better assist all students, 
and not merely ‘luck out’ with teaching the mathematically strong students in the chem-
istry classroom, physical meaning must be explicitly connected to quantities and the rela-
tionships between quantities must be explicated (Hestenes, 1987). Building the conceptual 
understanding behind chemical quantities will allow students to relate those quantities in 
all situations and reason through quantitative problem solving. By treating the quantitative 
aspects of the study of chemistry with concrete pedagogical approaches, students can more 
easily attain the concepts behind the principles, reason their way to a solution, and transfer 
their learning to a novel situation (Darling-Hammond, Low, Rossbach, & Nelson, 2003).

When you honestly consider the majority of students in a typical chemistry classroom, 
they are within the early years of teenage development. According to Vygotsky, to most 
successfully work within a student’s zone of proximal development during this age, teachers’ instructional methods must appeal to the concrete operational thinking that is char-
acteristic of this developmental period (Darling-Hammond, et. al., 2003). Merely teaching 
chemistry in a way that relies upon algorithms and strong mathematical abstract reasoning 
appeals only to students who are further cognitively developed. This method will not be 
effective; furthermore, it can serve as a discouragement to students whose present stage 
of cognition is mismatched to the instructional methodology. The language teachers use to 
communicate physical meanings of quantities and relationships can either promote algorithm-
ic memorization or support useful learning.

Avoiding the algorithmic pitfall, that will surely lose a number of students in the teach-
ing process, is possible. This can be achieved by making a very small adjustment to the
language used to talk about chemical quantities, proportions, and relationships (Cramer & Post, 1993). Utilizing traditional language such as, “100 centimeters is equal to one meter,” can give students a sense of the magnitude of quantities of length or the relationship between their magnitudes; however, this is of little use to students when they go to think about the physical meaning of the quantities or determine the number of centimeters in 13.4m (Lesh, Post, & Behr, 1988). Without an algorithm for using that equality, students have no reliable means to arrive at an answer for the number of centimeters in 13.4m. There is no mathematical operation or procedure embedded in the language used to describe the relationship; therefore, it is effectively and functionally useless to employ this language as a primary means of talking about quantities, relationships, or solutions to problems.

To illustrate the impact that language can have on the way we conceptualize mathematical quantities or operations, consider the difference between English and Chinese Language. Take the example of how we refer to the fraction 3/5. In English, we say, “three-fifths,” which tells nothing about the relationship between the numerator and denominator. In fact, many students become used to referring to 3/5 as, “three over five.” This is neither an accurate interpretation of the fraction nor a useful one. What does “over” mean as a mathematical operation? Ineffective language where 3/5 means “three-fifths,” reduces fractional relationships and ratios to tacit facts not functional knowledge. In contrast, consider the Chinese language for the fraction 3/5, which would translate, “for every five parts, take three.” This interpretation of the fraction uses functional language that contains a concrete conception of the relationship represented by the fraction (Gladwell, 2008). Knowing that 3/5 means, “for every five parts, take three,” can lead to a cognitive process of determining how many equivalent parts would you take in a group of ten parts. One could proportionally reason that since ten are twice five that twice as many as three would be the answer. Even if students struggle with the multiplication operation, they could still reason their way to the corresponding solution steps using “for every” language, because they could prove what the answer would be based on reason.

Gladwell continues to posit that the power of embedding instructions into language empowers thinking about mathematics. The second most powerful example, according to his argument, describes how the counting system in China is very intuitive. In English, we would say the number ‘13’ as “thirteen,” but in Chinese they would say “ten-three.” This pattern continues in Chinese, as the number ‘25’ is called “two tens-five;” in English, we say, “twenty-five.” This subtle difference entails having to think about more or less information when doing calculations. In English, to add ‘13 + 25′ we have to know what thirteen and twenty mean, and then we combine them algorithmically. In Chinese, they base it on the number of ‘tens’ and the rest is just the 0-9 counting numbers. So in Chinese, saying ‘13+25′ contains the instructions for adding it: “ten-three and two tens-five.” This easily allows the Chinese student to calculate the answer “three tens-eight.”

Though it is a consequence of language differences that students become used to thinking about fractions, ratios, proportions, and calculations differently, in English we have the option of using functional language to describe quantities. Using “for every” statement language to describe quantities and relationships contains cognitive instructions for thinking one’s way through solving a problem. Algorithmic methods are typically what teachers rely upon to help students solve proportional reasoning problems, because that’s what they were shown by their teachers before and it “made sense” to them, e.g., predict the theoretical yield of a certain chemical reaction based on a starting masses of the given
reactants and show your work. The typical approach used is the cross-cancelling table method. This is the one with a tic-tac-toe board where quantities and units are matched up so that the units cancel and give rise to the desired unit. The issue with an algorithmic approach is two-fold: first, solving the problem using an algorithm does not necessarily entail or demonstrate understanding of the relationships between the quantities being compared; second, if an algorithm is taught in lieu of the physical meaning behind the quantities in the algorithm (the shortcut first instead of the circuitous route) then the algorithm takes on no meaning. Some students can pick up on algorithms and arrive at the right answer fairly efficiently Algorithms can be utilized, but not until after a student truly understands and demonstrates proficiency with the concept and their reasoning through a problem (Darling-Hammond, et. al., 2003). In order to successfully use algorithms, they cannot just be shown to students for memorizing the procedural steps; instead, the thinking that underlies the algorithm, which is the proportional reasoning, must be made transparent to students through a cognitive apprenticeship (Collins, Brown & Holum, 1991) that includes scaffolding, coaching, and independent practice with the steps prior to implementation of the algorithm.

Consider the following question: “What is a ratio?” A fundamental answer explains that a ratio a comparison of two quantities. Most frequently, students are introduced to and exposed to ratios in a pure sense, using numbers without physical meanings, often in a mathematics course. This leads to the disconnection of ratios from the physical meanings of the quantities they relate as well as a tendency to utilize poor representations of the ratio (Karplus, Pulos, & Stage, 1983). As students gravitate toward, “three over five” language to represent 3/5, the ratios become decontextualized even before they get to a science class (Krajičik & Haney, 1987), let alone a chemistry class. Since many students enter the study of chemistry still at a concrete operational stage of cognition, it is important that proportional reasoning is utilized in a concrete way (Lawson, & Renner, 1975). The “for every” statement language can effectively accomplish maintaining a connection between the physical meanings of ratio quantities and the relationships between them; furthermore, “for every” statement language provides a reliable means of problem solving and reasoning that can easily transfer to novel contexts. By employing “for every” statement language in the chemistry classroom, teachers can reach students at a concrete operational level, creating a springboard for developing proportional reasoning skills (Cramer, & Post, 1993) and making quantitative problem solving less intimidating. Students who have fewer struggles with the mathematics involved in chemistry are more likely to approach the content with confidence and be successful with it. Using “for every” statements is a way to elucidate how to think about the quantities to students while preserving the physical meanings behind quantities. This small change to the way we refer to ratios and have students think about ratios will yield large returns of success in the long run from dimensional analysis to stoichiometry and beyond.

Making this simple adjustment to the language you use to talk about ratios and to hone proportional reasoning is really what “for every” statements are about. There is no algorithm here, though it may look procedural, it is about bringing out student thinking and giving them a reliable means to reason through the concepts, content, and calculations. This two-word strategy can be applied in many settings and is easy for students to use. Simultaneously, it will support the struggling learner in developing conceptual understanding and challenge the high-achiever to articulate their understanding. Making thinking visible is something that supports learning and assesses learning at the same time. “For every” speak in teaching and learning is the easiest change to make that elucidates the thinking process
behind proportionate reasoning in your teaching of chemistry, or any quantitative content, and yields large returns on investment with teaching and learning.

References
Developing 21st Century Scientists: A Venture Capital Perspective

By: Ecotek

Science and engineering readiness are building blocks for scientific and technical achievements which contribute to a better society. When one looks at the global economic landscape, it is clear that there are countries that are winning the war on education and countries that are clearly losing the war on education. Unfortunately, the United States and the State of Michigan in particular are on the losing side of the equation. According to the Organization for Economic Cooperation and Development (OECD), the United States ranks 25th in the world in math and science amongst industrial nations. Similarly, according to the Science and Engineering Readiness Index (SERI), the State of Michigan ranks in the bottom third amongst the 50 states in the country.

For some administrators, the goal is to meet state standards in math and science without overspending. For other school administrators, the goal is to pacify parents and students by having students do science projects for homework that require minimal work, such as going on the Internet and printing off a current event about a science topic. What’s more, some administrators expect that students will develop their math and science skills by watching educational videos in the classroom or logging onto a website and playing a video game. This is what I categorize as poor leadership and a disservice to our kids. It does not require risk taking, significant investment, hard work or innovation.

The Ecotek Lab Story

My experience in the world teaches me that great leaders are risk takers and courageous. I started Ecotek Lab for my kids in 2005, Keith Jr, Briana, Amber and Kayla. The goal was to provide them with the skills needed to compete in a global economy. This included introducing them to world leaders to learn about global politics; doing challenging hands-on science research; and showing them how to turn their scientific knowledge into economic assets and connecting them with like-minded students and working professionals.

Today, seven years later, there are over twenty five students working in Ecotek on research projects with UN member countries and agencies. Their innovations are being integrated into STEM curriculums at schools throughout the country, thus impacting thousands of future scientists. Ecotek students excel academically and are recruited by universities across the country for undergraduate admissions and research internships. They speak at conferences around the world about their innovations and compete in major science competitions. More importantly, they have the confidence to dream, discover, and innovate.

Students at Ecotek Lab do research in four areas: material science, alternative energy, environmental science and biotechnology. They are assigned to research projects based on their interest, academic record, work ethic and maturity level. The curriculum is process centric and result oriented. Student scientists are responsible for the project planning, resourcing, execution, risk management, and completion. Parents are heavily involved in the program (e.g. volunteer, travel, fund raising, and helping out with project work).
Think Like an Investor Not Like a Manager

Investing in STEM education is a very risky venture. Many things can go wrong, ranging from failed projects to underperforming student scientists. School leaders need to reevaluate their return on investment (ROI) models for STEM. This includes measuring the outputs and the inputs. It is just not about grades, it is about what type of person is being developed. I do not have a traditional background in the field of education (e.g. in-class student teaching at a school). I earned a technical degree from a small university in the State of Michigan. I have participated in leadership development programs at Harvard Business School. I gained my leadership experience in science and math by working with research scientists and inventors around the world.

My background gives me a different perspective on the definition of the term ‘success’. Some school leaders lack vision and courage. They complete the easy stuff (e.g. buying text books and paper towel) but they avoid doing the difficult work that will make a real difference in the long term competitiveness of their students (e.g. establishing a math and science program that teaches innovation).

Many school leaders allocate funds to STEM programs without looking at the ROI. The use of this approach may be largely due to the fact that it is taxpayer money. Ecotek Lab was founded using risk capital (i.e. I invested my own money). It uses a portfolio based model to fund STEM activities. Project funding is based on the long term benefits of the project output to the student, the program and the global community.

To be a leader in education today, you must view success using an evaluation model that extends beyond the classroom. Success at Ecotek is based on student academic achievement at school and on standardized tests; the number of copyrighted articles published, the number of patentable innovations/inventions produced, and the number of internships/scholarships awarded to our student scientists. Under the current model, our average annual ROI is approximately 120 percent.

Lead By Example. Set the Pace. Accept Uncertainty

School leaders need to set the pace for STEM. Students hear us talk about topics such as green science and combating global warming, but they never see us do anything to back up what we say. Talk is cheap and anyone can do it. Think about it. Do you know how to make biofuel, identify toxins in drinking water, make bioplastic or grow stem cells? As the founder of Ecotek Lab, I know how to do all of these tasks and more.

I have worked with my students to build an electric bike; make biofuel; make biodegradable plastic, grow stem cells; conduct ecological surveys in Africa; help with the clean-up of the BP oil spill; conduct research on barrier islands; canoe down streams and rivers; hike through national forests and wetlands; visit national research labs; present at international conferences, create commercial products and meet with world leaders at the United Nations.

To lead a 21st Century STEM program, you must be committed and willing to set measurable goals that require exceptional commitment from you, your staff, the student scientists, and their parents. That is, you must set the standard, rather than just meet standards. Do not spend time worrying about what you do not have, focus on what you want to deliver and the young minds you want to influence.
Conclusion
The world is becoming more competitive everyday. From a global perspective, the war is not being waged on the battlefield with guns and bullets, but in the classroom using books and beakers. Presently the United States and the State of Michigan are lagging behind countries like China and India in STEM. In order for the region to move forward, we need better leadership from school leaders. Ecotek Lab is a math and science program that has excelled by leveraging best practices in project management, capital investment and human resource development to produce award winning student scientists that travel the world innovating and creating.

Implementing change is difficult work. Improving student achievement in STEM will require a major shift in how school leaders manage and respond to challenge. Some ideas for improving your STEM programs include setting a vision of success that can adapt to changes in the global economy; funding program activities using a venture capital based perspective that focuses on the student; and being a leader that is comfortable with uncertainty. Using these and other performance based strategies, coupled with an unrelenting ‘can do’ attitude will not only help you develop more scientists in your school, it will help you be a better leader.
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“Screen Casting”
“Online Learning”
“Literacy and the Common Core”

and many more!
Author Guidelines

Deadlines: August 15th for the Fall Journal & March 15th for the Spring Journal!!

How to Get Published in THE MSTA Journal
Twice each year in October and April, MSTA publishes a journal that reaches elementary, middle, and secondary classroom teachers, principals, and science educators. Why not share your ideas with your colleagues?

Before You Begin
Review the current journal to get an idea of the types of articles that are published. We have two sections:
(1) feature articles that deal with research, MEAP topics, or address a learning theory
(2) classroom ideas that give classroom activities, usually in much the same format as the teachers use in their own classroom.

Write clearly and concisely, organize your material logically, and use an active voice and conversational tone. Write about your firsthand experiences or your unique area of expertise and stress classroom applicability.

You must guarantee the originality of your work. Credit any other author’s ideas that you use or build on. Do not copy illustrations from textbooks. All illustrations must be copyright free.

Your manuscript length can be variable. We have published articles that range from 1-16 pages. On the title page provide each author’s name, current position, mailing address, e-mail address, home and work telephone numbers and fax number.

Cite only direct sources, and use the author-date reference style in the text. Bibliographies and resource lists should be alphabetized and limited to current, readily available items. Check the accuracy of your items carefully.

How To Submit
Email your article to Lisa at (lweise@hpsk12.net) in Word format. If your article has specific formatting, please mail a printed hardcopy proof of your article to the editor for formatting reference. Note: If you do not supply a printed hardcopy proof for formatting reference, we can’t be held responsible for formatting errors or inconsistencies.

Photographs should be submitted electronically in high-resolution format (4” x 3”, 300 dpi). Students in lab must be shown following appropriate safety guidelines and wearing proper safety attire, including splash-proof goggles. Their faces should be visible, but they should not look directly at the camera. If the photo is used, a signed model release will be required of each student pictured.

Checklist
☐ Author’s name, current position, mailing address, phone numbers are included with article.
☐ Written clearly and concisely with an introduction and conclusion.
☐ Stresses classroom applicability.
☐ References are complete.
☐ Photos show students following appropriate rules of safety.
☐ Two printed copies and a disk are mailed to the editor.

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