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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Learning From the Biographies of Scientists

There is a limit to the lessons that can be learned from the biographies of scientists. The days are long gone since major advances could be made by a talented amateur using homemade apparatus, such as Michael Faraday, or an untrained scientist like Charles Darwin. New discoveries in experimental science require expensive equipment, and the design of investigations and analysis of data requires an extensive knowledge of the underlying theory. Theoretical science requires an understanding of high-level mathematics. Future scientists will need to be highly educated and work in university or other research institutions.

Source: Ben-Ari, M. (2005). *Just a theory: Exploring the nature of science*. New York: Prometheus Books.

Teaching Ideas

Techniques, demonstrations, activities, alternative conceptions, critical incidents, stories, and other ideas

Questioning Students

Among the suggestions Colburn (2009) provides for questioning students are the following:

- After asking an open-ended question (i.e., a question intended to produce a free response rather than a direct or one-word response), give students time to think by using "wait-time." For example, try counting silently to five. With practice, a teacher becomes more comfortable with such small periods of silence.
- Avoid praising or rejecting students' responses to open-ended questions, because either can inhibit students' reluctance to contribute for fear of saying something that is wrong or "bad." Rather, use the non-judgmental: "Ok, thank-you."
- Paraphrasing a student response (including rephrasing it to incorporate new vocabulary in context) shows that the teacher has listened and understood, and helps those who may have missed the response. Similarly, a student can be asked to clarify (e.g., "So, you are saying . . . . Is that right?). Then, the teacher might proceed with "Ok, thank-you. Who has another idea?"

Reference

Colburn, A. (2009). Ask questions – and listen! *The Science Teacher*, *76*(5), 10.

Science Poetry

Reading and/or listening to poems composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Blossoms of Life

Strong morning winds blew,
Sending the heat twirling 'round and 'round.
Sitting silently in a small garden,
A seed lay, waiting to be found.

One Spring afternoon,
A speck of green had begun to show.
For beneath the moist, rich soil,
The small seed had started to grow.

As the long days grew,
So, too, did the small sprout.
Inch by inch, upward it climbed,
Until, it pushed its way out.

From tiny seed to spindly sprout,
The speck had slowly grown.
Now, it had bloomed with colour,
And became so very well known.

From deep within its pistil,
Tiny seeds began to form.
Waiting for their chance to spread,
In conditions, moist and warm.

Days and days had passed,
And the flower had begun to die.
Happy at the source of life,
It watched its little seeds fly.

Colleen Smit, 12 years
Australia

Rainforests

Rainforests are the filter of the Earth
They're very important to environmental birth
They're mostly found near the equator
They'll all be gone sooner or later

In a rainforest there's a canopy
The canopy is way taller than me
Just down below is the understorey
Where undergrowth roams free

Down even more there's the forest floor
Where the bright sunlight is very poor
Right up high there's the emergent
Where monkeys swing and eagles soar

If we don't do something soon
All this wonder will go KABOOM!!
Rainforests are swarming of with trees
If they die we'll be in a catastrophe.

Sam Gardiner, 11 years
Australia

Ideas in Brief

Ideas from key articles in reviewed publications

Teaching the Big Ideas

A major problem that we have in science education is that students are being asked to learn isolated facts rather than being provided with opportunities to develop an understanding of the broader, central concept (i.e., the big idea). For example:

- Students learn about egg, larva, pupa, and adult but miss the central idea that all living things, including plants, people, birds, and worms, have a life cycle.
- Learning focuses on naming the parts of a plant and stages of plant growth rather than the notion that each plant or animal has different structures that serve different functions in growth, survival, and reproduction.
- Students describe the features of the rain forest, desert, and ocean and name three plants and three animals that live in each, yet fail to understand (by synthesizing across environments and looking for elements that are common and that are different) that there is a diversity of environments in the world and how different environments support different organisms.

A cause of this problem is that instruction is topic-related rather than concept-focused. Children's literature is topic-related, teachers commonly search for topic-related activities, and end-of-unit tests typically target facts that students may not need to know and that are quickly forgotten. A useful test is to ask students what they have learned. If they reply, for example, that "we have learned about plants" rather than "we have learned that the kind of structures living things have affects the functions they can do," we can conclude that the teaching has been topic-related.

To overcome this problem, the focus needs to be on the central concept (i.e., the big idea) as reflected in a standard, which many teachers also consider to be too vague, rather than taking a topic-focused approach. Learning experiences need to be chosen, and the instructional sequence structured, so as to promote the learning of the central idea over time and with a depth of understanding. Teachers need to constantly guard against getting sidetracked on things that students don't really need to know. Interestingly, stating behavioural objectives for each lesson, as many teachers have been taught to do, actually works against what is required, because these often require the display of trivial skills and/or recall of information after only a short period of time. By getting tangled in such details, the focus on the big idea may be lost.

Reference

Olson, J. K. (2008). Concept-focused teaching. *Science and Children*, *46*(4), 45-49.

Readers' Forum

Prayer Study (Continued)

In responding to the concerns I expressed in the last issue about a prayer study not being considered to be science, Kathy Gallucci wrote: "In this case . . . the investigators may be able to disprove (falsify) that prayer helps a patient's recovery" ("Prayer Study," 2009, p. 15). This is exactly what I was suggesting, so it might appear that we are agreed that a study of the impact of prayer on patient recovery can indeed be considered science rather than pseudoscience. This is also in accord with the role of science in testing claims/beliefs such as the following reflected in the work of Preece and Baxter (2000):

- Breaking a mirror brings bad luck.
- What happens to people during their lifetime is influenced by the positions of the planets and stars when they are born.
- The lines on the palms of your hands can tell what will happen to you in the future.

While Preece and Baxter chose to avoid beliefs with religious connotations, which is sound practice when working in a school environment as they were, such exclusion need not be the case.

Having said this, though, the remainder of the first three paragraphs of Gallucci's response is devoted to trying to argue the contrary; namely, that such a prayer study cannot be science! However, and with respect, I think the problem lies in the fact that this writing misrepresents the concept of a hypothesis in science, the notion of testable/falsifiable, and how science is done, and particularly the role of hypotheses in this process. Allow me to elaborate.

We need to distinguish between a prediction and a hypothesis (McComas, Clough, & Almazroa, 1998). I consider a prediction to be a statement about the expected outcome of a test and a hypothesis to be a possible explanation for the observed facts and laws (Eastwell, 2002; McPherson, 2001). That Gallucci does not distinguish between these two terms is demonstrated by the suggested responses to the first two questions provided in the teaching notes that accompany the case. The first question asks what hypothesis the researchers made, the second asks what predictions they made, and the suggested responses are the same. I even find it strange that students would be expected to provide the same response to each of two questions that appear different. Indeed, "life exists in other solar systems" ("Prayer Study," 2009, p. 14) and "in 100 years there will be no humans on Earth" (p. 14) are predictions rather than hypotheses, because they have no explanatory element. In a recent paper, Gallucci (2009) also inappropriately equated a hypothesis with an inference, which I consider to be that which is derived by reasoning. So, in the case featured in that paper in which family photographs are used to introduce human evolution, when one views a photo of a person and reasons about his or her age, one is making an inference rather than proposing a hypothesis.

Gallucci writes that a scientific hypothesis must be both falsifiable and testable, regarding these to be two separate and different things, but they are neither. When we say that a scientific hypothesis must be testable, we mean that it must lend itself to being falsifiable; that is, testable and falsifiable are the same idea. Further, a hypothesis is not unscientific because it cannot be tested right now. As Popper (1968) suggested, only ideas that are *potentially* falsifiable are scientific ideas. For example, there would have been a time when people hypothesized that the Earth was flat, but surely this wasn't to be regarded a non-scientific possible explanation at the time on the basis that it couldn't be tested at that time. So, it is the nature of the ideas that determine if they are scientific or not. Possible explanations that invoke the will of God, for example, cannot be tested/falsified and therefore cannot be regarded scientific hypotheses.

I do not think it is true to say that a correlation does not provide evidence for cause-and-effect in this case, because when an experimental design aims to change one variable only, a conclusion about cause and effect can be made. The last two paragraphs of Gallucci's response addresses issues about experimental design and therefore don't appear relevant to the issue in question.

As this case was presented, then, there are no hypotheses involved, but rather simply an idea (i.e., that intercessory prayer can help a patient's recovery) to be tested. Also, a claim (e.g., that the Earth is 6,000 years old) is not deemed to be outside the realm of scientific testing simply because it relates to a religious belief.

It may be instructive, though, to consider a couple of ways whereby the concept of a scientific hypothesis might very well be involved in such a prayer study. First, imagine that studies of the effect of prayer did suggest that intercessory prayer can impact positively on patient recovery. A scientist might then well ponder along the following lines: "Ok, so we have this phenomenon called prayer having an effect on patient recovery. While prayer is traditionally associated with religious beliefs, I wonder if some natural causal mechanism might actually be 'at play'?" The scientist could then propose a scientific hypothesis (e.g., some possible explanation involving the notion that prayer activates some presently-unknown form of energy) and go about testing this possible explanation by testing the predictions that follow from it.

Alternatively, consider this scenario. Scientists observe that some people recover more quickly than others, and wonder why. They might then propose one or more scientific hypotheses (i.e., possible explanations) for testing (i.e., falsification). These hypotheses might include the role of antibiotics, white blood cells, and even prayer (as described in the previous paragraph). The more I think about it, the more I feel convinced that a prayer study can make for legitimate science.

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Clarifying Hypothesis Testing

In their paper "Hypothesis Testing: It's Okay to be Wrong," Davis and Coskie (2009) seek to quite correctly stress that there is much value in having students formulate and test scientific hypotheses, even in the event that a hypothesis leads to a prediction that is subsequently found to be incorrect (i.e., where the hypothesis is not supported by the evidence that is collected), and that students should not feel uncomfortable if the evidence refutes their hypothesis. While the paper begins just fine, I would like to suggest some revisions to the activity, which forms the bulk of the paper, aimed at strengthening it by clarifying some issues.

Specifically, I think the paper confuses the notions of a prediction and a hypothesis and, as a result, uses the latter term inappropriately and hence confusingly. We need to distinguish between these two terms (McComas, Clough, & Almazroa, 1998), and failing to do so "not only loses the 'logic' of hypothesis testing but also loses the central goal of doing science, which is to generate and test *explanations*. Small wonder so many teachers and students are perplexed" (Lawson, in press, p. 23). A hypothesis is not "a prediction with an explanation" (Davis & Coskie, 2009, p. 58). Rather, a hypothesis is a possible (or proposed) explanation for the observed facts and laws (Eastwell, 2002; McPherson, 2001; Oehrtman & Lawson, 2008) and a prediction is a statement about the expected outcome of a test.

In the activity presented in the article, which in essence is a very good one for the purpose for which it is being used, students compare the growth of planted bean seeds, for the first few weeks only, that have been placed in a dark cupboard with others placed in sunlight. Students are typically surprised to find that the absence of sunlight does not affect the growth of the plants. Allow me to first précis the main steps in the activity while providing an accompanying commentary, and then follow with a suggested improved approach.

The main steps of the activity, with my commentary shown in red italics, are as follows:

1) Students are asked what things plants need to grow (although it is not made clear if students are told that it is the initial growth of seeds, rather than mature plants, that is to be investigated here, and this should be done so as to avoid it being a trick question.) They typically say "the Sun," saying that plants will not grow without light.
   When students respond to this question, which is called a causal question, they are formulating a hypothesis (i.e., a possible explanation as to the cause of the phenomenon).

2) Students design an experiment to answer the question: "Does light affect the growth of beans?"
   This question, on the other hand, is not a causal one and therefore does not require a hypothesis. Rather, students simply need to conduct the experiment, analyze the results, and draw a conclusion.

3) Students are then asked to write a hypothesis (i.e., to predict an outcome and include a reason). For example, they might write that the plants in the cupboard will not grow as well because "I know plants use sunlight" (Davis & Coskie, 2009, p. 59).
   So, students should not be asked to write a hypothesis here, because the question ("Does light affect the growth of beans?") is not a causal one. Rather, they are actually being asked to formally document a personal prediction (as opposed to a prediction that follows from the hypothesis the class is testing), and I'd like to suggest that this is also to be avoided. Because such a personal prediction will be based on personal experience, or in some cases perhaps even on nothing more than intuition, asking students to document it is a threatening exercise that is likely to make them feel uncomfortable, because they are actually being asked to publically declare what they don't know. After all, the whole purpose of the investigation is to find out what does happen, and they wouldn't even be doing it if they already knew the answer! Ironically, then, asking students to make such a personal prediction runs contrary to the aim of the authors in ensuring that students feel comfortable even if the conclusion of the investigation does not support the class hypothesis that plants need light to grow. In addition, documenting such a prediction early

in a report, and then subsequently stating whether it was right or wrong, is not in accord with the practice of real scientists when reporting on investigations aimed at answering similar, non-causal questions. A scientist might have an opinion about the outcome of an investigation aimed at answering a non-causal question before the investigation is conducted, but he or she is not asked to formally document it for the whole world to see!

At the same time, though, I am not suggesting that one should not elicit students' reasoning for what they personally think will be the outcome of the experiment. In a class of 20-30 students, there may even be some who don't think light is needed for plant growth in the situation being studied, and I'll consider this issue shortly. Rather than checking on the personal predictions of students, then, it is predictions that are generated from hypotheses that we should be checking on. Then, it is a hypothesis that might be refuted rather than students' personal ideas, and a different hypothesis can then be considered. This removes the personal threat to students because the class hypothesis, although suggested by students, was simply a possible explanation considered worthy of being tested, and testing ideas to answer questions is what science is all about.

4) The experiment is then conducted, results collected and analyzed, and the conclusion reached that the absence of light does not inhibit plant growth and that their prediction was wrong. As an extension, students are then invited to propose and test other hypotheses for plant growth.

May I suggest, then, that an improved approach might go something like this:

1) The attention of students is brought to the beauty of plants they can see, and the class is asked to recite the poem Blossoms of Life found in the "Science Poetry" section (page 36) of this issue (e.g., with girls and boys reading lines alternately). The teacher holds up a bean seed, saying that this seed can be made to grow as a plant, and asking: "I wonder what a plant needs to grow?"

2) Students are invited to propose several hypotheses to answer this question, and these hypotheses might include the role of soil, water, air, light, and even the seed itself. The class is guided towards choosing the light hypothesis (although other hypotheses could also be tested), and invited to design an investigation to determine if a plant needs light to grow.

3) Student reasoning as to what they think the experiment will show is then elicited in an anonymous, and hence non-threatening, way. For example, an audience response system, such as clickers, might be used to first determine how many students think light will make a difference and how many do not. Then, their individual reasoning might be collected anonymously and displayed to the whole class, providing an opportunity to identify alternative conceptions. In this case, I would advise against discussion of the value or otherwise of such student reasoning at this point, because it might take only 1 student with an appropriate background experience to convince the whole class that light is not needed for plant growth to reduce the motivation of students to proceed further (i.e., to conduct the experiment).

4) They conduct the experiment and conclude that this particular hypothesis is not supported by the evidence. Their reasoning, elicited in the previous step, is then revisited, with the teacher guiding student discussion as they evaluate what had been suggested, with particular emphasis being given to any alternative conceptions that appear. So, as Davis

and Coskie (2009) quite rightly note, even though this hypothesis might not have been supported, the exercise has been a valuable one in that new information has been learned. Then, just as in professional science, it could be "on with the next hypothesis." The students have been engaged in real science, which is precisely what is needed.

Using this example, let us now consider the broader picture. How common it is for students to be routinely asked to write a hypothesis before carrying out any investigation, and we can now see why this is inappropriate. When school students are asked to propose a hypothesis during experimental work, they are really most often being asked for a prediction, because most of the questions they answer are non-causal ones. Examples include: "Does light affect the growth of beans?" "Will plants grown in topsoil grow taller than plants grown in clay?" "How many types of living organisms can you identify in your school grounds?" "How do the energy values of cheese, peanut, and biscuit compare?" "What types of structures does a flower have?" In none of these cases is a hypothesis required before the investigation is conducted, although one or more hypotheses (i.e., a possible explanation for what has been observed) might certainly appear in the discussion section of the report of such an investigation as a suggestion for further research, and it is to this situation that Robertson (2009a,b) was referring when he suggested that hypotheses in science education are overemphasized and "maybe a bit overrated" (Robertson, 2009a, 57).

This then leaves us to see that students should be asked to write a hypothesis at the beginning of an investigation only in the relatively few cases where the question being answered is a causal one. Examples include: "What does a plant need to grow?" "Why does a potted plant placed outside for 2 days without any water supplied wilt, whereas a similar plant kept inside does not?" "Why does a basketball go flat when used outdoors in winter?" However, correcting the use of the term *hypothesis* in science is not likely to be an easy task. Not only are school textbooks presently riddled with misuse of the term, but even science and science educators use it incorrectly to mean a prediction as well as other things, as exemplified by Anton Lawson's commentary, that appears in this Readers' Forum section of this same issue, titled "The Role of Hypotheses and Predictions in Scientific Inquiry." Then, as a further challenge, we would do well to rid both science and science education research of the mathematical term *null hypothesis* (Lawson, 2008), and I exemplify this issue in a commentary titled "The Null Hypothesis: Good for Maths but not for Science" that also appears in this Readers' Forum of this issue.

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The Null Hypothesis: Good for Maths but not for Science

In her article “Straight From the Mouths of Horses and Tapirs," DeSantis (2009) shares a fine approach for using fossil teeth to investigate how ancient environments may have changed over time. However, I feel compelled to comment on two aspects of the content of the sidebar, that appears on page 20, designed to provide information on falsifying a hypothesis:

1) A hypothesis is not “a statement about data expectations” (p. 20). Rather, this describes a prediction or, if "predicting" the past, a retrodiction (Ben-Ari, 2009). A hypothesis, on the other hand, is a possible (or proposed) explanation for the observed facts and laws (Eastwell, 2002; McPherson, 2001; Oehrtman & Lawson, 2008). In addition, I suggest that because the question "have the diets of horses and tapirs changed over time?" is not a causal question, answering it does not demand a hypothesis up-front, but that a hypothesis might follow the investigation in the discussion section of a report.
2) The term *null hypothesis* (short for *null statistical hypothesis*) is a mathematical term rather than a scientific one. Its use in science and science education is both unnecessary and confusing, and the term should be culled from the language of both these fields (Lawson, 2008).

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The Role of Hypotheses and Predictions in Scientific Inquiry

Ben-David and Zohar (2009) taught what they called “general, explicit knowledge about thinking strategies” to improve eighth-grade students’ ability to “define research questions” and “formulate research hypotheses.” They referred to “general, explicit knowledge about thinking strategies” as “meta-strategic knowledge.” While research into helping students think more scientifically has been and will likely continue to be fruitful, success is predicated on a good understanding of what one hopes to teach. In other words, if one hopes to teach students how to inquire and how to think scientifically, then it is important to have a good understanding of how inquiry works and how to think scientifically. To borrow Ben-David and Zohar’s terminology, one needs accurate meta-strategic knowledge. To that end, the authors’ characterized scientific inquiry as a cycle consisting of the following thinking strategies: 1) Define research question(s), 2) formulate research hypotheses, 3) plan experiments, 4) observe outcomes and collect data, 5) analyze data, 6) summarize and communicate, and 7) revise question(s) or hypotheses and begin cycle again (p. 1659).

Whether or not these sorts of lists appeal to you, the devil is clearly in the details. For example, what sorts of questions qualify as “research” questions? What sorts of hypotheses qualify as “research” hypotheses? How does one actually test a hypothesis? Are experiments always needed? Or are there other ways to test hypotheses? And so on. Thus, one can ask: Do Ben-David and Zohar accurately characterize the nature of scientific inquiry? Their primary example involved absent-minded Professor Lazar who investigated the effect of cooking an egg. To do so he put one egg in salt water, put one egg in a pot of boiling water, put one egg in a refrigerator, and put one egg in water that he then heated. After about 30 minutes he weighed the eggs and concluded that cooking affects their weight. Students were told about this "experiment" and were asked to discuss it in terms of why the professor failed.

Although it seems worthwhile to have students critique faulty experimental designs, one has to also ask: Does this example accurately characterize the business of hypothesis testing? Is it an "authentic" scientific inquiry? Prior to generating hypotheses (i.e., proposed explanations), doesn't one first need some puzzling observation to explain? To test proposed explanations, doesn't one need to imagine some sort of test with specific expectation(s)? Doesn't one then need to conduct the test to see if the results turn out as expected? And finally, doesn't one then need to compare expected and observed results in order to draw a conclusion about the veracity of the tested explanations? In terms of a well-known classroom phenomenon, these steps look like this:

1) Puzzling observation(s): A burning candle standing in a pan of water is covered with an inverted jar. The candle soon goes out and the water rushes part way up into the inverted jar.
2) Causal question: Why did the water rush up into the inverted jar?
3) Some proposed explanations (hypotheses): (a) The oxygen was "burned up" creating a partial vacuum. So the water was pushed up by the greater external air pressure. (b) The candle's heat caused the air around it to expand and escape from the jar. After the candle went out, the internal air cooled and contracted. Thus the internal air pressure was reduced and the water was pushed up by the greater external air pressure.
4) Some imagined test(s) with expected results (predictions): *If*...water was pushed up to replace the consumed oxygen (explanation/hypothesis), *and*...the height that water rises with one, two, three, or more candles (all other things being equal) is measured (imagined test), *then*...the height of water rise should be the same regardless of the number of burning candles (prediction). This result is expected presumably because there is only so much oxygen in the jar to be burned. So more candles will burn up the available oxygen faster than fewer candles, but they will not burn up more oxygen. Hence, the water rise should be the same. Alternatively, *if*…explanation (b) above is correct, *then*…the water should rise higher with additional candles (prediction). This result is expected because the additional candles will produce additional heat, which will drive out more air. Hence when the candles go out less air will be under the jar. Hence when the air cools and contracts the internal air pressure will be even lower.
5) Observed result: When the imagined test was conducted, the water was observed to rise much higher with additional candles.
6) Conclusion: The observed result matches the predicted result derived from hypothesis (b) but does not match the predicted result derived from hypothesis (a). *Therefore*…hypothesis (b) is supported and hypothesis (a) is contradicted.

With this example as context, consider the three "hypotheses" that Ben-David and Zohar (2009) said they were testing:

> Our hypotheses are: (a) that explicit teaching of MSK (meta-strategic knowledge) in an authentic setting will have a positive effect on students' performance regarding both DRQ (define research questions) and FRH (formulate research hypotheses) thinking strategies; (b) that this effect will be preserved in delayed transfer tasks; and (c) that LA (low achieving) students will benefit from treatment more than HA (high achieving) students. (p. 1662)

Are these statements really hypotheses? Or are they better labeled predictions? Said another way, is this a list of proposed explanations? Or is it a list of expectations? Given that scientists and science educators agree that hypothesis testing is central to scientific inquiry, it would seem that the distinction between proposed explanations (hypotheses) and derived expectations (predictions) would, among other things, need to be made clear, particularly when trying to teach students how to inquire and think like scientists. Unfortunately, it would seem that this is not the case here. In fact, it is seldom the case (cf., McPherson, 2001).

In conclusion, if we hope to be successful in teaching students how to inquire, we need to have a clear understanding of what inquiry is and how it works. We need to embed authentic inquiries into our classroom instruction. And we need to properly label its key elements.

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Laboratory Safety Guidelines

This section presents a series of 40 laboratory safety guidelines kindly provided by Dr James A. Kaufman, President, The Laboratory Safety Institute (LSI), USA. Please visit http://www.labsafety.org for further information, products, services, and publications.

#9 of 40. *Make learning how to be safe an integral and important part of education, your work, and your play.*

For too many years at academic institutions and some companies, health, safety, and the environment has been something extra. It's time that it became part of the process. At Dow, we were told that we were being paid to do three things: (1) work safely, (2) conduct active research programs, and (3) publish the reports and patent disclosures resulting from our research. Safety was part of the job, not something extra.

The slogan at the Bell System is: "No job is so important and no service so urgent that we cannot take time to perform our work safely." At Dow, it was each person's responsibility to be sure that their work could be performed safely. If you don't think it's safe to do, don't do it. LSI has paraphrased the Bell System slogan in one of ours: “No lesson is so important and no task so urgent that we cannot take time to teach, learn, and practice science safely.”

These kinds of attitudes and values are built over time by companies and institutions that make it very clear that they value safety. Educators (art, science, technology) need to have the time (as part of their regular working day) to set up and test experiments, to look up the hazards of chemicals, and to find out what protective equipment and protective facilities are needed. This is the job.

I hope art, science, and technology educators will ask to be relieved from collateral duties to make time for these important safety, health, and environmental responsibilities. English, math, history, and foreign language teachers don't have these needs. You do. And remember, if you never ask, you'll never get. If the principal says no, just think to yourself, "that's an interesting opening position!" Ask every chance you get until you get what you want!

There's an interest quote from Jacob Riiss:

> When nothing seems to help, I go and look at a stone cutter hammering away at his rock perhaps a hundred times without so much as a crack showing in it. Yet at the hundred and first blow it will split in two, and I know it was not that blow that did it, but all that had gone before.

Further Useful Resources

Kitchen Chemistry (http://www.rsc.org/education/teachers/learnnet/kitchenchemistry/00.htm) Activities, worksheets, and videos about some chemistry used in both home and restaurant kitchens.

Supermarket Botany (http://www.csu.edu.au/research/grahamcentre/education/) Provides an explanation of plant structures and life cycles (emphasizing the difference between fruits and vegetables) and an interactive test. Use as a stand-alone application or in conjunction with a hands-on laboratory activity. Adaptable to many age levels.

Practical Biology, Practical Chemistry,* and *Practical Physics (http://practicalbiology.org/, http://practicalchemistry.org/, and http://practicalphysics.org/) Activities to promote practical work in schools. Includes notes about teaching and learning.

Scotch Science Fair Central (http://school.discoveryeducation.com/sciencefaircentral/#) Resources to help students plan, complete, and successfully present science fair projects.

Meet me at the Corner (http://meetmeatthecorner.org/) Uses video podcast technology to take 7- to 12-year-old students on virtual field trips.

Thinking About Climate Change (available from http://www.theweathermakers.org) A cross-curriculum teacher and student guide, for Years 7-10, aimed at inspiring today's students to be tomorrow's leaders in dealing with the challenges of climate change: the science, impacts, and solutions.

The ChemCollective (http://www.chemcollective.org/) A collection of virtual labs, scenario-based learning activities, and concepts tests that can be incorporated into a variety of teaching approaches as pre-labs, alternatives to textbook homework, and in-class activities for individuals or teams.

Queensland Museum: Learning Resources (http://www.qm.qld.gov.au/education/learningresources.asp) Online educational resources that include Wild Backyards, Mangrove Challenge, Disease Detectives, and Biodiversity & The Great Barrier Reef. The resources feature digital stories, interactive games, downloadable fact sheets, and suggested learning strategies.

Incorporating Informal Learning Environments and Local Fossil Specimens in Earth Science Classrooms: A Recipe for Success

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Abstract

In an online graduate paleontology course taken by practicing Earth Science teachers, we designed an investigation using teachers' local informal educational environments. Teachers (*N* = 28) were responsible for photographing, describing, and integrating fossil specimens from two informal sites into a paleoenvironmental analysis of the landscape in which the fossils were originally deposited. Our practicing teachers also developed mini-units for their individual classrooms, utilizing the fossils and the informal sites they investigated. Not only did teachers develop a multitude of innovative and effective activities, but they were overwhelmingly enthusiastic about incorporating aspects of local informal sites within their individual classrooms. Content analysis of teachers' anonymous responses revealed three stable findings: 1) The informal sites and local fossils affirmed the importance of the local environment and put it into a larger context, 2) directed student activities within informal sites can maximize learning, and 3) informal sites provide a context for information and can supply an interdisciplinary "big picture" for students. We propose that directed interdisciplinary investigations that incorporate the local environment may enhance science learning at informal education sites.

As students, most of us thoroughly enjoyed the opportunity to step outside the classroom for a day filled with new places to visit, fun-filled activities, and the obligatory bus ride. After all, this was essentially a day "without school." As science teachers, however, some of us may have hesitated to bring our classrooms to a museum, arboretum, botanical garden, or fossil park. Although a chance to escape the traditional classroom was a positive factor, could students really learn in these informal environments, or did they feel inundated with a multitude of exhibits, often precisely labelled and "caged" within glass displays or behind fenced areas?

Similar to traditional classrooms, the quality of informal education can vary across a broad spectrum, with some instructional methods being more effective than others. "One size" in instruction does not necessarily "fit all." Our students' backgrounds are often quite varied, yet important, when planning science lessons. Fortunately, our previous research with the Geological Sense of Place writing template revealed that the local landscape had a strong influence on the majority of our students (Clary & Wandersee, 2006). Students typically indicated that local rock types, landforms, and experiences had the greatest impact in their youth, as opposed to events and products that were highly publicized in textbooks and television documentaries. Therefore, in our Earth Science classrooms, we hypothesized that an integration of fossils within local informal environments, such as museums, national parks, and nature centers, might enhance informal learning opportunities.

Active Learning, Informal Learning Environments, and Local Fossils

Science education research has affirmed that student-centered and active learning strategies can result in learning benefits for our students (Lawrenz, Huffman, & Appeldoorn, 2005; McConnell, Steer, & Owens, 2003; Michael & Modell, 2003). One benefit of active learning techniques is improved student understanding of the research process (Felzien & Cooper, 2005; Hemler &

Repine, 2006). Both increased learning and positive student attitudes have been reported for inquiry-based biology exercises (Lord & Orkwiszewski, 2006), while higher grades have been correlated with informal, active-learning investigations with fossils (Clary & Wandersee, 2008). Burr, Chiment, Allmon, and Rigby (2003) have also reported success in using an unidentified fossil to engage students, as well as the public.

The value of informal education and free-choice learning is well-established (McComas, 1996, 2006; Wandersee & Clary, 2006). In addition to being the default learning environment for the majority of the adult population, students engage in this type of learning more often than learning in traditional school environments (Falk & Dierking, 2002). As a result of the value of informal education, researchers have investigated the theoretical bases, motivators, and assessments of learning in informal settings (Anderson, Lucas, & Ginns, 2003; Falk, 2001; Falk & Dierking, 2000; Meredith, Fortner, & Mullins, 1997; Orion & Hofstein, 1994; Rennie & Johnson, 2004). Informal educational programs have also been shown to engage citizens in global problems, independent research, and data collection (Roy & Doss, 2007).

Informal educational settings also can offer rich learning opportunities for our students (Anderson, Lucas, & Ginns, 2003). Field experiences provide environmental context and land ethic (McLaughlin, 2005). Furthermore, field experiences can reach students who have difficulties grasping subject matter, and provide holistic experiences that are retained (Bernstein, 2004). Elkins and Elkins (2007) indicated that significant geological concept gains could be achieved in a field-based course. Therefore, science educational research suggests that learning benefits can accrue in Earth Science classrooms with active learning strategies and informal environments. However, it should be noted that although active learning and informal environments may facilitate meaningful learning, results in each classroom will vary and are dependent upon the quality of instruction.

Methods

The graduate course, History of Life, is taught entirely online through a distance learning program at a research university in the southern United States (US). This course is part of the Teachers in Geosciences Program (TIG), in which practicing teachers earn a non-thesis master's degree through courses taught entirely in an online environment. The exception to the online course work is a 2-week field application capstone course. The majority of students enrolled in the History of Life course are practicing Earth Science educators enrolled from primarily across the US (n = 16 in 2007 and n = 12 in 2008). Therefore, we use the terms "practicing teachers" and "students" synonymously in our descriptions and discussions. These practicing teachers are either in their second year of the TIG program, or have completed their master's degree and are enrolled in a "Master's Plus 30" online program. The majority of these teachers are employed within US public schools, teaching science at the middle (US Grades 6-8) and high school levels (US Grades 9-12).

The History of Life course is taught each spring semester. The course is divided into 12 weekly units; three units combine to form one quarter. During each quarter, our students are assigned laboratory exercises with accompanying application classroom activities. Application activities typically involve in-depth research of a particular topic, and the subsequent development of lesson plans, with materials and assessments, that the practicing teachers can directly incorporate into their own classrooms. Therefore, application activities involve the implementation, at an appropriate level for the teachers' individual classrooms, of the content researched in the History of Life course. Quarterly assignment topics are complementary to the course content presented through video lectures, reading assignments, and online discussion board conversations. Course content includes the fossil record, systematics, evolution, functional morphology, paleoecology, biostratigraphy, biogeography, and paleobotany. The greatest emphasis is on invertebrate phyla, although protists, plants, and vertebrates are discussed.

In 2006, we designed an active-learning assignment in which each practicing teacher autonomously planned and investigated fossil outcrops in his/her geographic area. Our students were responsible for photographing, identifying, and discussing fossil specimens that they procured in their local field areas (Clary & Wandersee, 2008). Anonymous feedback revealed that practicing teachers consolidated the information presented in the History of Life course through this active, informal assignment.

Some teachers encountered difficulties with local fossil procurement, primarily because of weather constraints and physical access to sites. Therefore, in 2007, we required our students (n = 16) to investigate fossils and paleoenvironments through established informal education sites, including national parks, university museums, and nature centers. Fossil specimens at these locations could be displayed in cases, in situ at the site, or housed in an organization’s collections. All specimens, however, had to be accessible by the general public. Our practicing teachers selected a minimum of two informal education sites within traveling range, and photographed a minimum of 18 specimens, with each being a different species. A total of five phyla and/or divisions were required to ensure adequate depth and breadth of the paleontology content covered in the course. Informal sites were unique among students, and each site could be utilized by only one practicing teacher during the semester. Specific guidelines were provided for fossil photography, including the incorporation of a colored pencil and a unique university logo for scale. Objects used for photographic scales were changed each semester. This ensured that students visited the site during the assignment, and did not retrieve photographs from earlier excursions or former students.

After practicing teachers located their specimens, they had to describe the distinguishing features and explain the reasons behind the classification. For example, trilobites had to be identified through discussion of the cephalon, thorax, and pygidium characteristics. Geographic ranges and geologic ages were required. Often, this information was posted with displayed fossils; otherwise, our practicing teachers retrieved this from interpretation of the local stratigraphy and/or textbooks. They then integrated the specimens into a discussion of three depositional paleoenvironments represented by their fossil selections. This mandated a reconstruction of the conditions and locations under which the fossilized organisms once lived.

Our directions for Part II of the informal learning assignment required the practicing teachers to develop a mini-unit for their own middle or secondary science classrooms that used the fossils they had photographed and the paleoenvironments they had identified. A description of each practicing teacher’s current classroom (grade level, number of students) was mandatory, along with the identification of any of their students with special needs (and subsequent modifications of the activity and/or assessment, if necessary). This ensured that all learners in each teacher’s individual classroom were addressed. Learning objectives, state curriculum benchmarks or grade level expectations, and the US National Standards that the fossil activity addressed were to be included. Our teacher-developed activities needed to incorporate a minimum of two learning styles, and address higher-order thinking skills, such as application, analysis, synthesis, and evaluation. Finally, our practicing teachers had to develop an assessment tool for their activity, appropriate for their learners and their individual classroom.

A rubric for scoring the completed projects was posted on our course website. Our detailed rubric included a checklist for each fossil specimen (proper photograph, identification, distinguishing features, collection site, geologic age, range) and the mini-unit (classroom description, objective, national standards, state benchmarks, higher order activities, specification of learning styles, appropriate assessment tool). Students submitted their completed projects electronically through the course website, and the instructor's individual scores and comments were posted to students via their quiz link for the application activity. At the end of each semester, an anonymous electronic survey was posted for our practicing teachers. Open-ended questions sought the practicing teachers' opinions on the History of Life informal educational activity.

The success of this assignment in 2007 prompted us to repeat it in 2008 (n = 12). Students were again assigned a paleoenvironmental analysis using the fossils photographed from a minimum of two informal sites. The logo used for scale in the fossil photographs was changed to a modified logo of the university mascot. Our students were again assigned mini-unit development for their individual classrooms.

Analysis and Results

Informal sites and fossil choices. All students in the 2008 class researched informal sites, including museums, state parks, public lands, and fossil parks, within the continental US (Figure 1). Enrollment in the TIG program, and subsequently in the History of Life course, is influenced by the US states that have implemented an Earth Science course option or requirement at the high school level. In 2007, our practicing teachers had greater geographic dispersion, and the informal sites of the 2007 class also included Mexico and the Caribbean. Between the 2 years, some informal sites were selected more frequently, and were included in informal investigations in both 2007 and 2008 (Table 1). Although some students encountered initial difficulties in selecting informal sites, all students managed to locate the required minimum number for the assignment. Several well known US museums and informal sites were researched by students, including the Smithsonian, the Harvard Museum of Natural History, and the Page Museum at La Brea. However, students residing in areas without famous informal sites managed to incorporate smaller, local museums and nature parks (Figure 2).

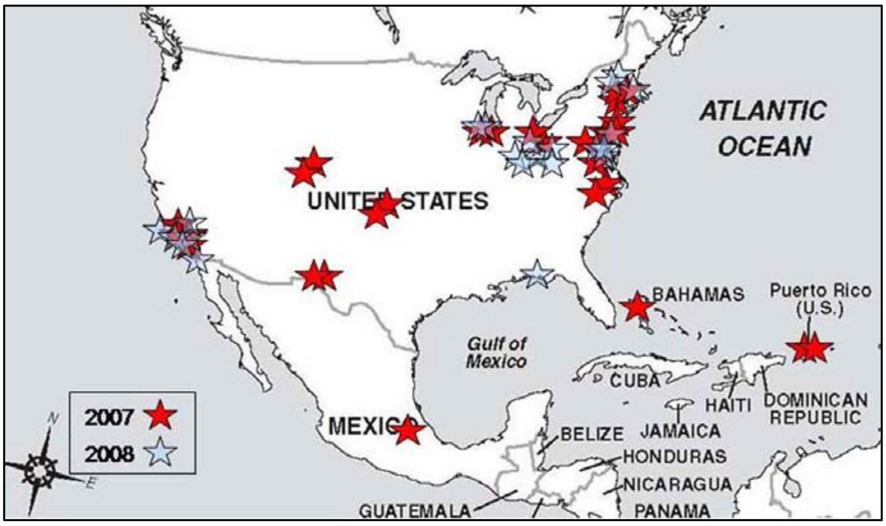

Figure 1. The geographic distribution of informal learning sites chosen by students in 2007 and 2008. Many students from the eastern US and southern California are enrolled in the online master's program, leading to greater density of informal sites from these areas.

Table 1
The Informal Site Selections of Practicing Teachers

Location	Site
United States	
California	**La Brea--Page Museum** *Laguna Hills Community Center* **Raymond Alf Museum of Paleontology** **Los Angeles Natural History Museum** **San Bernardino County Museum** *San Diego Natural History Museum* Pollack Library Cal State Fullerton
Colorado	Dinosaur Resource Center Florissant Fossil Beds National Monument Dinosaur Depot
Connecticut	Dinosaur State Park
Florida	*Okaloosa Walton College*
Illinois	**Field Museum** *Burpee Museum* Chicago Children's Museum Dave's Rock Shop
Maryland	*Maryland Geological Survey* *Calvert Marine Museum*
Massachusetts	**Harvard Museum of Natural History** Amhurst College Museum of Natural History
New Jersey	Morris Museum Rutgers Geology Museum Natural History Museum of Princeton
North Carolina	Aurora Fossil Museum
Ohio	*Caesar Creek State Park* *Cincinnati Museum Center* *Cleveland Natural History Museum* **McKinley Presidential Library and Museum** Ohio State University
Oklahoma	Northwestern Oklahoma State University Sam Noble Museum of Natural History
Pennsylvania	**State Museum of Pennsylvania** *Carnegie Museum of Natural History* Academy of Natural Sciences
Texas	University of Texas El Paso Centennial Museum El Paso Museum of Archaeology
Vermont	*Perkins Geology Museum* *Middlebury College*
Virginia	Virginia Living Museum
Washington, D.C.	**Smithsonian Museum of Natural History**
West Virginia	*West Virginia Geological Survey State Museum*

Table 1 (continued)

Outside United States	
Bahamas	Dan's Cave Hole-in-the-Wall National Museum of the Bahamas
Mexico	National Mexican Museum of Natural History
Puerto Rico	University of Puerto Rico Las Cabezas de San Juan

[a]2007 only. [b]*2008 only (italics)*. [c]**Both 2007 and 2008 (bold)**.

Figure 2. Famous museums, such as the Field Museum in Chicago, Illinois (left) were included in students' research. However, students who were not in geographic proximity to the larger, more famous sites were still able to find local museums and informal education environments that featured fossils. The Aurora Fossil Museum (right) is located in North Carolina.

In general, project submissions for both semesters were excellent, and students demonstrated knowledge of the paleontology content, as well as effective application and synthesis of the material. In both years, the photographed specimens were representative of all the invertebrate phyla, and several vertebrate orders and plant divisions. Figure 3 shows a representation of included fossils. Ichnofossils, especially track ways, were popular fossil choices for both classes. Not only were fossils diverse in their morphology, but both 2007 and 2008 practicing teachers photographed specimens from the Precambrian through the Pleistocene Epoch, encompassing most of the Earth's geologic history.

Paleoenvironment analysis and inclusion of local environments. Because the practicing teachers chose informal learning sites within driving distance, the majority of these informal sites included local area fossils, and our practicing teachers chose to incorporate them. In the paleoenvironmental analyses, the local environment was always included by our practicing teachers. The environments of deposition included both terrestrial and marine environments. Because our practicing teachers reside in several very different geographic areas, the fossils, paleoenvironments, and geologic times represented were quite diverse. Tar seeps, coal swamps, glacial moraines, lacustrine, turbid marine, deep marine, and reef environments--from a wide range of geologic time--were discussed as paleoenvironments by our practicing teachers.


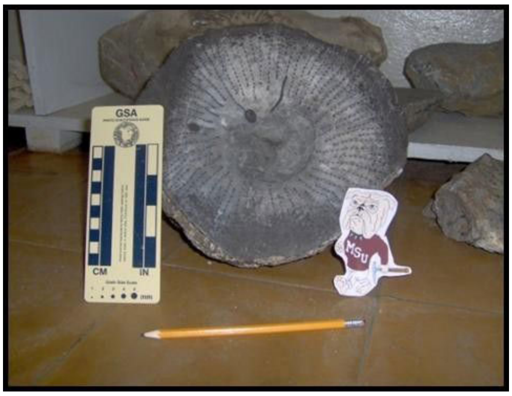

Figure 3. Fossils represented all major phyla, and ranged from Precambrian to Pleistocene in age. Many fossils selected by practicing teachers for inclusion were often collected within their local geographic areas. These included a Pleistocene bat skull, Phylum Chordata (left), courtesy of Nancy Albury and (right) a Puerto Rican rudist (an extinct bivalve, Phylum Mollusca, that contributed heavily to Cretaceous reefs of the US Gulf Coast) , courtesy of Janette Stewart.

Practicing teachers' mini-units and activity development. The practicing teachers developed a variety of informal and student-centered activities for their own classrooms. Both 2007 and 2008 practicing teachers integrated informal site visits in their mini-units, with the exception of one teacher who noted that her district no longer allowed teachers to take classes outside the school on "field trips." Informal field excursions had a common characteristic: Teachers focused upon a select group of fossils, a geologic time period, and/or an environment of deposition. Scavenger hunts at local museums were a popular activity utilized by the teachers. An example of a practicing teacher's activity that focused on fossils from the Academy of Sciences in Philadelphia, Pennsylvania is presented in Figure 4.

Practicing teachers also developed a variety of classroom assignments that included dichotomous key use, hands-on ichnofossil identification, fossilization experimentation, and Podcast development. Innovative assignments were in abundance, with geological time line "era menus," paleoenvironment dioramas and murals, and "travel brochures." A "Paleo Paparazzi" focused upon "stratigraphical fossil celebrities." Several teachers developed activities with Carboniferous swamps. Students would investigate the original ecosystem, fossilization processes, coal formation, and the economics of coal in the modern age.

In order to evaluate their students' knowledge gain, our practicing teachers developed a wide spectrum of assessment tools. Traditional test items (examinations), cooperative mural development, group multimedia presentations, and portfolios were all represented.

Teacher perceptions of informal sites in Earth Science classrooms. Most of the practicing teachers participated in the electronic end-of-semester survey (*n* = 13 in 2007 and *n* = 11 in 2008). The purpose of this survey was to improve our online classroom through feedback gathered from our practicing teachers. Questions were anonymous and open-ended, and included the practicing teachers' identification of the assets in our online classroom, the perceived problems that should be immediately addressed, and opinions on application activities and other assessment methods. We also probed our practicing teachers for opinions on each of the quarterly application activities. Questions specific to the informal site application included 1) teachers perceived value and impact of informal science education to formal geoscience learning through fossils and site visits, 2) teachers' perceived interest of their own students for informal activities and informal investigations, and 3) problems or potential difficulties in informal site investigation and paleoenvironmental interpretation.

"CALLING ALL CARS! CALLING ALL CARS"

In this assignment you will write a 15-second "all points bulletin" (APB) alerting police and the general public to be on the lookout for an escaped organism from the Academy of the Natural Sciences. In your APB you must address the following:

1) Name of specimen and any known aliases
2) General description
3) When it was last seen
4) Where it was last seen (region, not the Academy!)
5) Where it likes to "hang out"
6) If it should be considered dangerous and to what/whom
7) Species it could easily be confused with

An example is below (this organism is not from the Academy).

Calling all cars, calling all cars! Be on the look out for Apatosaurus ajax, also known as Brontosaurus ajax! This sauropod dinosaur is 15 feet tall at the hips and about 70 feet long! It weighs about 40 tons. It has a long neck, small head, long tail and walks on four legs. It was last seen 140 million years ago in the American West It is probably headed toward a forested riverbank where it likes to graze on the tops of trees. Even though it is not a meat eater, it should be approached with caution. It could easily crush an entire building with its foot or tail. Luckily it has a very small brain and should be spotted easily. It could be confused with Brachiosaurus. Stay on the look-out. Over and out!

Figure 4. Many practicing teachers utilized the informal learning sites and local fossils in their classroom units. A characterizing trait of the incorporation of informal sites was that the activities were directed and focused upon specific organisms, geologic time periods, or environments. This activity, courtesy of Amy Carpinelli, was developed for the Academy of Natural Sciences in Philadelphia, Pennsylvania.

We used Neuendorf's (2002) content analysis guidelines to code the anonymous responses from both semesters, and three stable themes emerged. The practicing teachers consistently noted that 1) the informal sites and local fossils affirmed the importance of the local environment and put it into a larger context with regards to science content, 2) directed student activities within informal education sites can maximize learning, and 3) informal sites integrate information and provide an interdisciplinary "big picture" for students.

Final examination scores attested to teachers' understanding of paleontology and paleoecology content presented in the course. Our practicing teachers also were overwhelmingly positive about the informal learning assignment. The local environment--investigated through local fossils and within local informal sites--appeared to be a key ingredient for the assignment's success. Several practicing teachers remarked that the informal project facilitated investigation, not only of local fossils and the former paleoenvironment, but also strengthened connections with the local community. Comments included: "I got to see a lot of my area" and "[the project] allowed me to focus on significant local fossils . . . . I began looking and asking questions that led to a larger question of a particular environment not explored." One practicing 2008 teacher, who was chronicling her informal investigation and paleoenvironmental reconstruction within her classroom, remarked: "When I have told my students about it, they are most interested in the fact that I have recreated OUR area, not some unknown area far away." Another teacher noted that students "hardly make the effort to use their community's resources and this could be the obligation they need to do just that."

Our practicing teachers acknowledged that directed activities in informal environments were an important component to maximize learning. A 2008 teacher noted that a directed activity "transforms a casual stroll through a museum to a focused visit. I also think by creating some guided specificity the overload factor is reduced." The 2007 teachers also thought the focus upon a paleoenvironment, a geologic period, and specific fossils were important, and that their own students "would enjoy it and it would be a good learning experience." Another commented that "students would enjoy learning about fossils and environment through the use of a museum."

Our practicing Earth Science teachers consistently noted that the informal education assignment synthesized the content of the course; not only for them personally, but that the informal sites had great potential to do this within their own classrooms. Fossil investigation at local sites addressed the geology (Earth's history), as well as biology and chemistry in the paleoenvironment reconstructions. Additionally, local human history could be incorporated with local informal sites. The 2007 teacher comments included "it brought everything in the course together and it made more sense. It was like a light bulb coming on" and "I learned the most [from the informal environments]." The 2008 students concurred that the informal site investigations and paleoenvironmental reconstructions require "more synthesis and application of information," and that the assignment "helped me review and synthesize what I had encountered throughout the course!" The investigation was interdisciplinary, and "forced us to incorporate many different disciplines into a focused unit."

Conclusions and Implications

When asked in the end-of-year survey to identify their favorite part of the History of Life course, 70% of 2007 practicing teachers and 90% of 2008 teachers ranked the informal learning site investigation and mini-unit development as their favorite activity. All teachers were able to develop activities and mini-units that could be utilized within their own classrooms. The informal education application exercises allowed our practicing teachers to synthesize History of Life course material and consolidate learning through an investigation of local sites. Our practicing teachers were consistent in acknowledging that informal education provided an effective means to learn outside of the classroom.

We were pleasantly surprised to see the level of affirmation for local informal site investigation within the teachers' individual classrooms. Although the second part of our assignment involved the development of a mini-unit for teachers' individual classrooms, teachers not only completed the activity, but in turn established directed local field excursions for their own students. The local environment appears to be a key factor: Exploring past local environments through local fossils, within local informal sites, allows a teacher to build upon the "common ground" and experiences of students. Investigation with local informal sites provides a familiar base to learners, and it can be a platform upon which to scaffold additional knowledge. Furthermore, local research provides context to the material presented in the classroom. This was applicable not only in our online classroom, but in practicing teachers' individual classrooms as well.

Our practicing teachers, with greater collective informal educational experience than we have, noted how important directed study was within an informal site during a site visit or investigation. Without guided activities, students might have difficulty focusing on the exhibits within a large museum or nature park. Assorted, although interesting, facts might be overwhelming, and not completely conducive to learning if not presented within a context that the students can understand, and which can be integrated into an existing knowledge base.

Informal field excursions are important to augment and enhance traditional classroom learning. Our practicing teachers noted that site visits "make the topic come to life. Field trips are wonderful." Informal sites can extend learning. As one teacher noted, "informal sites are great places to stimulate and reinforce what is done in the classroom." Another teacher stated that informal sites reinforce the concept that learning is not limited to classrooms: "Students would absolutely love this. Students can begin to explore geologic information outside of the classroom and see that people other than teachers can be purveyors of knowledge."

Our teachers also identified that their students have great enthusiasm for field excursions: "I can tell you the level of excitement my students have for their field trip is awesome! When I announce the dates, usually that day 6 students have already deposited their money for the bus!" Another remarked: "Anytime that we are able to actually get out and 'do' science they get excited."

Capitalizing on students' enthusiasm, focusing student research in an informal learning site, and integrating several disciplines within site investigation sounds like a recipe for science success to us. We propose that our exploratory research has potential implications beyond the use of local fossils and informal sites within Earth Science classrooms. Informal educational sites can be used to extend and enhance learning potential outside formal classrooms if lessons are designed to 1) integrate the local environment, 2) provide interdisciplinary study opportunities, and 3) focus upon a limited topic of organisms, environment, or other specific theme.

Perhaps one of our practicing teachers best summed up the potential impact of informal learning as follows: "I have seen some of my students from years ago and the one thing they remember is the field trip that I take them on. That is what I like to think is a life-long learning experience!" We invite practicing teachers to capitalize upon the possibilities for informal science learning within their local communities.

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Science Poetry in Two Voices: Poetry and the Nature of Science

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Abstract

Poetry can be used during science instruction to foster interest, excitement, and wonder among elementary-level students. Children can read poetry, or have poetry read to them, as a way of learning about their world. They can also create poems to share their own science learning with others. We introduce two formats of the Poetry in Two Voices form of poetry (namely, Five Senses in Two Voices and Scientific Approach in Two Voices) that we use to help students in Grades 1-5 develop science observation skills and adopt a scientific approach during their science investigations. Integrating poetry with science is a historically accurate pedagogical approach in that poetry was at one time the language of philosophy and science. The purpose of this action research report is to share our experiences and the results of utilizing these two poetry formats with elementary-level children.

Poetry in Two Voices

Poetry in Two Voices (see Figure 1) is a form of poetry created by Paul Fleischman (see *Paul Fleischman's Official Website*, n.d.). In his book, *Joyful Noise: Poems for Two Voices*, Fleischman (1988) used poetry to describe the natural world around us. Poetry in Two Voices requires two readers. One person reads lines on the left side of the page while the second person reads lines located on the right. The lines of text are sometimes contrasting, but always complementary. Readers begin at the top of the page and take turns reading their lines. Text printed on the same horizontal line is read in unison by both readers.

Poetry does not have to rhyme. According to the Miriam-Webster dictionary, poetry (n.d.) is "writing that formulates a concentrated imaginative awareness of experience in language chosen and arranged to create a specific emotional response through meaning, sound, and rhythm." Meant to be read aloud, poetry in two voices establishes its rhythm by the poet or poets' thoughtful word selection and interplay between voices by conscientiously alternating readers. Consistent with Fleischman's (1988) poetical works, students can be encouraged to also include rhyme, alliteration, simile, metaphor, and personification in their poems.

The Nature of Science

Poetry in Two Voices can mimic the nature of science (American Association for the Advancement of Science [AAAS], 1993; Council of Ministers of Education, Canada [CMEC], 1997; Curriculum Council of Western Australia [CCWA], 1998; Lederman, 1992; Millar & Osborne, 1998) in four important ways. First, an important aspect of science is to ask questions about natural phenomena experienced and to seek answers through observation. Throughout the academic year, we explicitly and repeatedly refer to this with students as the *nature of science*. To help children better understand the nature of science, we use a modification of Poetry in Two Voices that is based on questions and answers, and the templates of Figures 2 and 3 provide examples of the two printed formats that we use with students. As student scientists, elementary-level students ask questions and seek answers through science investigations. Using this approach, students create poetry that requires two readers and mimics the nature of science. With the exception of a few introductory lines and a line designated for a closing exclamation, one reader asks questions and the other reader provides answers based on what they did and learned during their observations and/or science investigation. Consistent with the nature of science, poems are written so that the readers sometimes read the same words in unison when consensus has been achieved, while the words of each reader may be different when no data-driven consensus has been reached.

Reader 1	Reader 2
I am reader one.	
	I am reader two.
Our students love poetry.	
	Yes, it's true.
Our students love science.	
	Truer still!
Poetry in two voices . . .	
	is read by two people.
I read the left.	
	I read the right.
Sometimes we read . . .	
in unison.	in unison.
Two voices can share . . .	
	what we observe.
Two voices can share . . .	
	our science investigations.
I ask the questions.	
	My answers are based on observations and investigations.
Just like . . .	
science!	science!

Figure 1. Science Poem in Two Voices (by W. Frazier and K. Murray). Readers alternately read their lines, with lines on the same horizontal being read in unison.

____
(Title)

(Reader 1)	(Reader 2)
__________________________*!*	
	__________________________*!*
__________________________*?*	__________________________*?*
What do we see with our eyes?	
	__________________________
What do we hear with our ears?	
	__________________________
What do we feel with our skin?	
	__________________________
What do we taste with our tongue?	
	No! No! No!
What do we smell with our nose?	
	________________________
__________________________*!*	__________________________*!*

Examples of prompts for the opening lines:

(What is it?)

(An observation)*!*

(Another observation)*!*

(A question related to the use of the senses)*?* (The same question repeated)*?*

Instructions for the last line of the poem can be decided by the teacher and class, but students should be instructed to use identical words on the left and right sides to convey to their audience that a consensus has been reached based on observations (either in the student's mind if sole author, within the small writing group, or across the class when creating a class-wide poem). If students have been observing a mystery item, the last line could be the children's inference about the identity of the mystery item, a really cool descriptive word that describes the object, the purpose of the object, or the name of the object restated.

Figure 2. Poetry template: Five Senses in Two Voices.

____

(Title)

(Reader 1) (Reader 2)

(Reader 1)	(Reader 2)
____________________________*!*	
	____________________________*!*
____________________________*?*	____________________________*?*
What is our question?	
	____________________________
What else do we need to know?	
	____________________________
What is our prediction/hypothesis[a]*?*	
	____________________________
How do we test our prediction/hypothesis[a]*?*	
	____________________________
What are our results?	
	____________________________
Eureka!	*Eureka!*

[a]Older students can be asked to distinguish between these two terms by drawing a line through the one that does not apply.

Examples of prompts for the opening lines (which are decided by teacher and class):

(A title that conveys the topic)

(First word of topic)*!*	
	(Second word of topic)*!*
(A descriptive word related to topic)*?*	(The same word repeated)*?*

\---

The last line of the poem follows with "*Eureka!*" (on both left and right sides, thus being exclaimed in unison) to consistently convey to children that experimental findings are important whether or not their findings support the stated prediction/hypothesis.

Figure 3. Poetry template: Scientific Approach in Two Voices.

Second, scientists are creative in the ways they solve problems (AAAS, 1993; Lederman, 1992). Elementary students are frequently taught the "steps of the scientific method" as the principal strategy for learning about their world, but what is lost is the creative nature of the science discipline. There are a multitude of ways in which scientists go about "doing science." By having students create poems about their science observations and investigations, the underlying message is that creativity and science go hand-in-hand. Creativity is evidenced by forming new ideas, insights, restructurings, and inventions of scientific value and real-world application (Vernon, 1989). To be creative, the novice scientists in the elementary classroom, as well as experienced scientists in the laboratory, require an understanding of science concepts that is fluid, flexible, and complex (Guilford, 1950). Additionally, novice scientists and experienced scientists alike need positive attitudes toward creativity and risk-taking (Bereiter & Scardamalia, 2006; Lubart, 1994; Sternberg & Lubart, 1991; Sternberg & Williams, 1996), and they need to operate in design mode (Bereiter & Scardamalia, 2006) where their focus is on the application of what they learn. In this case, we ask children to focus on applying what they learn to their creation of poems in order to communicate their observational and/or experimental findings. Cumulatively, we help students develop the three components of creativity through utilization of poetry in two voices: Ability to think creatively, positive thoughts about being creative, and purpose for action (Sternberg, 2006). While we present two templates for supporting children's work, please understand that the templates can and should be modified by teacher and students to fit the particular investigative strategies the children are using to learn more about their world.

Third, integrating poetry into science conveys to students the importance of sharing their scientific learning with others. This aligns with the nature of science as a body of growing knowledge that is meant to be shared (AAAS, 1993; Lederman, 1992). To quote one elementary student: "They listened to my poem because my poem was funny and what I found out was important." When queried further about what the student meant by "funny," she explained that their group had a particular question in mind that they wanted to answer, but they were surprised by how nothing in their investigation went as planned. In fact, her group ditched their idea of performing a controlled experiment and decided that their question would be better answered with a survey. Grounded in the sharing of answers to questions raised about the world around us, the two poetry formats introduced in this paper can be used by teachers and children alike as a form of communicating scientific literacy that simultaneously conveys the creative aspects of the nature of science to the elementary classroom audience.

Fourth, poetry in musical verse was at one time the language of philosophy and science. In ancient times originating before the birth of formal education in the 5th century B.C., children of the ruling class of ancient Greeks studied "*gymnastyke* for the body and *mousike* for the mind or spirit. . . . *Mousike* covered all of the arts presided over by the muses, especially music and poetry" (Lindberg, 2007, p. 68). Ancient Greek mythology, as an example of mousike, illustrates the blending of poetry and explanation of natural events (Lindberg, 2007). Later, the historical divide between science and poetry can be attributed to Aristotle (384-322 B.C.), who in his *Poetics* (Aristotle, 4th century B.C./1812) began to differentiate between work driven by creative, imaginative liberties versus work driven by his definition of scientific thought. However, poetry continued to be an avenue for the communication of scientific thought. Examples, both before and after Aristotle, include *On Nature* (Empedocles, 5th century B.C./1898), *Peri Physeos* (Parmenides of Elea, 475 B.C./1996), *Phaenomena* (Aratus of Soli, 3rd century B.C./1921), *De Rerum Natura* (Lucretius, 1st century B.C./2003), and *Astronomica* (Manilius, 1st century A.D./1977). Despite this ancient tradition of poetry having been used to communicate scientific ideas, the significant divide between science and artistic endeavors set in motion by Aristotle continues today. To bridge the "two cultures" gap noted by Snow (1959, p. ix), we return to a unity of science and poetry in the classroom.

Poetry Template for Observations

Student scientists collect data using their sense of sight, touch, smell, hearing, and sometimes taste. The poetry template Five Senses in Two Voices (Figure 2) guides students' observations. When asked to make observations, we find that children frequently forget to use all their senses. They might focus more on touch or sight, while ignoring opportunities to listen and smell. Additionally, they might want to taste something that the teacher would rather they did not. Using this template also encourages students to apply new vocabulary they learn through written prompts in the form of questions. As a result, this template helps students make more complete and descriptive observations safely. One teacher explained as follows:

> The entire poetry format serves as an effective series of prompts to support children's observations and written recordings incorporating new vocabulary. While the template is simplistic, this is exactly what children need to help them understand that systematic observation and communication of findings is what scientists do.

Appendix A contains a series of poems written while elementary students observed both the materials used to make "Goop," and then the Goop itself, during a unit on the physical states of matter. Goop is a colloidal suspension that has characteristics of both solids and liquids. Goop can be made by combining 1 part water with 2 parts cornstarch in a shallow container, such as a disposable pie pan. Cornstarch is an edible, fine powder commonly found in the baking section of the grocery store and is frequently used to thicken gravy. Students can observe water, cornstarch, and the results of combining water with cornstarch to form Goop with their senses. Please note that in these poems we gave the students permission to taste the substances since classroom conditions allowed for appropriate hygiene and safety during their observations. If the particular substance children are observing in your classroom should not be tasted, then the line "No! No! No!" can be inserted in advance to remind students not to taste the substance, as shown in Figure 2.

It is important to monitor students' thoughts and feelings both during and after this poetry writing experience. In one classroom, students were surprised by the variety of observations in the poems that they shared and wanted to swap their samples of Goop with other students and then write a new poem. Allowed by the teacher to do so, students discovered that the use of different proportions of cornstarch and water, which were the result of simple human error, produced varying consistencies of Goop that behaved differently. One student hypothesized: "I think everybody's Goop was different because we weren't careful and splashed water on the sidewalk when pouring it in." Additionally, providing one line only for a student response may constrain some children's thinking, so lines, as well as the template itself, can be expanded as needed. As one student remarked: "I like adding lines because it's hard to make it all fit. I talk a lot and my poems have more words than everybody's."

Emphasis on a variety of modes for observation is important, since approximately 30% of elementary students may be primarily visual, 25% primarily auditory, and 15% primarily tactile-kinesthetic learners, with an additional 30% of learners exhibiting a mixed, multi-mode preference (Khalsa & Miyake, 2005). We consider it pedagogically sound to inclusively address children's different learning styles, due to different prioritizations of their sensory modalities. Engagement, variation in modality, differences in sensory primacy, and variation in learning style may best be approached through sufficient motivation, clarity, and connection to prior knowledge and to their intuition and sensory awareness of the world around them.

Poetry Template for Using a Scientific Approach

The second poetry format, Scientific Approach in Two Voices, guides children's use of a scientific approach as one of many strategies for learning about their world (Fleener & Frazier, 2004; Frazier & Fleener, 2004). Figure 3 provides the template for this poetry format. During whole-class investigations, teacher and students complete the first few lines of the poem together before performing the investigation. The poem is then completed and read aloud once the class has collected and made sense of their data. When the time comes to read the poem aloud, the teacher can read lines on the left while the whole class reads lines on the right. Alternatively, the class can be split in half with one half reading lines on the left side of the page and the other half reading lines on the right. According to our students, reading poems that have been created by the whole class aloud is an experience that they really enjoy for a variety of reasons stemming from students' perceived novelty of this poetry format. The novelty is further enhanced through variation in how the poem is read aloud, the higher value that students place on reading what they have created together versus an assigned reading from an unknown author, the students' perceived ownership and pride in the poetry they have worked to create, the low-risk experience of reading text in unison with their peers, and the positive feedback and encouragement they receive from their teacher to be creative while drafting their class poem. From our experience, even children who are not interested in the investigation are very interested in finishing the poem. Some children do the investigation just so they can read the poem aloud with the rest of their classmates.

Appendix B contains an example of a poem created by a class of students while examining the effect of the concentration of soap in water on the germination of seeds during a unit on plants. In this experiment, radish seeds were placed in Ziploc bags with a paper towel, and each bag was watered with a different concentration of soap solution (0%, 10%, 20%, and 30%). We demonstrated how to make these soap solutions for our students. Appendix C contains instructions for how to make soap solutions in various concentrations and for watering. Students recorded their observations of plant growth for the next 3 weeks and created several different versions of their poems based on what they observed over time.

Appendix D contains a poem that a small group of students created during an animal senses unit. They were trying to develop a habitat for their mealworms that the mealworms could not escape from, and wanted to know what mealworms can climb. After considering various hypotheses that comprised the texture, color, smell, and flexibility of the surface, they decided to investigate the first; surface texture. They compared the distances mealworms traveled on a slightly slanted tabletop lined with surfaces they organized from smoothest to roughest: Plastic wrap, notebook paper, and sandpaper. Even when groups of children perform the same experiment across the class, the group poems vary. The variety of poems increases engagement in the communication process as individual students listen to the differences in each others' poems versus the traditional alternative of listening to different groups share the same thing over and over. As one teacher remarked:

> I used to dread when it was time for students to share their experiment findings. I felt so bad because each of them had really invested a lot of time in their experiments, but let's face it, sharing the same thing repeatedly across groups gets boring quickly. However, sharing poems is very different. The students really respect and support each other. I would say this has been the most significant change in my classroom that I have ever experienced.

Using Poetry to Assess Science Vocabulary and Observation Skills

We use these two poetry formats to assess our students' development and understanding of scientific vocabulary and skills. In the early-elementary grades, students learn how to use words (e.g., colors and shapes) and word pairs (e.g., rough-smooth, curved-straight, and fast-slow) to describe their surroundings. When early-elementary students create poems as a class using the Five Senses in Two Voices format, we determine alternative conceptions in students' science vocabulary development through examination of their word choice with respect to scientific literacy and model appropriate usage. For example, while describing the texture of a surface, a child may refer to the surface as "rough" versus "soft" rather than "rough" versus "smooth."

In the worksheet examples of Appendix A, students originally wanted to use the words "weird, yummy, good." As a result, the teacher encouraged the children to be more specific and precise with their word choice. Students ended up choosing more descriptive words, such as cold, clear, wet, white, and smooth. Here, we find that brainstorming descriptive words in advance and recording them on a word/reference wall really helps and provides additional opportunities to enrich vocabulary. Developing and reading poetry aloud, including opportunities for rehearsal and practice with a peer, also provides a low-risk opportunity for English Language Learners to practice their developing language skills (Hadaway, Vardell, & Young, 2001). To best assist students, the teacher should monitor which student reads words on the left and which student reads words on the right to ensure that each child is appropriately challenged and supported in their language development. Readers of the left side have an opportunity to read teacher-structured questions that model appropriate grammatical usage of teacher-selected vocabulary, while readers on the right side have an opportunity to read less predictable phrases that incorporate new vocabulary but generally model less appropriate grammatical usage.

Across the elementary grades, the Five Senses in Two Voices format helps children organize their thoughts and ideas into words. In the examples of Appendix A, the first- and second-grade students used their series of poems to explore, organize, record, and share their observations. From this series of poems, we observe students' natural tendency to question, predict, and try to confirm ideas based on observation. As another example, upper-elementary children in Grades 4-6 can observe baking powder mixed with vinegar to learn about the characteristics of a chemical change. The students can record, in a chart as a class, their observations before, during, and after mixing the baking soda and vinegar. Students can refer to this observation chart as they develop a series of three Five Senses in Two Voices poems to describe a chemical reaction in terms of what they observed throughout the process.

Using Poetry to Assess Adoption of a Scientific Approach

In the upper-elementary grades, the Scientific Approach in Two Voices format can be used to assess children's adoption of a scientific approach as one of many strategies for learning more about their world. During their investigations, our students complete a data table of their recorded observations along with their poem. We compare a student's data table and poem so we can determine how accurately the student is able to interpret findings and use findings to make a decision about a prediction. To ease our work as teachers, we instruct students to state their poem's prediction in two parts as an "if . . . then . . . " statement. The first part of the prediction describes a purposeful change the student will make to the independent variable. The second part of the prediction describes what happens to the dependent variable when the independent variable is changed. By reading the prediction, we can determine if the student has correctly identified the independent and dependent variables. In the case of the poem in Appendix B, the group correctly defined their independent variable as the amount of soap added to the water used to irrigate radish seedlings. However, they inaccurately defined their dependent variable as the length of the seed rather than the length of the root. The poem helped us identify this misconception so we could address it with the group. When queried further, it was discovered that this group thought that the seed would turn into a radish rather than the radish developing as a taproot. A student explained: "After we read our poem, our teacher had my group look at this website that helped me see what a radish is when it's still in the dirt."

The Scientific Approach in Two Voices format also helps us determine if students' beliefs, thoughts, and practices are consistent with the nature of science (AAAS, 1993; CCWA, 1998; CMEC, 1997; Lederman, 1992; Millar & Osborne, 1998). Often children want to say their hypothesis is "wrong" after a single test, without reflecting on the validity of their results. Data can fail to support a hypothesis and even contradict a hypothesis, but substantial testing and assurance of valid testing conditions are required to actually falsify a hypothesis. To further complicate matters for students (and teachers), hypotheses can never be proven true due to the tentative nature of science as a continuously evolving body of knowledge based on observations forming laws and hypotheses forming theories, both of which are subject to change, though laws less so (AAAS, 1993). To aid students in thinking critically about their investigations and results, they are therefore encouraged to decide if their data supports or does not support their hypothesis, helped to shift away from thinking that hypotheses can be proven true, and also helped to recognize that substantial data and validity assurances are required to falsify a hypothesis. Appendix E contains an example of a poem where the students' thinking is consistent with the nature of science as they make a decision about their hypothesis when their data failed to support it. In this experiment, students made ice cream and a group of students hypothesized that their ice cream ingredients would freeze faster if they used milk with a higher concentration of fat in it. (See Appendix F for instructions on how to make ice cream using plastic bags with elementary-level students.) Different student groups elected to use skim milk, 2% reduced fat milk, and whole milk. The class performing the experiment found that groups using skim milk had ice cream quicker than those groups that used reduced fat or whole milk. Rather than stating that their hypothesis was wrong because of this one single experiment, the students recognized that they still have much work to do in fully testing their hypothesis that fat concentration influences freezing rate, which they referred to as "do over" on the last line (i.e., the students opted to continue testing their original hypothesis after clarifying the procedures of their controlled experiment to better ensure a valid result).

Additionally, we want our students to develop a positive attitude towards investigations that do not turn out as they expect. We find that children are frequently disappointed when their data does not support their prediction. We encourage our students to write poems using the Scientific Approach in Two Voices format for all of their investigations, even the ones that have unexpected results. As a result, children take ownership of their findings and realize that even when an investigation does not support their prediction, their findings are still worthy of being shared with others.

For the poem shown in Appendix E, the group of students opted to change the last line from "Eureka!" to "Do over," and we continued to work with this group to help them understand that their finding was a "eureka moment" even though their prediction was not supported by their data. One student explained: "We didn't have a right prediction, but that's ok. I guess we could create a new poem, but we don't have to. That's just science: 'You get what you get and you don't throw a fit.' Our teacher was telling us about how scientists get surprised, too." We used this opportunity to discuss with students different formats for predictive statements, especially when the independent or dependent variable is not a directional, continuous variable. The students also discussed whether or not they should use a controlled experiment or if there is a better strategy to use to answer a question. A different student explained her reason for selecting a controlled experiment:

> When creating our "questions poem," at first I really wanted to do a survey to see which ice cream people like best and that's ok to do, but we did a controlled experiment instead, so we could mix the different ingredients together more, and see and feel what happens, and write a poem with answers that were facts. Mixing stuff together and seeing what happens is more fun and it's facts while surveys are opinions and people can change their mind.

As further testament to how utilizing this particular form of poetry helps students and teachers better understand the nature of science, one teacher explained:

> Having a poem based on questions and answers is important. Using either template helps me remember that science is about having a question, or series of questions, and finding answers. This means that the students and I are both asking questions, but the students have the responsibility for collecting information through their observations and investigations to discover answers. They shouldn't only get the information from me or a textbook or the web. Science is about getting the children moving, exploring, and learning. Most of all, it is about getting them to think, plan, observe, draw conclusions, and ask more questions. I find that the templates help me remember this, just as much as they help my students remember.

Additionally, one second-grader concisely explained: "The poem is just like science. It's questions and answers. Sometimes I ask the questions, sometimes I don't, but I find the answer with my four senses . . . sometimes five."

The use of poetry in intellectual endeavors pre-dates Aristotle's empiricism in the 4th century B.C. and the modern scientific approach developed by Ibn Al-Haytham in the early 11th century A.D. (Steffens, 2007), and yet is coherent with the inquiry skills we desire to instill in students. Later echoes of the pre-Aristotelian tradition that illustrate an integration of poetry and inquiry span from Antipater's poem from the 1st century B.C. (that includes description of a water-driven mill) (Landels, 2000) through Chaucer's "The Canon's Yeoman's Tale" (a satirical work about the practice of alchemy written sometime in the latter half of the 14th century) (Purvis, 1870), Edgar Allen Poe's "Sonnet: To Science" (Poe, Ingram, & Willis, 1902) written during the 1800s, to modern-day Paul Fleischman's (1988) collection of nature poetry in *Joyful Noise: Poems for Two Voices* upon which the strategies being shared in this article are based.

A Surprise to Us

We are amazed by how frequently the children mentally call upon the templates during their investigations. The templates for writing poetry in Figures 2 and 3 can simultaneously be used as a powerful and long-lasting metacognitive prompt to support children's design and performance during science investigations throughout the year. Metacognitive prompts provide hints to children to guide their thought processes during classroom activities (Zimmerman, 1989). By thinking in a manner similar to scientists, children systematically learn more about the world around them. As one student explained: "I really like having an old senses poem [Figure 2] in my notebook. I use it to remember to use all of my senses because sometimes you forget one you know. The other poem [Figure 3] helps me remember what to do when doing experiments because I sometimes get nervous and forget; it helps me you know."

Modern Scientists and Poetry

Beyond ancient times, there has been a long, continuing tradition of major scientists who write poetry to communicate their scientific ideas, and this long-standing tradition provides a rationale for integrating poetry with science during instruction today as a vehicle for children to share their science learning. Providing examples to children of science-related poetry, which spans the centuries from the Ancient Greeks to current times, makes explicit to students how language arts and science are related through a long history of integration. Additionally, incorporating these authentic examples into the classroom can foster students' motivation and interest. For example, children may be intrigued to discover that Oliver Wendell Holmes worked as a physician in the 1800s and wrote a number of poems including "Extracts From a Medical Poem" (Holmes, 1850), which could be read by the teacher to the class or in a literacy circle. As another example, teachers might share excerpts from the following books of poetry of Nobel Prize-winner in chemistry, Roald Hoffmann (1987, 1990, 2002): *The Metamict State*, *Gaps and Verges*, and *Soliton*. More accessible to elementary-age children, modern day paleontologist Richard Fortey wrote *The Dinosaurs' Alphabet* (Fortey, 1990), which is a collection of poems about 26 dinosaurs--one for each letter of the alphabet.

Try It!

When "doing science," these two poetry templates provide a structured, yet creative, outlet for children by structuring their observations and investigations. Students use their language arts skills to share their observations and results in a way that is meaningful for themselves and others. We find that the real joy comes when the children read their poems aloud. Try both templates with your students to enhance their learning and interest in science through poetry. As students become more familiar with the two formats, we recommend that you modify the number of lines, and the templates themselves, to support students' expanding ideas about their world around them. As one student explained: "I didn't think our teacher would let us change the poem['s format], but she did. We could add parts in to fit our experiment. Scientists are creative [, so] our poem is unique."

Use of Poetry in Two Voices during science instruction does not have to be limited to just one or two classrooms. Beyond use in a single classroom, Poetry in Two Voices via the two templates shared in this paper can be used to increase the intellectual vigor of an entire school's science program. One teacher explained:

> I really like how the observation poem format is perfect for the early grades and the scientific approach poem is fit for the upper grades. This means that teachers across all elementary grade levels can incorporate this strategy and each grade can build on the next. Having each grade present their poems at a PTA [Parent Teacher Association] meeting is a perfect way to show off how our students are growing as scientists each year.

Conclusion

Utilizing poetry during science instruction is a pedagogically sound strategy based on poetry's historical relevance to science understanding from ancient to modern times. In this paper, we share a particular form of poetry selected because of its relevance to the nature of science as an inquisitive, creative, and social process. Action research findings from children's poems and reflections illustrate the appropriateness of this strategy for structuring children's knowledge gains about the world around them through observations and investigation. Consistent with the nature of science as a creative endeavor, the templates provide guidelines to support children's creation of poems as a vehicle for sharing their findings, but the templates themselves are meant to be fluid, flexible, and adjusted to the variety of children's learning needs resulting from differences among children, as well as the diverse nature of the world around them.

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Appendix A: A Series of Five Senses in Two Voices Poems Involving 2 Students (The text in italics was provided by the teacher)

Water

(by Lauren, Grade 1)

It's a liquid!	
	It's moving!
Is it wet?	Is it wet?
What do we see with our eyes?	
	Takes the shape of a bowl
What do we hear with our ears?	
	Drip!
What do we feel with our skin?	
	Cold
What do we taste with our tongue?	
	Like ice
What do we smell with our nose?	
	Nothing
I can drink it!	I can drink it!

Water

(by Allison, Grade 2)

It is a liquid!	
	It wiggles!
Is it hot?	Is it hot?
What do we see with our eyes?	
	Clear
What do we hear with our ears?	
	Splash!
What do we feel with our skin?	
	Cold
What do we taste with our tongue?	
	Wet
What do we smell with our nose?	
	Nothing
It's water!	It's water!

Cornstarch

(by Lauren, Grade 1)

It’s snowing**!**	
	It’s snowing**!**
Can we eat it**?**	Can we eat it?
What do we see with our eyes?	
	White
What do we hear with our ears?	
	Shh! Shh!
What do we feel with our skin?	
	Smooth
What do we taste with our tongue?	
	Old flour
What do we smell with our nose?	
	Dough
We can eat it!	We can eat it!

Powder

(by Allison, Grade 2)

I see smoke!	
	I see smoke!
Is it baby powder?	Is it sugar?[a]
What do we see with our eyes?	
	Dust
What do we hear with our ears?	
	Nothing
What do we feel with our skin?	
	Soft
What do we taste with our tongue?	
	Flour
What do we smell with our nose?	
	Dough
It's cornstarch!	It's cornstarch!

[a]Normally, the text on this line would be identical on the left and right sides of the page. However, this student wanted this line of her poem to consist of two different questions because she was equally concerned with both. Consequently, and as encouraged by the teacher, she altered the template to better fit her needs.

Goop

(by Allison and Lauren, Grade 1-2)

It’s so gooey!	
	It feels weird!
Is it a solid?	Is it a liquid?[a]
What do we see with our eyes?	
	Looks like a lagoon
What do we hear with our ears?	
	Drip! Drop! Drip! Drop!
What do we feel with our skin?	
	Feels like a wet rock
What do we taste with our tongue?	
	Tastes like yucky dough
What do we smell with our nose?	
	Smells good
It’s a solid!	It’s a liquid![a]

[a]Normally, the text on both these lines would be identical on the left and right sides of the page. However, the 2 students wanted each other’s ideas represented in the poem. Consequently, and as encouraged by the teacher, they altered the template to better fit their needs. To ensure that their audience could comprehend their poem while it was read aloud, the teacher visually displayed the poem on the overhead projector so that the audience could follow along.

Appendix B: A Scientific Approach in Two Voices Poem, Created by an Entire Class, With Dependent Variable Incorrectly Identified (The text in italics was provided by the teacher)

Soapy Seeds

(by entire fourth-grade class)

Radish!	
	Seeds!
Grow?	*Grow?*
What is our question?	
	Does soap affect the growth of a radish?
What is our prediction/hypothesis?	
	If more soap is added to the water, then the length of the seed[a] will be shorter.
What else do we need to know?	
	How many drops do we add?
How do we test our prediction/hypothesis?	
	Add different amounts of soap to the water cups and measure the length of the seed[a].
What are our results?	
	Our data matches what we predicted!
Eureka!	*Eureka!*

[a]Students later edited their poem for scientific accuracy by adjusting their dependent variable to length of the root.

Appendix C: Soap Solution Concentrations and Watering Instructions

Soap solution concentration (%)	Amount of liquid soap (mL)	Amount of water (mL)
0	0	100
10	10	90
20	20	80
30	30	70

Watering Instructions: We recommend that your class initially water each of their baggies with 15 mL of solution and continue to water each of their baggies with 10 mL of solution every third day. This class-wide schedule can be adjusted based on your classroom's environmental conditions.

Appendix D: A Scientific Approach in Two Voices Poem Created by a Small Group (The text in italics was provided by the teacher)

Mealworms: A Sticky Situation

(by Sarah, Jeannie, Jason, and Molli, Grade 5-6)

Meal!	
	Worms!
Worms?	*Worms?*
What is our question?	
	What can they climb?
What is our prediction/hypothesis?	
	If the surface is too slick, less little worms can do the trick. If the surface is rough, it's not too tough.
What else do we need to know?	
	Can they climb at all?
How do we test our prediction/hypothesis?	
	Place 4 on and let them climb!
What are our results?	
	Let's find out. On slick surfaces they do not succeed, but on rough surfaces they move with speed.
Eureka!	*Eureka!*

Appendix E: A Scientific Approach in Two Voices Poem Where Hypothesis is not Supported (The text in italics was provided by the teacher)

Ice Cream, You Scream

(by Adam, Sarah, Ann, Kate, and June, Grade 5-6)

Ice!	
	Scream!
AAAAAAA!	AAAAAAA!
What is our question?	
	Why does some ice cream freeze fast and some freeze slow?
What is our prediction/hypothesis?	
	If there is more fat in the milk, then it [the ice cream] will freeze faster.
What else do we need to know?	
	Will fat freeze?
How do we test our prediction/hypothesis?	
	Skim milk and whole, we're on a roll. Shake it like a Polaroid picture.
What are our results?	
	Prediction not supported. Let's do it again.
Do over!	Do over!

Appendix F: Suggested Recipe and Instructions for Making Ice Cream

Ingredients

120 mL (½ cup) milk, 10 mL (1 teaspoon) vanilla, and 50 g (¼ cup) sugar, granulated cane.

Instructions

1. Place above ingredients in a sealable, sandwich-sized bag and zip closed.
2. For extra protection, place bag inside another sandwich-sized bag and zip closed.
3. Put sandwich-sized bags inside a sealable 3.78-L (1-gallon) bag.
4. Add 110 g (6 tablespoons) of rock salt to 3.78-L bag.
5. Three-quarter fill the 3.78-L bag with ice and zip closed.
6. For extra protection, place bag inside another sealable 3.78-L bag and zip closed.
7. Shake and roll for about 15 minutes, wearing winter gloves to protect hands.

Notes

1. Check for food allergies in advance. Provide students who are allergic to any ingredients with a substitute. For example, fruit juice makes a delicious treat when frozen (do not add milk, vanilla, or sugar to juice).
2. Instruct students to wear goggles throughout the procedure.
3. Require appropriate hygiene practices by both teachers and students:
   a. Carefully wash hands with soap and water in advance.
   b. Do not share utensils or ice cream samples.
   c. Maintain personal work space.
   d. Clean classroom surfaces before and after class.

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