Volume 9, Issue 1 - 2010

THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Dolphins Second Brightest

Dolphins have been declared the second most intelligent creatures after humans, with scientists suggesting they are so bright that they should be treated as “non-human persons.” The communication of dolphins is similar to that of humans and their brains have many key features associated with high intelligence.

Source: Leake, J. (2010). Dolphins second brightest on planet. *University World News*, Issue 0107.

Teaching Ideas

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

Science Story: Silly Putty

During World War II, many products were scarce, or unavailable, in the United States. Nylon was needed for parachutes, making stockings a rationed luxury. To conserve copper, coins were made from steel. With rubber in short supply, the search was on for a substitute.

Rubber, both natural and artificial, is a carbon-chain polymer. With silicon being chemically similar to carbon, it attracted much attention as a possible substitute. However, while carbon-carbon bonds are strong and chemically inert, silicon-silicon bonds are much weaker and more reactive. Silicon-oxygen bonds, though, are very strong, making silicones--polymers made of chains with alternating silicon and oxygen atoms--quite stable.

In the spirit of trial-and-error, engineer James Wright added boric acid to silicone oil. While the boron atoms caused the silicone polymer chains to crosslink, these cross-links did not provide for a rubber substitute because such bonds can break and reform rather readily. So, when the material was stretched slowly, it stretched without snapping back to its original shape. Samples were shared with scientists and engineers around the world, all of whom enjoyed playing with it but none of whom could suggest a practical use for it. Then, a toy store owner stumbled across a sample and called it Silly Putty, a toy that has been providing much fun since 1950.

Source: Rohrig, B. (2007). Serendipitous chemistry. *ChemMatters*, *25*(3), 4-6.

Critical Incident: Overcoming a Lack of Materials

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(A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher.)

As a science educator, I've noticed two things: 1. Many science teachers face great odds when they get into the classroom to teach because of insufficient, or sometimes a lack of, teaching materials and 2. many science teachers are poor at describing things. In the course Practical Techniques in Integrated Science taken by Integrated Science/Education students, I included an idea coined Show & Tell whereby each student was required to choose a topic from one of the three Integrated Science texts and improvise one of the teaching materials needed by either making it or selecting an alternative from their everyday environment. Each student stood up front in class and told what she or he had, how it was made or obtained, and what it is used for and demonstrated how to use it to teach a lesson. The hope was to encourage pre-service science teachers to learn to describe accurately and gain an insight into knowing that the teacher can do something about helping to provide teaching materials instead of complaining about a lack of them. The course assessment comprised 60% exam and 40% continuous assessment, and the Show & Tell activity was 20% of the 40% continuous assessment. The rule was that no 2 students were to choose the same topic, thus ensuring that nearly all topics in the set of texts were covered.

The student teachers were encouraged to transfer this idea to their future science teaching context. Their students could be given notes, addressed to their parents, inviting some materials required in class to be brought from home. The request to a particular family might reflect the occupation of the parent. In this way, both students and parents would be involved in finding solutions to the problem of a lack of teaching materials. After all, parents can be farmers, doctors, nurses, engineers, business people, and so on, so they do possess many useful materials that, if asked for properly, can be provided for use at the school.

Initially, this course had only 25 students, but over the past 6 years the number has increased to 58. This has seen Show & Tell become a major part of class time. However, it has always been enjoyable and a time to teach what it means to improvise and how accurate this must be to be of any scientific significance (e.g., if you need transparent glassware, it is not good enough to bring an opaque bottle as the improvised material. Or, if it is calibrated, the improvised material must also be accurately calibrated.

Two years ago, I met one of the graduates from this course who excitedly shared with me how she has put Show & Tell to good use in an urban school, with her class enjoying it very much indeed. Prompted by that report, I started asking any graduates of that course that I met about this activity, and the reports have been similar, with confirmation that Show & Tell has equipped them to overcome the problem of a lack of materials that otherwise would have caused despair.

My aim was to simply try to look ahead into situations in the school system and alert student teachers about them. My observation is that it's gone beyond that; teachers are telling me that their science students are gaining confidence to communicate well in front of a class and talk to, and involve, their parents in relation to school science needs and some parents even ask their children to bring more information home about science. A colleague has drawn my attention to the observation that, on average, Integrated Science student teachers have scored As and Bs in their practice teaching course, performing better than Biology/Education, Chemistry/Education, and Physics/Education students in the same year. So, I'm wondering if the confidence to describe better and the ability to improvise materials that they gained in my course may be impacting positively here. Obviously, Show & Tell is making science teaching easier, allowing more activities/inquiry to be done and making teachers feel less handicapped in facing their junior science classes.

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 .

The Name's Bond

It's an oft repeated story –
A tale as old as time
Much loved by barbs and poets
Enshrined in song and rhyme –

Of two divergent forces
Unlike in every way
Each opposite the other
As the night is unto day.

Yet when the two converge,
Oh! How the sparks doth fly
As an instant bond's created
That neither can deny.

There's an instant recognition
An immediate reaction
As they move ever closer
Drawn by mutual attraction.

What is this magnetism?
This strange compelling urge
To fasten close together,
To meld, adhere and merge?

Love is not the answer
(Though a good guess, I'll admit)
Nor is it an adhesive
Though they are known to stick.

No – it's something elemental
Chemical no less –
As atoms come together
And combine with great finesse.

To what formal designation
Does this strange event respond?
I'm here to tell you friends
It's name is Bond: Ionic Bond!

Jack Burnham, 15 years
Australia

Research in Brief

Research findings from key articles in reviewed publications

Inquiry, Direct Instruction, and Understanding

Does an inquiry approach to learning facilitate better science conceptual understanding than a direct instructional approach? Cobern et al. (2010) addressed this question in a controlled, experimental study involving 180 eighth-grade students who studied the two topics of dynamics and light, climate, and seasons during a special, 2-week summer program.

Both approaches were experientially-based and engaged students actively (i.e., they were both hands-on and minds-on), and were expertly designed and constructed. The complete units, including learning objectives, lesson materials, and assessments, are available from Cobern (n.d.). The guided inquiry used for the inquiry approach was based on the three-phase, Karplus learning cycle: exploration, concept formation, and application. Here, students “invent” the scientific concepts and “discover” the relationships, guided or scaffolded by the teacher. In the direct instruction approach, the teacher presented and explained the concepts and relationships directly to students as finished products to be learned and understood. The approach taken can also be described as a direct-action one, because it included hands-on practical work, albeit confirmatory with prescribed steps.

The two approaches led to comparable conceptual understanding, measured by the ability to apply concepts in conceptual problems, in comparable times. Many feel that an inquiry approach to instruction is more in keeping with the widely-accepted constructivist theory of learning, but it should be noted that this is a theory of learning rather than instruction, and students need to construct their own understanding regardless of the resources used or the instructional approach taken. Direct instruction may be easier from a teaching point of view, particularly for less-experienced teachers and those not confident with the content. It may also be less demanding for weaker students, at least initially. However, by modeling aspects of the nature of real scientific inquiry, inquiry-based instruction may better promote an understanding of the nature of science. Also, in the affective domain, inquiry may spark students’ interest in science more naturally or improve longer-term retention, and there is scope for further research into all these considerations.

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Instructional Activities and Group Work in the US Inclusive High School Co-Taught Science Class

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US Public Law 108-446 about the education of students with learning disabilities (LD students) stipulates that the primary instructional placement of LD students should be the regular classroom. Placing LD students in a regular classroom presents the challenge of teaching a group of students with a wide range of accommodations. According to Norman, Caseau, and Stefanich (1998), most teachers do not feel that they are adequately prepared to teach LD students, feel lack of support to implement inclusion effectively, and believe that instructing LD students should be the responsibility of special education teachers. In addition, secondary science teachers tend not to make adjustments to meet the needs of LD students. To facilitate the delivery of high-quality instruction in inclusive classes, one instructional model is to also introduce a special-education teacher (SET) into the class. Compared to solo-teaching, the co-teaching model is expected to make available a wider range of instructional alternatives to meet the needs of all students. This wider range of instructional strategies would place a strong emphasis on laboratory-based work, de-emphasize language-based learning, and promote organization in small group work as recommended for the science instruction of LD students. In the study reported in Moin, Magiera, and Zigmond (2009), we attempted to find out if the assumed greater potential of having 2 co-teachers in the inclusive class translated into the delivery of an enhanced educational experience for all students than is possible in solo-taught lessons and that reflect the recommended science teaching strategies.

The extent to which those recommended strategies were implemented in the inclusive class was compared to the extent of such strategies for regular high school classes as reported in the literature. The National Science Teachers Association (NSTA) (2007) recommends the implementation of lab work in science classes at least once a week and such work should be authentic to the work of scientists rather than verification or “cook-book” lab work. In turn, Quinn (1996) recommends that science teachers minimize the use of lectures and make greater use of naturalistic observation and laboratory experimentation. Finally, the America’s Lab Report (Singer, Hilton, & Schweingruber, 2005) found that most high school science classes experience lab work at an average rate of about once a week. The recommended extent of group work, however, remains elusive (Quinn, 1996).

Methods. Six schools (three urban, two suburban, and one rural) with 10 pairs of co-teachers in science participated in the study. The schools ranged in size from 350 to 1,553 students and class sizes varied from 18 to 36, with the number of LD students in them varying from 3 to 15. All teachers had co-taught for at least 1 year. We interviewed the 10 pairs of science-special education co-teachers and observed them teach a total of 53 science co-taught lessons. The observation notes were free narrative paragraphs entered in the observer’s journal every 5 minutes of class time. The entries described: (a) what the teachers were doing, (b) what the students were doing, (c) the organization of the class, (d) the materials used, and (e) additional comments. From our observation notes, we coded the lessons by activities and organization according to the dominant criterion; the task that students experienced for one half or more of the lesson time (Dieker, 2001). Our lesson activity classification scheme was: (1) direct instruction (language skills), (2) reading and writing tasks (language skills), (3) lab investigations, (4) diagramming, (5) games, and (6) problem-solving. For group work, we also noted the duration of group work in each lesson according to what the majority of students experienced. We classified whole lessons as: (i) whole class work, (ii) small group work, or (iii) individual work.

The interview questions asked teachers how they became involved in co-teaching, their number of years co-teaching experience, the length of the partnership with the co-teacher in the study, the number of years co-teaching the same subject (asked of the SET), the training for co-teaching, the weekly co-planning time, and their general perceptions of the co-teaching model.

Classroom observations. Language-based instruction occurred in 72% of the lessons: 42% direct instruction and 30% reading and writing. During lectures, students took notes, just listened, or followed presentation along with an organizer. Students asked or answered questions but the dominant voice was that of the science teacher. Teachers tended to use overhead projectors and transparencies. Most of the reading and writing activities involved short-answer formats for which students could find the information in the textbook. Thus, co-taught classes seemed to only slightly improve in reducing language-based instruction over pull-out programs in which science instruction is delivered by special-education teachers and is 90% textbook-based (Cawley, Hayden, Cade, & Baker-Kroczynski, 2002).

Lab-based instruction occurred in 13% of the lessons and was mostly highly guided by the teacher, with step-by-step instructions. Lab safety measures were never discussed. In all lab lessons, students worked in small groups collaboratively. The five diagramming lessons (9%) mostly included copying from the book, drawing, labeling, and listing. The three instructional games (7% of the lessons) seemed to have been designed to help students memorize or illustrate content. Problem-solving activities were not observed during any lesson.

In 24 out of the 53 lessons observed, students worked as a whole class, mostly completing worksheets, extracting information from the teacher’s lecture, playing a game, and labeling a diagram. In 11 lessons, students worked on completing worksheets individually. Collaborative group work occurred in 18 of the 53 lessons (34% of the lessons) and lasted an average of 27 minutes (60% of class time). Hence, collaborative work occurred for about one fifth of total instructional time observed (i.e., 34% of 60%). This amount was similar to reported amounts in regular solo-teaching practices (Quinn, 1996). Student pairs were the most common group size and mostly occurred between classmates who sat close to each other. Teachers assigned students to groups or just asked students to form previously-agreed groups.

Teacher interviews. Dieker (2001), Cawley et al. (2002), and Morocco & Aguilar (2002) reported findings from successful co-teacher pairs. They reported abundant hands-on instruction and group work. In those cases, the co-teaching model was adopted school-wide or strongly encouraged by the school administration by scheduling co-planning time for teacher pairs, either weekly or during a summer professional development seminar for both pair members together. Also, in those cases, the special education teacher had some science knowledge gained from formal training or through permanence with the same science teacher over the years. Permanence of the pairs together may also contribute to the development of synchronous, and at times unconscious, mechanisms of teaching together.

In our sample, administrative support was not so apparent. Teachers were concerned with instability of the co-teacher pairs, many teachers also expressed feelings of not having been given a voice in the implementation of the model, and all teachers reported lack of scheduled co-planning time. No curricular adaptations for LD students were apparent in these co-taught classes.

In our study, teachers who expressed more satisfaction with the model tended to conduct more lab-work instruction. These pairs had significant prior co-teaching experience (albeit not with the same partner), developed a positive inter-relationship, and tried to find some time to talk about the class.

Discussion and recommendations. Our study asserts that, even when the special education teacher was included in the classroom, the kind of instruction that students received was not markedly different from instruction in the solo-taught class and only a slight improvement over pull-out programs. For the most part, in the observed classes, the special education teacher was drifting around the room, redirecting students, doing clerical work, or just observing the lesson. Cook and Friend (1995) describe this role as a beginning stage in co-teaching. After this first year, the special education teacher might bring in a wider variety of instructional methods to thus assume an instructional role in implementing accommodations for special-needs students that could better address the learning styles of LD and non-LD students alike, and teaching learning processes to help students understand science concepts. In the lab, a second teacher can add safety by providing additional guidance for students and reducing the student-teacher ratio. In addition, the special education teacher could also facilitate group work by providing guidance to students regarding how to efficiently organize group work.

The second teacher in the class could also conduct a separate and simultaneous lesson that delivers science content related to ethical dilemmas in real-life science cases, could give directions for completing tasks, could assist students with searches, could guide students' practice and problem-solving, and could help them conduct experiments. Groups of students could rotate between the lessons delivered by each of the two teachers.

In the classes we observed, students were almost never expected to find out knowledge on their own. Rather, they were explicitly instructed to search and copy the information from the textbook and in most lab work simply followed a "cookbook recipe." This kind of poor-quality lab work, however, seems to be the general norm in US science classes (Singer et al., 2005).

The effort of modifying science classroom life, however, cannot be solely placed on the already overworked teachers' shoulders. The NSTA addresses the critical role of school administrators in enhancing science instruction and mentions the need for professional development in co-teaching. Our sample teachers also recommended (a) that the professional development should be conducted for the co-teacher pairs together, (b) the inclusion of co-planning time in teachers' schedules, and (c) having a voice in the implementation of the co-teaching model, which mainly referred to their choices of partners and maintaining the pairs that work well together.

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Readers' Forum

The Scientific Method: Critical yet Misunderstood

It looks as though there is indeed a single, scientific method, not in the sense of a method that scientists necessarily use exclusively in their day-to-day work, but in the sense of a method, or general plan, that is at the core of most science and that guides, or should guide, the work of scientists and the way science progresses. In this piece I will overview the scientific method, provide evidence that many science educators and curriculum materials appear to lack a knowledge and/or understanding of it, and consider how a more explicit use of the scientific method would improve both science education research and learning in science classrooms.

The scientific method. To ask whether or not there is a scientific method is confusing, because the answer can be yes or no, depending on how the term *method* is defined. Harwood (2004) interviewed over 50 research scientists, representing a broad range of fields, to find that, as they went about their work, they engaged mainly in as many of the following 10 activities, and in whatever order (including using a particular activity more than once), as was needed: Asking questions, observing, defining the problem, forming the question, investigating the known, articulating the expectation, carrying out the study, examining the results, reflecting on the findings, and communicating with others. This multiplicity of approaches taken by scientists is echoed by Bell, Blair, Crawford, and Lederman (2003): "There is no single prescribed set of procedures that all scientists follow when conducting investigations. Rather, scientists use a variety of methods and approaches when conducting research" (p. 497).

However, upon analyzing the work of scientists more closely, it appears that their efforts do, at the same time and in the main, either follow a more general plan or contribute to this plan, even if the scientists themselves might not realize it. In this more general sense, then, there does appear to be a scientific method, a method that is also referred to as the hypothetico-deductive (HD) approach (Lawson, 2000, 2005, 2010a, 2010b). The steps in the HD approach are as follows:

1. A **puzzling observation** is made. An observation is particularly puzzling if it contradicts the predictions of current understanding.

2. A **causal question** about the observation is asked (i.e., why does this happen?). A causal question may even be the result of a descriptive study (i.e., a study void of hypothesis generation). Rather than following from a puzzling observation, a causal question may also be derived from a theory.

3. A **hypothesis** (i.e., a proposed explanation) is advanced to answer the causal question. The making of such an inference is called abduction, because one's store of declarative knowledge, which includes analogies with already-explained observations, is being used (i.e., being abducted, stolen, or transferred). Alternatively, rather than originating from a puzzling observation, a hypothesis in the HD process may stem from one or more existing theories. A second type of inference being used here, and one that happens

subconsciously, is that of retroduction, whereby one checks that the proposed explanation explains what is already known (i.e., the puzzling observation).

4. A **prediction** is generated from this hypothesis, based on the assumption that the hypothesis is correct (this represents the inference of deduction), and a **test** is designed and conducted to check on the prediction.

5. The results of the test are compared with the prediction from the hypothesis and a **conclusion** is made as to whether the results of the test support or contradict the hypothesis. If the latter is the case, and the deduction and test appear to be sound, there is the need to return to Step 3 and propose a modified, or new, hypothesis. This drawing of a conclusion represents the inference of induction, but not induction in the sense of enumerative induction that some have claimed generates general conclusions from limited cases (i.e., reasoning from observed particulars to general statements, or "laws," or hypotheses), a reasoning process that probably doesn't exist (Lawson, 2005; Popper, 1965). At best, enumerative induction might suggest a descriptive claim that is in need of deductive testing (Lawson, 2010a).

It might be noted that support for a hypothesis from such a test does not prove the hypothesis correct, because a different hypothesis may make the same prediction. However, the HD process is cyclic in the sense that a hypothesis can be subjected to further and further testing in this same way, and the more a hypothesis, or explanation, stands up to continued testing the more confidence we gain in it.

The heart of the HD approach, then, is the generation and testing of hypotheses, a process that is also really quite intuitive and common sense, even though we may often use it implicitly without being conscious of the fact. It follows an "If...and…then…And/but…Therefore…" (or, for brevity, "If/then/therefore") pattern of reasoning; that is, in trying to answer a causal question, we reason along the lines of "if this hypothesis (i.e., explanation) is correct, and we do this planned test, then we should get this result (i.e., the prediction). And/but when we do the test we get these results (results that may be circumstantial, correlational, or experimental [Lawson, 2000]). Therefore, we can reach this conclusion about the hypothesis."

Misunderstanding and misuse. Curriculum materials, teachers, and science education researchers often confuse the term hypothesis (or hypothesized) with the term prediction (or predicted), inappropriately using the former to mean the latter, as exemplified by the following:

- A hypothesis is "a sentence describing what you think your experiment should demonstrate" (Hsu, 2005, p. 9).
- "A hypothesis is a statement about data expectations" (DeSantis, 2009, p. 20).
- A hypothesis is an "educated guess or prediction that can be tested about how a scientific investigation or experiment will turn out" (Center for Gifted Education, cited in Kim, Bland, & Chandler, 2009, pp. 41-42).
- "A hypothesis is a prediction of the effect that changes in the independent variable will have on the dependent variable" (Cothron, Giese, Rezba, 2006, p. 45).
- "A hypothesis is a prediction with an explanation" (Davis & Coskie, 2009, p. 58).
- "Hypothesis: There is a negative relationship between the incidence of cosmic rays and the thickness of the ozone layer" (Brouwer et al., 2009, p. 495).
- "We hypothesized that open inquiry students . . . will outperform students who experienced guided inquiry" (Sadeh & Zion, 2009, p. 1137).

- “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 (Ben-David & Zohar, 2009, p. 1662).

Indeed, even scientists get it wrong. For example, virtually all contemporary biological research incorrectly claims to test hypotheses, when in fact the research describes patterns rather than testing mechanisms underlying the patterns (McPherson, 2001). Science revolves around the answering of causal questions, and by misrepresenting the scientific (HD) method in such ways, we lose the logic of generating and testing hypotheses that is central to this scientific task. Interestingly, if not somewhat alarmingly, Anton Lawson (personal communication, March 3, 2010) reported an award-winning scientist recently saying that he was of the opinion that only about one third of scientists understood the scientific method.

Improving science education research. Carey and Smith (1993) posit that there are three levels of science epistemologies:

1. Descriptive (i.e., does not involve the generation of hypotheses).
2. Hypothesis generation and test (where knowledge comprises well-supported hypotheses).
3. Theory driven (i.e., theories are generated and their postulates tested, and theories are used to generate specific hypotheses that are tested).

Applying this to, and for the betterment of, the field of science education, science education researchers have a way to go in desirably progressing the field towards Level 3 (Lawson, 2010b). While much research in science education is at the descriptive level, it is common for researchers working at a higher level and who do understand the scientific method to generate and test hypotheses in a largely implicit way. The more conscious and explicit use of the scientific (HD) method by science education researchers would result in vastly improved research efforts and reports (Lawson, 2010a). Where applicable, research reports should be structured so as to make hypothesis (or hypotheses), prediction, test (outcome), and conclusion clear.

To provide an example of improving science education research, consider a descriptive study that uses interviews and surveys, for example, to determine students’ reasons for leaving a course of study. Often, such a study will summarize the reasons provided by subjects, present this summary in the form of conclusions, and end with a consideration of implications of the study, but Anton Lawson (personal communication, February 10, 2010) views this as being insufficient. Rather, he suggests the data collected from subjects in the form of reasons for leaving the course are better viewed as hypotheses for testing, in the HD way, using appropriate interventions. However, perhaps it is here that we run into an obstacle with science education research that may at least help explain why progress towards a Level 3 epistemology in the field has been somewhat slow; it can be very much more difficult to implement interventions with real people and/or in real classrooms, and especially if the testing requires a longitudinal component, than to simply manipulate variables on command in a science proper investigation.

Improving classroom learning. Since the scientific (HD) method is at the core of how science progresses, a more explicit and more often use of it in science classrooms would impact positively on the development of scientific literacy. Let’s consider how this might be accomplished.

Learning science in a school is a very different context from practicing science research proper, and one difference is that student investigations in school subjects are often conceived rather artificially. Considering the possibilities, I cannot imagine a worse way to introduce students to a scientific investigation than to have them turn the page of their textbook to find an investigation title--and a rather non-informative one at that, such as "Let's Make a Splash"--for a stand-alone activity (i.e., one that is not integrated into a learning sequence in the text) that is accompanied by a series of steps to be followed "blindly" by students, and was very surprised to find just this structure in a relatively recently-published textbook for lower high school students. The students are expected to follow the "cookbook" without even knowing what they are trying to cook, which hardly appears motivating.

Improving on this, one might provide students with a title, aim, and procedure, which now provides students with some sense of purpose. Better still, though, the activity can be made more authentic by providing a question instead of an aim. Now, here comes a crucial moment. Questions can be causal or non-causal, and a non-causal question, such as "is there a relationship between the incidence of cosmic rays on the surface of the Earth and the thickness of the ozone layer?" does not require a hypothesis to be generated, because there is nothing to explain. Non-causal questions like this one, "what types of structures does a flower have," and "does eating spicy food cause your body temperature to rise" have a place in science education, but answering them does not require the scientific (HD) approach.

To provide students with experience in using the scientific (HD) method, then, we need causal questions (either supplied to students or generated by the students themselves) for them to investigate, and these might arise naturally during a course or be "engineered" by the teacher. For example, following from everyday experience students might be asked: "Why does a basketball go flat when used outdoors in winter?" Indeed, a teacher can even engineer a situation so as to change a non-causal question into a causal one. For example, instead of asking "what local climate changes are associated with El Niño," students might investigate the question "why does our local climate change?" by testing, possibly among others, the hypothesis that local climate changes are caused by El Niño. Or, instead of asking "is there a relationship between the incidence of cosmic rays on the surface of the Earth and the thickness of the ozone layer?" students might be asked to investigate: "What causes the incidence of cosmic rays on the surface of the Earth to vary?" In this case, students would be invited to generate hypotheses (with even the teacher suggesting one or more if it helps to achieve the goals of the learning experience), one of which might be that a thicker ozone layer prevents more cosmic rays from reaching the Earth's surface. Students would devise a way to collect appropriate data and find that a decrease in the thickness of the ozone layer is indeed associated with an increase in the incidence of cosmic rays, concluding that their results support the hypothesis. The student lab reports, featuring hypothesis, prediction, test (outcome), and conclusion, would then reflect one complete hypothetico-deductive cycle or argument. Of course, the alternative hypothesis that an increase in cosmic ray incidence degrades the ozone layer and thereby allows more cosmic rays to reach the surface would also be supported by the evidence (illustrating how support for a hypothesis does not prove it correct), and the need for further research to distinguish between these two explanations could also appear in the reports.

Comparing the different ways in which a non-causal question and a causal question need to be investigated, it is now perhaps easy to understand why so many curriculum materials incorrectly label the prediction of, or guess about, the answer to a non-causal question a hypothesis. As David Rudel wrote: "There is a push today to get students to use the scientific method as much as possible. If a textbook says a hypothesis is merely a guess as to what will occur in a given experiment, the procedure can be applied [albeit incorrectly] to almost anything the student is asked to study" (personal communication, May 25, 2010). Perhaps only after establishing such confusion does a statement such as "the first thing scientists do to conduct an experiment is to form a hypothesis" (Kim, Bland, & Chandler, 2009) make sense! Finally, perhaps another mechanism for providing students with experience with the scientific method is to structure even lectures on it.

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? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Mentos Fountain: Making it Impressive

I have been unable to reproduce the spectacular fountain, some metres high, that I have seen reported as a result of dropping Mentos into a bottle of soft drink. I use a newly-opened 2-litre plastic bottle of soft drink (and have tried different varieties including Coca Cola), Mentos mints (which, by having a rougher surface than the fruit-flavoured and sugar-free types, apparently better promote nucleation), and a small tube to add a full roll of mints at practically the same instant in time. However, the result is only some fairly unimpressive frothing from the top of the bottle. What is the "secret" for obtaining a higher, and hence more impressive, fountain, please?

The following is primarily a composite of the suggestions submitted by Chris Astall, Mark Benvenuto, David Geelan, Heather Mace, Lee Marek, Richard NeSmith, Vladimir Petrusevski, and Colleen Reid, together with information gleaned from Coffey (2008):

1. **Use Diet Coke.** Diet Coke contains aspartame (a sweetener) and potassium benzoate (a preservative), both of which are more effective than sugar at reducing the surface tension of the liquid and hence the work required to form bubbles within the liquid, with the latter allowing carbon dioxide to escape more rapidly from the soft drink. Caffeine-free Diet Coke is just as effective.
2. **Use mint Mentos or Lifesavers.** Advising what to best add to the soft drink appears to be somewhat complicated, so some experimentation with the products available in your own country may be informative. For example, while mint Mentos is probably a sound first choice, it can come wrapped in either a silver or blue foil (these may perform differently) and mint Mentos from the United States (US) has been observed to work better than mint Mentos from New Zealand (NZ), although the experimenter cannot recall the type(s) of wrap on the Mentos used.

   There are many types of Mentos available. Contrary to what is often written, fruit Mentos in the US are as effective as, if not even better than, mint Mentos there, and this has also been confirmed by Eichler, Patrick, Harmon, and Coonce (2007). Although fruit Mentos may seem shinier to the naked eye and therefore have a surface that is less likely to provide growth sites for carbon dioxide bubbles, closer examination shows that these two types of Mentos have comparable roughness. What is more, the coating on all Mentos contains gum arabic and dissolves very quickly after the Mentos make contact with the soft drink. This releases the gum arabic that then acts as a surfactant to reduce the surface tension of the liquid and thereby assist bubble formation. In fact, fruit Mentos have a thicker coating than mint Mentos, with the additional surfactant being an advantage. The Mythbusters: Diet Coke and Mentos (n.d.) television program seems misleading, because the fruit Mentos used apparently had a waxy coating added by the Mythbusters team, but this is not clearly communicated in the video. However, with all that said, it has been observed that, in NZ, fruit Mentos are nowhere near as effective as mint Mentos.

Wint-O-Green Lifesavers are actually five times as rough as Mentos but lack a coating containing a surfactant. They also fall through the liquid somewhat slower than Mentos and this, as we will see in Point 6 below, detracts from the effect. The overall result is that Wint-O-Green Lifesavers perform as well as Mentos. However, this flavour of Lifesaver does not appear to be sold in Australia, although one contributor assures us that other kinds of Lifesavers also work just fine.

3. **Use warmer Diet Coke.** Because the solubility of a gas in a liquid decreases with increasing temperature, using room temperature Diet Coke is better than using a bottle that has just been taken from a refrigerator.
4. **Use a nozzle on the bottle opening.** Restricting the flow of liquid from the bottle builds up pressure in the bottle, thus producing a higher fountain. A tornado tube adapter makes a useful nozzle. Alternatively, a hole can be drilled into a spare bottle cap. However, such restrictions prevent Mentos falling through them, and a couple of mechanisms to overcome this situation are outlined in what follows. A 6-mm hole tends to produce the highest fountain. However, if you want to produce a fountain that is somewhat less high but that lasts very much longer, and which may also be considered impressive, a 3-mm hole is suggested. Using too small a hole results in an aerosol effect rather than a fountain.
5. **Use multiple Mentos.** While a single Mentos will work, multiple Mentos (7-11, say, of a roll that contains 14) will provide many more nucleation sites and hence a better effect. The simplest way to use multiple Mentos is to use a cylindrical tube of some kind to guide the fall of the Mentos into the opening of the drink bottle, but this does not capitalize on the advantages of also using a nozzle. In addition, the bubbling caused by the introduction of the first few Mentos tends to inhibit the remaining Mentos from falling through the liquid, if not preventing them from even getting into the bottle.

   To use multiple Mentos with a nozzle, the Mentos may be drilled, tied together using dental floss, say, and held, prior to release, so they hang below the nozzle but above the liquid surface, with the dental floss protruding through the nozzle. Some liquid may first need to be poured from the bottle to allow space for the Mentos to fit. Using Lifesavers avoids the need to drill the holes through Mentos.

   Chris Astall removes the rim inside a tornado tube connector with a keyhole saw and fits a 2-L plastic bottle preform, in which a 3-mm exit hole for the fountain has been drilled in the middle of the closed end. (All plastic soft drink bottles begin as small bottles called preforms, which are heated and blown into the larger bottles. Preforms may be obtained from scientific suppliers, second-hand junk stores, or plastic bottle manufacturers who often sell-on faulty preforms.) The preform is filled with 11 Mentos that are held in position by a small steel sphere, at the bottom of the Mentos column, that is in turn held stationary by a magnet positioned outside the apparatus. The tornado tube is then connected to a bottle filled with Diet Coke and the magnet removed, allowing the Mentos to fall into the liquid and a fountain to emerge from the 3-mm hole at the top of the assembly.

6. **Cause the Mentos to fall quickly.** Finally, the fountain effect can be further enhanced by causing the Mentos, or Lifesavers, to fall through the liquid quicker than usual. Then, the bubbles formed on the Mentos will detach from them and rise upwards, acting as growth sites that cause the carbon dioxide still dissolved in the liquid to move into the bubbles and thus promoting the liberation of even more carbon dioxide from the bottle. In his contribution that follows, Mark Benvenuto elaborates on the use of a lead sinker with Lifesavers to achieve this result, and Marek (2008) provides a video showing the result of

using a combination of Mentos and Lifesavers, metal nuts, and nozzle. Chris Astall's preform apparatus described above could be so modified by using a relatively large steel sphere and Mentos, all with a hole drilled in them, that are tied together with, for example, a length of thin wire, to form a column. Perhaps a lead sinker could even be added to the column.

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Peter Eastwell, Editor

The Mentos Fountain has been misnamed, perhaps by the Mentos manufacturers themselves, as that particular mint doesn't do a great deal to produce a very tall fountain. Here is a better method:

1. Use a 2-L bottle of Coke or Pepsi. I don't know how well other sodas work, as these two work very well (and thus I've never seen a need to change).
2. Take a cap that fits on a 2-L bottle and drill a one quarter inch hole in it. This does not have to be the cap from the bottle you will use. Just make sure it screws onto such a bottle. Any bigger hole and your fountain won't be too high. Any smaller hole, and you will produce an aerosol effect. That's fun, but not too directional, and not nearly as high as it could be.
3. Tie two Wint-O-Green Lifesavers to a piece of dental floss (easy to do as they have a hole in the center), leaving perhaps 12" of floss on one end and a few feet on the other end. Don't just thread the Lifesavers onto the floss. Tie them, so they will not slide along the floss.
4. Tie a lead fishing sinker to the end of the dental floss closest to the Lifesavers. A couple of washers or steel nuts from a hardware store work fine as well. What you are doing here is placing a weight very close to the Lifesavers.
5. Thread the end of the dental floss that has nothing tied to it through the hole in the bottle cap. Make sure you can easily pull the floss up to the point where the Lifesavers are touching the cap, with the sinker hanging a centimeter or so below it. Also, make sure the floss slides easily along the inside of the hole. It shouldn't stick or catch in any way.
6. Now, go outside with your 2-L bottle, still unopened, and your cap-Lifesaver-sinker-floss set-up.
7. Uncap the 2-L bottle, and place it where you want your fountain to be.
8. Double check the floss to make sure it slides freely along the inside of the hole in the cap. Insert the sinker and Lifesavers into the 2-L bottle while they are still threaded through the cap with the hole in it, making sure the Lifesavers do not touch the soda. Since you are holding the other end of the floss, this isn't too hard.
9. Screw the cap to the bottle. You now should have a capped 2-L bottle with a hole in the cap, one end of a piece of dental floss in your hand, and two lifesavers and a lead sinker dangling in the space immediately below the cap but above the soda pop. If the sinker gets wet, it's no problem.
10. Let go.

11. Run several meters; fast.

The weight of the lead sinker will pull the Lifesavers to the bottom of the bottle. In a few seconds, the nucleation will occur to a sufficient degree that the pop comes rushing out of the bottle. After the reaction is complete and the fountain settles, you may find that over one half the pop has rocketed out of the bottle. Also, you will probably find that about one half the Lifesaver mass has gone. If you have students who want to drink the remaining pop--flat, minty-tasting, rather gross pop--use steel washers or nuts as a weight in lieu of the lead sinker.

It's really all about the size of the hole in the cap of the bottle, and about the sinker pulling the Lifesavers down into the pop quickly. Just dropping Mentos into the bottle doesn't get them under the liquid fast enough, no matter how many you use.

I have run this demonstration for well over a decade. When I first tried it, at my home, my sons were watching. We had several unsuccessful attempts with string that wasn't as slippery as dental floss, and with Lifesavers that were strung, but not tied, to the dental floss. Our first successful attempt though was amazing, in part because my driveway is at a slight incline and the pop literally spewed over my garage roof! Both my sons pronounced that the coolest thing they had ever seen.

Mark Benvenuto, University of Detroit Mercy, Detroit, MI, USA

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.

#11 of 40. ***Require Every Pre-lab Discusssion to Include Consideration of Health and Safety Aspects***

When the guidelines were first written in 1976, this was not a common practice. Fortunately, we've made some progress in this area. Many science faculty now realize that this is essential and must take place.

Providing instruction in the safety hazards, appropriate precautions, and potential emergency procedures is one of a teacher's duties under the law. Failure to do so can result in being found negligent by reason of nonfeasance (i.e., failure to provide a warning).

The use of a Hazard Review Form is a good way to formalize this procedure. Prepare a list of all the hazards present, the necessary precautions, and the appropriate emergency responses. This will allow the teacher to end up with a written record of the instructions that have been given for each class on each day.

How do students/employees know that a particular topic of instruction is important? You give emphasis, you set a good example, and you test on the material. Be sure to have quiz and test questions on your safety instruction. I really like the Ebbing lab manual because each set of pre-lab questions contains the question: "What are the precautions required in this experiment?" (See #14 . . . the big four.)

Take it one step further. Add "what are the hazards? What would be the worst things that could happen? What are the prudent practices, protective facilities, and protective equipment needed to minimize the risk?" An Emergency Preparedness Review is available from LSI. In addition to assisting in the planning for emergency responses, the 16-page brochure covers many safety program topics.

Further Useful Resources

Clicker Resources (http://www.cwsei.ubc.ca/resources/clickers.htm) Includes an instructor's guide to the effective use of personal response systems (i.e., "clickers") in teaching, a suite of videos on using clickers in the classroom, and links to clicker question banks.

teachers.tv (http://www.teachers.tv) Freely downloadable video clips to use as classroom teaching aids. Includes downloadable activity and information sheets.

Virtual Ecology Project (http://faculty.etsu.edu/jonestc/Virtualecology.htm) Provides interactive, inquiry-based activities to demonstrate ecological principles.

The National Science Digital Library (http://nsdl.org/) An online library for education and research in science, technology, engineering, and mathematics.

Overwhelming Scientific Confidence in Evolution and its Centrality in Science Education--And the Public Disconnect

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Abstract

The teaching and learning of biological evolution has been beset by a host of challenges ranging from pedagogical obstacles to social controversy. These include two distinctive sets of problems: one arising from the fact that many evolutionary concepts may seem counterintuitive to students, and the other stemming from objections rooted in religion. A misconception common to both of these categories is the notion that significant doubt exists within the scientific community as to whether evolution actually occurred, or that it is "a theory in crisis." This article reviews the positions of the scientific and science education communities and how these compare with those of the general public. Despite the overwhelming acceptance of evolution among scientists, and despite evolution's centrality to modern biology education, virtually all national polls indicate that a strikingly large proportion of North Americans reject evolution, indicating a great disconnect between the scientific community and the largely dissenting and apparently under-informed, or misinformed, public. Large-scale research efforts regarding current practices related to the instruction of evolution, and into more effective methods of teaching evolution, are needed; certainly in the United States, but urgently, even if surprisingly, in Canada.

Scientific Consensus on Evolution and its Centrality

Evolution, defined narrowly, is the scientific principle that the diversity of life on Earth has arisen via descent with modification from a common ancestry. In the broader sense, evolution can refer to cumulative change in the natural world over time (Scott, 2004). Under both of these definitions, evolution has been deemed by scientists and science educators alike as a central and unifying concept in the natural sciences, especially in biology.

To be sure, scientific claims are based on, and tested against, evidence drawn from the natural world, rather than dictated by an authoritarian leadership. Therefore, and nonetheless, the scientists who have gathered and analyzed the data that have shaped the scientific understanding of evolution are surely the most qualified to speak as to the nature and weight of the physical evidence. Likewise, professional practitioners and researchers in science education are naturally best situated to remark on the value and relative importance of a given concept when it comes to the teaching and learning of science. Herein, I offer a review of the positions of the scientific and science education communities, as they have been articulated by relevant scholars and their organizations, regarding evolution as defined above.

Expert Scientists on the Certainty of Evolution

It has become very nearly a cliché for authors, including this author, when writing on issues in life science education, to cite the famous proclamation of the revered geneticist Theodosius Dobzhansky (1973) that "nothing in biology makes sense except in the light of evolution" (p. 125). Perhaps this assertion is so frequently quoted because it "accurately reflects the central, unifying role of evolution in biology" (National Association of Biology Teachers, 2008, ¶ 1).

Dobzhansky (1973) is certainly not the only scientist to have made such a statement about evolution. The eminent palaeontologists Stephen Jay Gould (1983) and Robert Carroll (1997) both acknowledged the power of evolution to connect the broad and otherwise disjointed fields of the life sciences. Carroll called it “the greatest unifying principle of biology” (p. 1). The venerated biologist E. O. Wilson (1998) described evolutionary biology as being “linked by consilience to the rest of the natural sciences” (p.11), a statement in full accord with his long-time Harvard University colleague Ernst Mayr (1970), who explained that “the diversity of organisms, similarities and differences between kinds of organisms, patterns of distribution and behavior, adaptation and interaction” (p.1) were all “merely a bewildering chaos of facts” (p.1) before they were unified and given meaning through evolutionary theory.

Members of the general, non-scientist public are often confused by common conflation of the scientific and vernacular uses of the word *theory*. When used in casual, non-scientific parlance, the word is often understood to mean a guess or hunch (Scott, 2004). But in scientific terms, according to the National Academy of Sciences (NAS) (1998), a theory represents the pinnacle of the scientific enterprise. Referring to the NAS description of a theory, Eastwell (2009) elaborated: “A scientific theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena. Some theories have been modified or rejected, while others--the most useful ones--are standing the scientific test of time, which gives us increasing confidence in them” (p. 86). And there may not be a more useful or thoroughly substantiated body of knowledge in all of science than that of evolutionary theory.

To clarify, however, the occurrence of evolution is not itself a theory. That the genetic make-up of biological populations can change over generations and that the diversity of life on Earth today is drastically different than it was during previous periods of geologic history are demonstrably factual. *Evolutionary theory* encompasses these and other observable facts, as well as laws (e.g., the Hardy-Weinberg law), inferences, and a variety of competing and complementary theories regarding how (not whether) evolution occurs. And for at least a century and one half, a parade of scientists has endeavoured to communicate the difference between the fact of evolution itself and the explanatory body of evolutionary theory.

Charles Darwin (1859) listed sufficient evidence to assert the veracity of evolution in his *The Origin of Species*, and he affirmed the factuality of evolution in *The Descent of Man* while subtly and humbly admitting that the debate over his proposed mechanism was still somewhat tentative (Darwin, 1871). One hundred years after the publication of Darwin’s *Origin of Species*, the Nobel-Prize-winning geneticist H. J. Muller (1959) summed up a century’s worth of additional evidence and corroboration by saying:

> So enormous, ramifying, and consistent has the evidence for evolution become that if anyone could now disprove it, I should have my conception of the orderliness of the universe so shaken as to lead me to doubt even my own existence. If you like, then, I will grant you that in an absolute sense evolution is not a fact, or rather, that it is no more a fact than that you are hearing or reading these words. (pp. 304-305)

As Mayr (1997) explained, the evidence for the occurrence of evolution is so overwhelming that today's biologists "consider it a fact--as well-established as the fact that the Earth rotates around the sun and that the Earth is round and not flat” (p. 178).

In his final (i.e., non-posthumously) published book, Stephen Jay Gould (2002) devoted 1,343 pages to explaining *The Structure of Evolutionary Theory*. Gould's explanation is extensive, complex, and somewhat contentious, but he agreed with Mayr (1997) that the occurrence of evolution is indeed a fact. In an earlier essay, he described evolution as factual in that it has been "confirmed to such a degree that it would be perverse to withhold provisional assent" (Gould, 1983, p. 255). According to Gould, evolutionary theory involves explanations about the mechanisms of evolution, essentially how evolution occurred rather than whether it occurred.

Richard Lewontin (1981), another great Harvard evolutionary biologist, also sought to clarify what is fact and what is theory regarding evolution, writing:

> Evolution is a fact, not theory [used in the colloquial sense of a guess or hunch] . . . what is at issue within biology are questions of details of the process and the relative importance of different mechanisms of evolution. It is a fact that the Earth with liquid water is more than 3.6 billion years old. It is a fact that cellular life has been around for at least half of that period and that organized multicellular life is at least 800 million years old. It is a fact that major life forms now on Earth were not at all represented in the past. There were no birds or mammals 250 million years ago. It is a fact that major life forms of the past are no longer living. There used to be dinosaurs and Pithecanthropus, and there are none now. It is a fact that all living forms come from previous living forms. Therefore, all present forms of life arose from ancestral forms that were different to them. Birds arose from non-birds and humans from non-humans. No person who pretends to any understanding of the natural world can deny these facts any more than she or he can deny that the Earth is round, rotates on its axis, and revolves around the sun. (p. 559)

Dobzhansky (1973) held that the occurrence of evolution has been "established beyond a reasonable doubt" (p.129), adding that "evolution as a process that has always gone on in the history of the Earth can be doubted only by those who are ignorant of the evidence or are resistant to evidence, owing to emotional blocks or to plain bigotry" (p.129).

In his widely-used, university-level textbook on evolutionary biology, Futuyma (1986) wrote:

> The statement that organisms have descended with modifications from common ancestors--the historical reality of evolution--is not a theory. It is a fact, as fully as the fact of the earth's revolution about the sun. Like the heliocentric solar system, evolution began as a hypothesis, and achieved "facthood" as the evidence in its favor became so strong that no knowledgeable and unbiased person could deny its reality. (p. 15)

Famed scientists like Carl Sagan (1980), as well as Richard Dawkins and Jerry Coyne (2005), have also stated flatly that evolution is a fact. As Dawkins and Coyne elaborated, "evolution is a fact: as much a fact as plate tectonics or the heliocentric solar system" (p. 5).

These comments from prominent scientists are a mere smattering of such acknowledgments from individual experts regarding the factuality of evolution and its central and unifying role in science. It would be a monumental endeavour indeed to attempt to collect an exhaustive catalogue of qualified scientists who are in agreement with these assessments of the status of evolution. As further evidence of the essentially universal acceptance of evolution among the scientific community, consider the numerous statements in support of evolution offered by various groups of scientists.

Evolution is Overwhelmingly Accepted by the International Scientific Community

A panel of 72 Nobel laureates in the sciences signed a document agreeing that “the evolutionary history of organisms has been as extensively tested and as thoroughly corroborated as any biological concept” (Amici Curiae, 1986, Argument, Part 11, ¶ 10). The National Center for Science Education (NCSE) keeps a list, although it was admittedly compiled in jest, of scientists, all of whom hold doctorates in one of the natural sciences from accredited universities. These scientists have affirmed a statement that reads:

> Evolution is a vital, well-supported, unifying principle of the biological sciences, and the scientific evidence is overwhelmingly in favor of the idea that all living things share a common ancestry. Although there are legitimate debates about the patterns and processes of evolution, there is no serious scientific doubt that evolution occurred or that natural selection is a major mechanism in its occurrence. (National Center for Science Education, 2008, ¶ 5; Scott et al., 2004, p. 26)

There are over 1000 signatories; but only scientists who are named Steve (or some cognate thereof, such as Stephanie, Esteban, Étienne, etc.) were permitted to sign. “Steve” was chosen in tribute to the late Stephen Jay Gould.

As for more officially organized groups of qualified scientists, many national academies of science and other professional scientific organizations have issued position statements regarding the overwhelming acceptance of evolution among the scientific community. For instance, as the Academy of Science of the Royal Society of Canada (RSC) (1985) attested:

> The theory of evolution by natural selection was first clearly formulated in 1859, and for over a century it has been tested and improved by the research of many thousands of scientists: not only by biologists and geologists, but also by chemists and physicists. From deductions based on abundant data, the theory has been developed to explain the changes that have taken place in living things over much of the Earth’s history. In its modern form, it remains the only explanation for the diversity of life on this planet that is acceptable to the scientific community. (p. 21)

This position was reaffirmed by the RSC in 2006, adding that evolution is “the only credible scientific position” regarding the history of life on Earth and that “the teaching of evolution is a benchmark of legitimacy” for biology education (Demers, 2006, p. 84).

The American Institute of Biological Sciences (AIBS) is an umbrella organization comprising nearly 200 professional societies with a total individual membership of over 250,000. According to AIBS (1994), “as a community, biologists agree that evolution occurred and that the forces driving the evolutionary process are still active today. This consensus is based on more than a century of scientific data gathering and analysis” (p. 29).

The (United States) National Academy of Sciences (NAS) has addressed the certainty of the occurrence of evolution under its narrow, as well as its broad, definition. Excerpts from one statement issued by NAS (1984) read:

> The processes by which new galaxies, stars, and our own planetary system are formed are sometimes referred to as the “evolution” of the universe, the stars, and the solar system. . . . Evidence that the evolution of the universe has taken place over at least several billion years is overwhelming. (pp. 11-12)

The same document concludes that biological evolution is also “supported by an overwhelming body of evidence” (NAS, p. 15) and that “evidence for relation by common descent has been provided by paleontology, comparative anatomy, biogeography, embryology, biochemistry, molecular genetics, and other biological disciplines (p. 15). The NAS reaffirmed this assessment in 2008, writing that evolution “is the only tested, comprehensive scientific explanation for the nature of the biological world today that is supported by overwhelming evidence and widely accepted by the scientific community” (NAS, 2008, p. 53).

The list of similar statements from scientific societies is long. Indeed, virtually every major scientific organization has issued a statement in support of evolution, and these statements have been neatly compiled as part of the National Center for Science Education’s *Voices for Evolution* project (Sager, 2008)[1]. And they represent not only the positions of North American and European organizations, but those of the worldwide scientific community. In fact, no fewer than 67 national academies of science have attested that the evolution of galaxies, stars, planets, and of life on Earth over billions of years is supported by observations and experiments from all branches of the natural sciences and that the evolutionary sciences represent an extraordinarily interdisciplinary understanding of the history and workings of our planet and its inhabitants. As this cross-cultural body of the world’s most qualified experts attested, evolution is an “*evidence-based* fact . . . never contradicted” (Inter-Academy Panel, 2006, p. 1) by science. National academies of science from all inhabited continents and “representing countries from Albania to Zimbabwe” (National Center for Science Education, 2006, ¶ 1) were signatory to the Inter-Academy statement, including the African Academy of Science and the Academy of Sciences for the Developing World, which serve member scientists from countries having no formal academies of their own. Not only does this indicate the strength of the evidence for evolution, but also that evolution is not merely a construct of Western scientists and that informed acceptance of evolution as a factual phenomenon is not limited to any one culture.

Evolution’s Centrality in Science Education: Official Positions of the Science Education Community

The practically unanimous acceptance of the occurrence of evolution and recognition of its central and unifying position in science is not limited to professional scientists, but is in turn embraced by science educators who are trained in the sciences as well as in pedagogy. Consequently, most major science education organizations have also issued statements acknowledging the factuality of evolution and its power in unifying the sciences, especially biology (see Sager, 2008, pp. 127-185). Like many of the statements ratified by scientific societies, these statements generally endorse evolution as a foundational principle upon and around which to structure the teaching and learning of biology as well as science in general.

A section from one such statement issued by the National Science Teachers Association (NSTA), one of the world’s largest science education organizations, reads:

> Evolution in the broadest sense can be defined as the idea that the universe has a history: that change through time has taken place. If we look today at the galaxies, stars, the planet Earth, and the life on planet Earth, we see that things today are different from what they were in the past: galaxies, stars, planets, and life forms have evolved.... There is abundant and consistent evidence from astronomy, physics, biochemistry, geochronology, geology, biology, anthropology, and other sciences that evolution has taken place. As such, evolution is a unifying concept for science. (NSTA, 2003, ¶ 7, 8)

This statement goes on to discuss evolution as an organizational principle for science teaching, citing the National Science Education Standards' recognition of evolution as a "conceptual scheme" that can "unify science disciplines and provide students with powerful ideas to help them understand the natural world" (National Research Council, 1996, p. 104).

The *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) also offer evolution as an example of a unifying concept, and noting this, the NSTA concludes: "Scientific disciplines with a historical component, such as astronomy, geology, biology, and anthropology, cannot be taught with integrity if evolution is not emphasized" (NSTA, 2003, ¶ 8). Accordingly, the curriculum guidelines of most U.S. states (Gross et al., 2005; Lerner, 2000; Mead & Mates, 2009) prescribe the teaching of evolution in biology and other science courses. Moreover, evolution is prominently featured in most of the widely-used and highly-rated biology textbooks (Flammer, 2001; Morse, 2001).

Disconnect Between the Scientific Community and the General Public

Notwithstanding the overwhelming evidence supporting the occurrence of evolution; in defiance of the consonant assurance from the scientific community that evolution is factual; despite the insistence of all relevant authorities on science education that evolution is indispensable to effective teaching and meaningful understanding of biology; although evolution is widely represented in state, provincial, and national curriculum documents; and regardless of the coverage of evolution in science textbooks, a large portion of the North American public remains resistant, often resolutely so, to the notion of an evolutionary natural history, suggesting that they think scientists, teachers, and textbooks are simply wrong.

In the United States, polls have consistently shown that over one-third to about one-half of adults overtly reject evolution, and, over a span of 20 years, the percentage of adults in the U.S. who accept evolution declined from 45% to 40% (Miller, Scott, & Okamoto, 2006). Figures on the public acceptance of evolution in Canada are only marginally higher. An Angus Reid poll in 1993 found that 53% of Canadians surveyed disagreed with the statement "human beings as we know them today developed from earlier species of animals" (Sonderstrom, 2000, p. 16), and, although Brown and Delodder (2003) have questioned the methodology of the survey, a 2000 poll suggested that "Canadians are about evenly divided in their views about the origin of life" (Compas, 2000, p. 1). A more recent Angus Reid poll returned a slightly higher figure, 59%, for Canadians accepting evolution; however, only 37% of this population disagreed with the notion that dinosaurs and humans co-existed on Earth--a central claim among many evolution rejecters--which is a curious datum indeed (Angus Reid, 2007). And just as the all-but-universal acceptance of evolution among the scientific community is global in scope (Inter-Academy Panel, 2006), so, it seems, is the rejection of evolution by large proportions of the general populations of many countries worldwide (Asghar, Wiles, & Alters, 2007b; Branch, 2008; Chinsamy & Plagányi, 2007; Cornish-Bowden & Cárdenas, 2007; Miller et al., 2006; Numbers, 1992, 2004, 2006).

This widespread rejection of evolution among members of the general, non-scientist public has been lamented by a host of scientists and science educators. In their oft-cited article on teaching evolution, Alters and Nelson (2002) reported that most science educators and researchers consider the public understanding of evolution to be "woefully lacking" (p. 1891). In 1998, Randy Moore, who was then the editor of *The American Biology Teacher*, described the state of public understanding and rife rejection of evolution as "by far the biggest failure of science education from top to bottom" (Christensen, 1998, p. D3). And the situation has apparently not appreciably improved (Branch & Scott, 2008; Miller et al., 2006).

Battles over the teaching of evolution in the United States have been well publicized as religious activists have continuously attacked evolutionary science curricula for decades. The situation in Canada, however, appears to be of a different nature, and somewhat less visible, as the problem there may be more related to a general lack of evolution in the provincial curricula to begin with. It may be quite common for Canadian students to go through their entire public education without hearing about evolution (Savory, 2008; Wiles, 2006a), and the resulting lack of knowledge about evolution may leave its citizens vulnerable to anti-evolution evangelism. There are plenty of creationist groups currently operating in Canada, many with very active public outreach projects (Wiles, 2006a; Wiles, 2006b), and Canada's science curricula may become a target of choice for creationists owing to certain legal and logistical peculiarities. For one, the line separating church and state is less clearly drawn in Canada than it is in the U.S., and private religious schools--even those that teach creationism--are often provincially funded (Lampman, 2010). Furthermore, education systems in Canada are more centrally directed at the provincial level, unlike those of the States where education policy is largely determined at the local school district level. So Intelligent Design or other forms of creationist pseudoscience could conceivably find their way into provincially-prescribed curricula if even one Minister of Education or other high-ranking official is disposed to such policy. This is particularly troubling in light of the skepticism being levelled at the current Conservative government's allegedly anti-science agenda, including the appointment of a Science Minister who "won't confirm belief in evolution" (McIlroy, 2009).

It is difficult to be sure how much Canadian students know about evolution or what may influence their conceptions about evolutionary history. A recent attempt to determine whether the popularization of Intelligent Design Creationism had detrimentally impacted the teaching of evolution in the nation's schools was thwarted when the grant that would have funded the project was denied. Disturbingly, this proposal was rejected in part because the academic committee appointed by the Social Sciences and Humanities Research Council of Canada (SSHRC) determined that there was not "adequate justification for the assumption in the proposal that the theory of evolution, and not intelligent-design theory, was correct" (Bauslaugh, 2008, p. 57), which simultaneously discounts the enormous body of evidence for evolution, ignores the extensive body of knowledge encompassed by evolutionary theory, and inappropriately construes the religious doctrine of Intelligent Design Creationism as a scientific theory.

The disconnect between the positions of the science and science education communities and those of the general public may beg the question "what are we doing wrong?" Frustratingly, the answer to the question remains, to a large extent, "we do not know." We have learned much about what may influence student understanding and acceptance of evolution, what practices are more effective for teaching evolution, and what might influence teachers' decisions about what or whether to teach about evolution (Asghar, Wiles, & Alters, 2007a; Bishop & Anderson, 1990; Bybee, 2001; Cherif, Adams, & Loehr, 2001; Clough, 2006; Johnson & Peeples, 1987; Lawson & Worsnop, 1992; McComas, Clough, & Almazroa, 1998; Osif, 1997; Rudolph & Stewart, 1998; Rutledge & Warden, 2000; Ryan & Aikenhead, 1992; Scharmann & Harris, 1992; Summers, 1982; Trani, 2004). However, evaluations of what is *supposed* to be taught about evolution according to the official curricula of the United States have revealed high levels of variability. Although there has apparently been a general improvement among these standards in recent years, there have also been notable regressions (Lerner, 2000; Gross et al., 2005; Mead & Mates, 2009). Comprehensive analyses of Canadian curricula have yet to be completed, but, for both countries, we have yet to determine what is *actually* taught about evolution in North American science classrooms.

Berkman, Pacheco, and Plutzer (2008) produced the first "National Portrait" of how much time American biology teachers spend on evolution. A few of their less-surprising conclusions were that the more biology courses teachers take during their post-secondary training, the more time they devote to evolutionary concepts when teaching; that having taken at least one course in evolutionary biology substantially increases the amount of time teachers spend on evolution in their classrooms; and that the teaching of human evolution in particular tends to be scanted. Perhaps their most striking finding was that 1 in 8 teachers presents creationism as science, but particularly relevant here is the revelation that only 2% of the teachers surveyed reported that they excluded evolution from their instruction entirely (Berkman et al., 2008). If that is the case, then whatever is taught by the 98% of biology teachers who include evolution is apparently not sufficient to convince a large proportion of students that the science is sound. No such national survey has been conducted among Canadian science teachers, but until we know what students are really learning, or not learning, about evolution in our schools, we will have no way to determine, on the whole, what we as educators are doing wrong.

What we need are large-scale research efforts focused on evolution education at all academic levels in North America; including what students learn, what teachers teach, and how teachers are trained to teach about evolution. This information will be essential if we wish to effectively ameliorate the disconnect between the high degree of confidence among the scientific community and the ambivalence of the general public regarding the veracity and importance of evolutionary theory.

Note

[1]*Voices for Evolution* also contains pro-evolution position statements issued by science education societies, civil liberties organizations, and the leadership bodies of several religious affiliations. The latter indicates that rejection of evolution is not a necessary component of conventional religious faith, as further attested by the *Clergy Letter Project*, with over 13,000 priests, preachers, pastors, ministers, rabbis, etc. signatory to a statement of their faith and the complimentary truth of scripture and evolutionary science (http://blue.butler.edu/~mzimmerm/Christian_Clergy/ChrClergyLtr.htm).

Acknowledgments

The author would like to thank Brian Alters and Glenn Branch for their helpful suggestions during early drafts of this paper. Additional thanks are due to Kevin Carlton, Kent Chambers, Abour Cherif, Vicki Compton, Kim Kaplan, Ana Maria Carneiro Leão, and Helen Meyer for their thoughtful comments on the penultimate version of the manuscript.

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A Martian Invasion of Teachable Moments for Environmental Science and Related Issues

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Abstract

The recent missions to Mars have produced a mass of data and information in all forms and have forced the minds of many people world-wide to rethink their own perspectives on life itself. This drama unfolding about 35 million miles from Earth, and digitally on our TV screens, is offering a growing reservoir for teachable moments. The curiosity and wonder of every image received prompts innumerable opportunities for inquiry. In this paper we share some of our ideas on how to bring into the classroom these exciting resources emanating from the Red Planet. Opportunities to reflect on myth and hypothesize about possibilities are obvious places to start when teaching about the potential of life on Mars. The explosion of resources and information (previously unavailable) from recent explorations of Mars stimulates students to examine further the environment around them. We share some of the activities we have been using in our classrooms to motivate readers to develop their own ideas on how to take advantage of the Mars missions for their classrooms. We offer strategies to create authentic learning experiences to engage students. In addition, we intend the activity to inspire teachers to use other contemporary teachable moments that may capture the imagination of their students as they discover science. Whether you are teaching topics related to desertification or deforestation, design and technology, or space travel or colonization, to name a few, the planet Mars and the recent missions to its environment will become part of your continually expanding resources in teaching science.

Helping teachers develop ways to utilize and capitalize on emerging scientific data as it materializes is very useful. The learning activities we describe and discuss in this paper integrate some of the recently available photographs from Mars (including some from the Mars Rover missions) to pose thought-provoking questions that are environmental and geological in nature. It is our particular goal to use this and similar activities to dispel a couple of pervasive misconceptions that we have observed, and that some students (and the general public) might still hold about science and the environment. In one of these misconceptions, science is perceived as static and thus answers can be found in textbooks and memorized in order to learn science. Another misconception is that environmental change happens largely or solely as a result of people doing bad things, and that geological, and in turn environmental, change does not happen without human intervention (Berry, 2009; Cherif, Adams, & Loehr, 2001; Chew & Laubichler, 2003; Miller, 2005; Shuttleworth, 2009).

Strategy and Pedagogical Approach

The main idea of this learning module is to provide students with a set of unidentified photographs from two different planets, Earth and Mars. To encourage comparative thinking, the photographs are paired; each pair of photographs in the set features one general landscape from planet Mars and one from planet Earth (one of the pairs features Mars and the Moon instead) that share some recognizable landform features. While we tried to select photographs that contain visual features that are familiar to people on planet Earth, there are surely unfamiliar landforms on Mars, and also on the planet Earth (for some students), and that is why it is innovative and exciting to look at these photographs. Because the students are uncertain how any of the landscapes formed and evolved, it is conjecture, deduction, and justified reasoning that we wish the students to apply in their inquiry and exploration of these photographs.

The pedagogical approach is for students to study the photographs and then try to answer several open-ended questions about what they observe. Students first describe what the landscape looks like, consider of what it might be made, and then speculate about how it came to be formed. Encouraging them to speculate on what processes might have formed particular landform features on the photographs (including craters, relatively smooth surfaces, mountains, valleys, etc.), and to guess the planet represented in each photograph, is essential for promoting the development of scientific inquiry and critical thinking. Then, following a brief introduction to geomorphology and various landscape-forming processes, students are asked to propose multiple, alternative hypotheses about how some of the observed features had formed. Finally, they are asked to propose locations for future planetary lander missions on Mars that might provide data to help decide among their competing hypotheses. This helps students to learn how to focus on decision-making by engaging in thinking about evidence and applying ideas for a purpose. Through a combination of pedagogical approaches, the students are likely to learn a range of fundamental concepts and principles about the geology of the planets Earth and Mars and also achieve the scientific process learning objectives of the activity.

Intended Learning Outcomes

There are two strands of intended student outcomes in the proposed learning module, one set about the process of scientific inquiry itself, and a second set about the nature of change in the environment. In the “science as a process” intended student outcomes, we want students to experience, appreciate, and internalize that: 1) science is an ongoing and active process, not just memorized answers to questions; 2) answers to one question often lead us to ask more and better questions; and 3) science is a collaborative process. In the “earth and environmental science” intended student outcomes, we want students to understand that: 1) processes on many planets’ surfaces produce recognizable landscape features, many of which are similar from planet to planet; 2) differences among landscapes come about as a result of the different conditions that formed each landscape, just as similarities can be related to similar processes; and 3) recognize that the presence of living things, and particularly of humans and human civilization, is not necessary for landscape, climate, and other changes to occur. In general, landscapes (natural, city, urban, rural) form as a result of time and interplay between various physical forces and climatic conditions (that may include human or biological influences, but do not necessary do so).

Finally, the proposed learning module is intended to illustrate how teachers can use emerging evidence about new planets to stimulate their own creativity and imagination, rather than to be applied as a static package in its entirety to teachers’ individual situations. As an end result, we hope that the learning module will also model for instructors how to use the observations from ongoing planetary missions (like Cassini), and other sources of publicly accessible research, in order to stimulate students to become active, scientific thinkers. But first, to understand how science works, what distinguishes a scientific inquiry approach from non-science in understanding the world around us, it is essential to begins with a consideration of the nature of science. After all, scientists share certain basic beliefs and attitudes about what they do and how they view their work (American Association for the Advancement of Science [AAAS], 1999).

The Nature of Science

Either consciously or unconsciously, all scientists conduct their work based on the underlying assumption that nature can be understood, and more particularly, that natural events are orderly and occur as a result of consistent, knowable causes. This assumption is the familiar principle of cause and effect, and is one of the cornerstone beliefs of Western civilization. Therefore, through science, which means to know through the exercise of reason, scientists aim to find better explanations for the natural phenomena and the world around us based on actual observations, the use of reason, and the discovery of objective knowledge and the elucidation of natural laws of causation (Futuyma, 1983; Moore, 1993; National Academy of Sciences, 1998; Trefil, 2003, 2007). This choice is based on the proposition that the application of reason that we call science can only be effective when directed toward objective observations (that do not change from one observer to another). For a proposal to be called a scientific hypothesis, it must satisfy a few, rather straightforward criteria: 1) the proposal must involve natural occurrences; 2) the proposal must be testable, by agreed-upon standards, so that it can be contradicted; 3) the proposal must be subject to revision or rejection based on the outcomes of such tests or the acquisition of new, objective observations (Kieffer, 1985; National Academy of Sciences, 2008; Trefil, 2003).

Science, simply, seeks to reveal all of the causes of all the events that have such causes. The practice of this search involves observation of events (or the acquisition of data), followed by inference of the possible causes of the events (forming alternative hypotheses), and finally, testing the inferred causes (to reject insufficient hypotheses, and select the best explanation). As Cherif, Adams, and Loehr (2001) have argued:

> Acceptance of a proposal (hypothesis or theory) in science involves several steps: 1) recognition of the body of evidence that gave rise to the proposal; 2) understanding the process of inference by which the proposal was created from the evidence; 3) ability to reproduce the process by which the proposal was tested; 4) ability to reach the same conclusion about the outcome of the test(s). Furthermore, acceptance of the proposal is still provisional, because the testing process and the acquisition of new information can and do lead to revision of an hypothesis, or its replacement by a more effective alternative. (p.15)

One of the critical components of the scientific reasoning process is that in order for a hypothesis to be called scientific, it must be capable of being contradicted. Thus, “the objectivity of science lies in its willingness to subject every aspect of the hypothesis to rigorous testing, [and] if the predictions derived from the hypothesis are not confirmed by observation and experiment, the hypothesis is rejected and a new model sought” (Bowler, 1992, p.17). The ability of an explanation to be contradicted in this way helps scientists distinguish between scientific and non-scientific claims or proposals.

Another critical aspect of the scientific process is repeatability; that is, the ability for all other researchers to obtain the same result, using the same scientific procedures in a given experiment. The conclusions drawn by one researcher about a given hypothesis are only accepted if the same results can be achieved by other researchers using the same methods. (While strict repeatability is not always possible in the historical sciences like geology, palaeontology, evolutionary biology, and others, other researchers should be able to repeat the observations made by the original researcher.) Repeatability is central to scientific inquiry as well as scientific integrity, accountability, and responsibility (AAAS, 1990; Cherif, 1998). As a result, scientists most often present their discoveries and experimental results by submissions that follow agreed upon formats, and which are subject to critical scrutiny by editors and by other scientists in the field (peer reviewers) to be validated. This approach of presenting scientific studies makes it easy for the researcher and for other scientists to read, critically analyze, and repeat the experiments or observations as necessary to confirm the results. The publication of scientific results also ensures another important characteristic of science; that of transferability. Other scientists can read about and use both the knowledge and the methodology of any published study (with proper citation) in their own work, regardless of what field they pursue.

In summary, modern science offers a mechanism to interpret natural events and to see the world in an objective way as it is (not how it ought to be), and to understand and cope with that world. In the activities that follow, we use the preceding description of the processes of scientific inquiry to explore with students the formation and testing of their own hypotheses. Students also examine the steps that scientists take before accepting a given hypothesis or a theory in science. Finally, before we start any activity, we make sure that students understand that scientists generally accept (by common consent, and without it being provable) that nature can be understood, and that all observable events occur as a result of consistent, natural causes (colloquially, the law of cause and effect). Still, as Einstein is often quoted as saying, “no amount of experimentation can ever prove me right; a single experiment can prove me wrong” (Kaplan, 2001, p. 181).

A Martian Invasion of Teachable Moments: The Teaching and Learning Module

The Teaching and Learning Module is divided into a number of activities, each with specific learning goals and objectives, and each could be targeted to a wide range of different student audience and school levels. The level and the depth of discussion is left to the discretion of the teachers based on their types of students. However, borrowing a phrase from one of the manuscript reviewers, “the differentiation between levels will be in the assessment of, and the sophistication of, responses.” The authors have used several of the activities, in part or in their entirety, in freshman- and sophomore-level college classes, but each could by readily adapted to middle school and high school levels.

Activity I: Tapping Into Students' Curiosity

(This activity is suggested for any introductory science course, particularly in the earth and environmental sciences.)

In this three-part activity, we capitalize on students’ past experiences to stimulate their thinking and activate their prior knowledge to encourage them to become active learners. The class is divided into groups of 4 students, and each group is given an identical set of photographs. Table 1 contains the suggested photographs for this activity. The photographs are given to students a total of three times during the activity: first without any identification, then with titles, and finally with titles and an attached brief description. Initially, the photographs are given as a set printed on one page, and after that the photographs are given in pairs printed on separate pages.

Table 1
Suggested Photographs for Tapping Into Students' Curiosity Through Exploring Landscape

Identifier	Title	Description	Location	Source
Pair A	Dry rivers	• Example of dry rivers on Earth, a high resolution view of dry river beds crossing a desert in China Xinjiang Uyghur region. • Example of dry river channels on the surface of Mars.	http://earth.esa.int/showcase/ers/china_west.jpg http://starchild.gsfc.nasa.gov/Images/StarChild/solar_system_level2/mars_rivers_big.gif	ESA Earthnet Online NASA
Pair B	Sand dunes	• A satellite image of sand dunes in the Sahara desert on Earth. • An image of sand dunes near a polar region on Mars during a period of "defrosting" or sublimation of CO_2 ice.	http://landsat.gsfc.nasa.gov/earthasart/images/sahara_hires.jpg http://antwrp.gsfc.nasa.gov/apod/image/0803/dunes2_hirise_big.jpg	NASA HiRISE, MRO, LPL (U. Arizona), NASA
Pair C	Polar regions	• This image of the Canadian Arctic region of Ellesmere Island displays several glacial features including ice flow. • This image of the northern polar cap of Mars shows layered appearance of deposited ice and dust. The measured temperature lies above the freezing point of CO_2 ice, suggesting that the ice is water ice.	http://www.nasa.gov/images/content/271991main_wardhuntTERRA_20080905_HI.jpg http://rst.gsfc.nasa.gov/Sect19/originals/Fig19_70.gif	Jesse Allen, using data provided courtesy of the MODIS Rapid Response team NASA
Pair D	Craters	• On the Moon, the ejecta of impact craters display features that appear to have "flown" outward as a result of impact. A significant difference between craters on the Moon and Mars is due to the Moon being very dry (devoid of subsurface ice) and Mars being very wet (presence of subsurface ice). • On Mars, fluidized ejecta around impact craters suggest that the martian subsurface was saturated with water ice when the impact occurred. The appearance of the ejecta varies from crater to crater implying differences in amounts of subsurface ice content. Image taken in 1977 by the Viking 1 orbiter.	http://www.hq.nasa.gov/office/pao/History/SP-362/hrp107.jpg http://solarsystem.nasa.gov/multimedia/gallery/Mars_Rampart.jpg	NASA Headquarters Website: http://www.hq.nasa.gov/office/pao/History/SP-362/ch5.1.htm NASA http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=824

Pair E	Surface terrain	• Sand dunes in the Namib Desert in southwest Africa. The red-orange color is the result of iron in the sand being oxidized over time. These dunes are the tallest on Earth rising as high as 300 m above the desert floor. • Martian surface terrain. This is a color image mosaic of areas traversed by Sojourner, the rover that accompanied Mars Pathfinder in 1997. Here we see rocks and dunes that are out of Pathfinder's view.	http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16328 http://marsprogram.jpl.nasa.gov/MPF/ops/rover_traverse_area.jpg	NASA/GSFC/MITI/ERSDAC/JAROS and U.S./Japan ASTER Science Team NASA JPL
Pair F	Water erosion	• Images of the Betsiboka Estuary in northwest Madagascar. Multiple decades of rainforest logging has led to the erosion. After each heavy rain, bright red soil from hillsides wash into the tributaries and heads towards the sea. The bottom image was taken in September 2003 by the International Space Station. • A view of gullies in the Terra Sirenum region on Mars taken by MRO's HiRISE camera on October 3, 2006. This camera can image colors within shadows.	http://earthobservatory.nasa.gov/images/imagerecords/4000/4388/ISS008-E-19233.jpg http://marsprogram.jpl.nasa.gov/mro/gallery/press/20061016a/D-Gully-highlight.jpg	Image Science & Analysis Laboratory, NASA Johnson Space Center http://earth.jsc.nasa.gov/sseop/images/EO/highres/ISS007/ISS007-E-14344.JPG
Pair G	Interesting terrain	• Geegully Creek, a river tributary in north Western Australia. Several stream channels and a wide flood plain are present here, along with several dry lake beds. Other features include sand ridges and dark and light patterns, a result of brush fires. Image taken in December, 1990 by the International Space Station. • Ares Vallis, an ancient flood plain on the surface of Mars selected as the landing site for the Mars Pathfinder.	http://earth.jsc.nasa.gov/sseop/efs/photoinfo.pl?PHOTO=STS035-76-66 http://quest.nasa.gov/mars/photos/images/marspfsite.gif	Image Science & Analysis Laboratory, NASA Johnson Space Center Online resources provided by NASA Quest Project at NASA's Ames Research Center
Pair H	Volcanoes	• Kilauea Volcano, Hawaii with visible plume. Image taken on July 7, 2008 by the MODIS instrument on NASA's TERRA satellite. • Olympus Mons, the largest volcano in the solar system. This volcano in currently believed to be extinct.	http://earthobservatory.nasa.gov/images/imagerecords/20000/20217/kilauea_tmo_2008189_lrg.jpg http://nssdcftp.gsfc.nasa.gov/photo_gallery/image/planetary/mars/olympus_mons.jpg	NASA image courtesy Jeff Schmaltz, MODIS Rapid Response team NASA

Part One

1. Using your own experience and background, examine the set of photographs provided to you by your instructor, interpret them, and write a paragraph about each pair. Use a magnifying glass if necessary. In your analysis, consider the following:

    a. Identify and describe as many kinds of landscape features as possible in these photographs.
    b. What mechanisms might have formed these features?
    c. State whether the landscape reveals the existence of living organisms in the present or in the past, and evidence for your reasoning.
    d. Are there any parts or features of the photographs that seem older or newer? Why do you think so?

2. Classify the photographs into those that were taken on planet Earth and those that were taken on another planet.

3. Using Table 2, justify your selection for each photograph and write it down.

4. Share your interpretations, selections, and justifications with the other members of your group.

5. Engage in a general discussion with your group regarding the similarities and differences in members' interpretations, selections, and justifications.

6. Save your written interpretations, selections, and justifications, and keep notes on your discussion for further analysis and comparison.

Table 2
Student's Description and Categorization of the Photographs Based on His/Her Own Knowledge and Background

Photo number	Photo description	Identified landforms	Origin of the photo: Earth, Mars, others	Reasons for origin selection and description

Part Two

This stage takes place after the learners examine some basic, but specific, principles of earth science. Specifically, students should be introduced to the concepts and methods of relative dating, and to the landforms associated with impact crater formation, volcanic processes, and processes of running water and wind. Teachers who are unfamiliar with any of these concepts can readily find basic information in any general geology textbook, Wikipedia, or other online reference sources. Students then re-examine the photographs, and respond to the following questions:

1. Using your newly gained understanding, re-examine and re-interpret the photographs using what you have learned about landscape forming processes.
2. Re-evaluate the events that you think took place on the surface of the planet(s) from which those photographs were taken, and record this in Table 3.
3. Re-divide the photographs into two groups, those that you think belong to planet Earth and those that belong to another planet, and record your selection in Table 3.
4. Justify your selection for each photograph and write it in Table 3.
5. What do you conclude from comparing and analyzing your own interpretations in Tables 2 and 3?
6. Share your new interpretation, selection, and justification of the photographs, and your conclusions from comparing Tables 2 and 3, with the members of your group.
7. Engage in a general discussion with your group regarding members' interpretations and categorization of the photographs, the reasons behind them, and your final conclusions from comparing Tables 2 and 3 with the members of your group.

Table 3
Student's Description and Categorization of the Photographs Based on His/Her Newly Gained Knowledge and Information

Photo number	Photo description	Identified landforms	Origin of the photo: Earth, Mars, others	Reasons for origin selection and description

Part Three

In this part of the activity, students are provided with the locations and brief descriptions for each of the pairs of photographs, and then directed to respond to the following:

1. Identify at least two criteria for good landing sites on another planet.
2. Speculate on what processes might have formed particular landform features on the planet Mars (including craters, relatively smooth surfaces, mountains, valleys, dunes, etc.).
3. Propose alternative hypotheses about how those features had formed.
4. Propose landing sites that would provide information to help choose among the competing hypotheses.

5. Compare your selections of landing sites with those chosen by real NASA scientists, as described in the January 2004 issue of *National Geographic*. Then complete Table 4 to indicate whether or not you agree or disagree with the 6 scientists who explained where they would land a Rover on Mars and why.

Table 4
I'd Send It To … Six Scientists Explain Where They Would Land a Rover--and Why (from Morton, 2004, p. 29)

Scientist	Scientist's proposal for landing site on Mars	Agree or disagree with the given proposal and why
1. Phil Christensen, geologist, Arizona State University	"Somewhere cold enough for snow and ice but warm enough for it to melt, such as the small crater at 43° South. … Snow--and the gullies it formed--may hold clues to past climate."	
2. Agustin Chicarro, Mars Express project scientist	"Wrinkle ridges in the plains south of Valles Marineris. Such ridges indicate that the planet shrank as it cooled, a clue to the tectonic history of Mars. "I'd love to go there myself."	
3. Maria Zuber, geophysicist, MIT	"Terrain near the South Pole, where Mars Polar Lander was headed in 1999. A look at the layers of dust and dry ice will reveal the timescale of climate cycles."	
4. Michael Malin, geologist, Malin Space Science Systems	"Sediments deposited by an extinct lake in Holden crater. There are layered sedimentary rocks on the southwest floor of the crater that are easily accessible and unusually similar to terrestrial landscapes. The layers record the history of Mars."	
5. Bruce Jakosky, Astrobiology, University of Colorado	"The edge of the north polar cap. Drilling several feet down might reveal ice that was liquid water tens of millions of years ago, greatly improving the outlook for finding evidence of life on Mars."	
6. Michelle Minitti, petrologist, Arizona State University	"Some blatantly igneous place like the top of Olympus Mons. Rocks on the solar system's biggest volcano could explain Mars' interior workings, and how volcanism shaped the surface."	

Activity II: Testing for Evidence of Life on Mars

(Suggested for introductory biology, environmental science, and general and integrated science courses. This activity is adapted from Kaskel, Hummer, and Daniel, 1995, pp. 3-4.)

Biologists and astrobiologists have been searching for evidence of life in outer space for many years. Biology is the study of life and living things. Biologists use the process of testing hypotheses to study living things and how the natural world of living organisms works. They generate hypotheses and test the hypotheses using the process of deductive reasoning in which they use the hypotheses to make predictions about the outcomes of new actions or observations. We intend for this activity to stimulate student's thinking about the possibilities of life on other planets. If life were to be found on any other planet it would have profound implications for the presence of life on many other planets throughout the universe.

When the Viking Spacecraft landed on Mars, the Viking Lander obtained and tested soil samples from Mars' surface for evidence of existing, or previously existing, organic molecules. More recent Mars missions also collected and tested soil and rock samples for similar reasons.

1. If you were a biologist working for NASA biological laboratory:
    a. What types of experiments would you conduct with martian soil to test for evidence of life on Mars?
    b. Explain the reason for selecting this particular type of experiment to search for evidence of life on Mars using martian soil.
2. NASA biologists added radioactive nutrient to the soil brought from planet Mars. Explain how this simple experiment could prove to scientists whether or not living things were present in the martian soil?
3. The Lander did not find materials that make up living things.
    a. Do these results support the idea that life doesn't exist on Mars now?
    b. Do they support that life never existed on Mars? Explain.
4. Today, Mars is observed to be a desert planet with notable dust storms, freezing temperatures, and a thin carbon dioxide atmosphere. However, on Tuesday March 23, 2004, NASA scientists announced that a salty sea once existed on the surface of Mars. This announcement was greeted with much excitement, because of the possibility that such an environment could have supported life at an earlier stage of martian history (Vergano, 2004).
    a. From your own perspective, what is the significance of the salty sea environment to the concept of life as we know it?
    b. Why do you think NASA scientists suspect that a salty sea environment could have supported early life on Mars?
5. What have you learned from being engaged in this activity?

Activity III: Landing Safely on Mars in 2012

(Suggested for physics, general science, and integrated science courses.)

To allow spacecraft (and astronauts) to travel into outer space and to land safely on the Moon, Mars, or any other planet and return safely to planet Earth, scientists must understand many basic concepts. One idea that they need to understand very well is the changes that will happen in the weight of the spacecraft as it uses fuel and as occupants (if any) use food, water, air, and other resources. This will affect the influence of gravity of a given planet or moon on which the spacecraft has to safely land, and from which it needs to take off. For example, the gravitation of the Earth is the most significant barrier standing in the way of traveling in space, because, as Noordung (1995) explained:

> A vehicle that is supposed to travel in outer space must be able not only to move; it must primarily and first of all move away from the Earth--i.e., against the force of gravity. It must

> be able to lift itself and its payload up many thousands, even hundreds of thousands of kilometers! (p. 3)

Gravity is not the only fundamental force that exists in nature. There are four fundamental forces in our present Universe with very different characteristics. These forces are electromagnetic force, the strong interaction (strong nuclear) force, the weak interaction (weak nuclear) force, and the gravitational force. The gravitational force is the weakest of the four, but its effect can be felt over greater distances than any other force. Gravity, which works throughout the universe, is defined as a force of attraction that arises between objects by virtue of their masses. It is the force that keeps our feet on the ground, keeps the Moon in orbit around Earth, the planets in orbit around the sun, and even causes whole galaxies to attract each other across billions of light years throughout the cosmos. As Sir Isaac Newton first explained, gravitational force between two objects is proportional to the mass of each object divided by the square of the distance separating them. The greater each object's mass, the stronger the pull of gravity, but the greater the distance between the objects, the weaker the pull.

In a recent issue of Popular Mechanics, Lord (2009) wrote that:

> When the NASA Mars Science Laboratory rover lands on Mars in 2012, it will face a unique obstacle: With an Earth weight of nearly a ton (compared to about 400 pounds for previous Mars rovers) and a Mars weight of about 750 pounds, it is too massive for any existing space parachute. So to cushion its fall through the thin martian atmosphere (which is less than 1 percent as dense as Earth's), NASA engineers had to come up with something really big. (p.15)

To engage students in grappling with these concepts, we suggest the following questions for research and discussion:

1. Compare and contrast Mars and Earth in terms of diameter, atmosphere's main gases, planetary mass, distance from the sun, density, and surface gravity. Use Table 5 to record your answers.

2. Estimate the maximum speed with which a falling raindrop can hit a person walking in the street. Then conduct an Internet search to find estimations that have been made by other people of the maximum speed with which a falling raindrop can hit a person walking in the street. Compare your estimation with the estimations made by other people, including your own classmates.

3. From your own perspective, describe why it might be that "incoming meteoroids that would burn up as fireballs in Earth's atmosphere often make it to the ground on Mars and create small craters just a few meters wide" ("Very Fresh Martian," 2009, p. 16). Then conduct an Internet search to find out why scientists think that incoming meteoroids that would burn up as fireballs in Earth's atmosphere often make it to the ground on Mars. Compare your own answer and the answers of your classmates with what you have found out through literature.

4. Working in small groups, suggest a well-thought-out proposal of how NASA engineers might solve the problem of landing a heavy spacecraft on Mars.

5. Share and discuss each of your individual proposals with your classmates. Try to convince your classmates that your individual proposal is the most promising in solving the problem and thus should be accepted by the whole class.

6. Conduct an Internet search to find out how NASA engineers have proposed to solve the problem. (You could start by looking at the July, 2009 issue of *Sky & Telescope*.)
7. Does your individual proposal agree or disagree with how NASA engineers have proposed to solve this problem?
8. Does the agreed-upon proposal by the whole class agree or disagree with how NASA engineers proposed to solve this problem?
9. What have you learned from this activity?

Table 5
Comparative Properties of Planet Earth and Planet Mars

Property	Planet Earth	Planet Mars
Diameter		
Atmosphere’s main gases		
Mass		
Distance from the Sun		
Density		
Surface gravity		

Activity IV: Traveling in Space

It is only a matter of time before traveling in space becomes a common occurrence, especially for those who can afford it. With the help of our advances in science and technology, we will be able to solve many problems that might become obstacles to our traveling in space. However, new challenges will also arise. In this activity, you are in charge of identifying and solving the problems of astronauts who will travel and spend more time in space than what is usual today (a few days to a few months). From your perspective, identify some of these problems and propose how you will deal with and (hopefully) solve at least three of them. An example of one possible problem and a proposed solution are given in Table 6, which you can use for your own answers.

Note for Teachers

Some of the astronaut problems that your students will most likely identify are as follows:

1. Providing adequate supplies of energy, air, and nutrition.
2. Controlling temperature in both space suits and spacecraft.
3. Dealing with gravity and weightlessness in space.
4. Providing adequate space in the spacecraft for healthy resting and sleeping.
5. Preparing and packaging food in a way that takes less space and weighs less (dehydration and freeze-dried techniques).

6. Dealing with high doses of radiation during the long duration of the space flight.

Table 6
Problems and Proposed Solutions for Extended Travel in Space (adapted from Adams, Cherif, & Johnson, 2001)

Problem	Proposed solution	Investigation	Applicability in other traveling situations
Example: Packaging & preparing food	Use dry food.	Measure the volume and weight of dry noodle soup. Then add hot water and re-measure the volume and weight to calculate the difference.	Traveling across the oceans and deserts.

Student Assessment and Evaluation

McCormack and Yager's (1989) taxonomy for science education is very useful and effective in assessing students' learning in these activities, and Figure 7 contains examples for each domain. Note that many assessment tasks could fall into more than one domain, depending upon how the tasks are formed. These questions will help you, as an educator, to build tasks that you would use within an assessment instrument.

Final Remarks

Satellite and on-location imagery of landforms on Earth and Mars provide us with a contrast in worlds that make them good teaching and learning objects. We see evidence of change everywhere on Earth, as landscapes are subject to atmospheric weathering, erosion, volcanism, or even plate tectonics (and human activity), all of which erase and rewrite Earth's surface features. Orbiting imagery of landforms on other planets provide a picture of our uniqueness in the Solar System, and of the potential for Mars. Mars does not appear to be subject to plate tectonics (as we perceive that process on earth). Atmosphere is one one-hundredth as dense as Earth's. Mars does not have a magnetic field that can deflect solar charged particles. We see evidence of less change on Mars, as there are heavily cratered areas dating back to the early bombardment of the solar system. There are also instances of change on Mars, albeit over longer time scales, and the evidence includes the volcanic plains and valleys eroded by liquid water in the distant past. There is also evidence for seasonal changing of the martian polar caps, and imaging that suggests liquid water in the more recent past. The recent Phoenix lander mission found evidence of water ice on (Phoenix Mars Mission, n.d.).

We send space probes to Mars to learn more about outer space and life elsewhere, which in turn might help us learn about ourselves on Earth. Only in the overall scope of exploring several planets do we truly begin to get a true picture of our own planet, and of our place in the cosmos. We are also acquiring further data that might inform possible views of our future as we explore other worlds and prepare for extending the human species upon some of these other worlds.

Table 7
McCormack and Yager's (1989) Taxonomy for Science Education

Domain	Description	Examples of assessment tasks
I. Knowledge	What concepts did students learn and how well did they understand them? How well did the students integrate knowledge from different subject areas? To what extent did students demonstrate the understanding of multiple relationships of various bodies of knowledge? What kind of explanations did students offer for the relationships and/or phenomena they observed and understood?	When students proposed processes for land formation in Activity 1, Part Three, did they use correct connections between the processes they cited and the land forms they observed? Did the students use appropriate terminology?
II. Process	How did members of a given group compile data and information? Was there cooperation in putting the information together? How efficient was each group in presenting and communicating the collected data and information? Was the delivery of their statements and arguments smooth and coherent? How well did the students use knowledge meaningfully? Did all members participate in the activity?	Share your interpretations, selections, and justifications with the other members of your group. Engage in a general discussion with your group regarding the similarities and differences in members' interpretations, selections, and justifications.
III. Creative	In what new ways did students use information and ideas generated during the activity to enlarge their understanding? How imaginative were students in identifying relevant problems and solutions, and conceptualizing new ideas?	What do you conclude from comparing and analyzing your own interpretations in Tables 2 and 3?
IV. Attitudinal	How persuasive were group members in articulating their positions in order to justify these and/or to change the attitudes of the others? How effectively did each group function? Did members of a given party demonstrate skills and abilities to resolve conflicts with others constructively? How might each group have functioned more effectively?	Share and discuss each of your individual proposals with your classmates. Try to convince your classmates that your individual proposal is the most promising in solving the problem and thus should be accepted by the whole class.
V. Application and connection	Did the students come up with practical and workable solutions? To what extent did the students utilize their personal experiences and collective group understanding in making decisions related to the activity? How well did the students integrate knowledge from different disciplines in problem-solving strategies? How well did the students learn to negotiate constructive solutions to conflicts? Were the students able to demonstrate their understanding using means other than speaking and writing?	Propose landing sites that would provide information to help choose among the competing hypotheses. Compare your selections of landing sites with those chosen by real NASA scientists, as described in the January 2004 issue of *National Geographic*. Then complete Table 4 to indicate whether you agree or disagree with the 6 scientists who explained where they would land a Rover on Mars and why.

Throughout recorded human history, there has always been a thirst for knowledge and a spirit of adventure. One of the distinguishing features of our species is the intellect, the reasoning circuitry in our brains that makes observations and attempts to explain phenomena. Throughout the process of science we are continually designing and conducting new experiments, making new observations, and attempting to explain these observations in the form of existing, modified, or new models or theories. In some cases, textbooks become obsolete even before they are published. All of us, teachers and students, continue to learn throughout our lifetimes.

As is the case in all fields of science, in the experience of the planetary space program, as soon as some questions are resolved, new surprises with new questions always emerge out of the throngs of data aching for explanation. We see something interesting and try to explain it in the form of a hypothesis. To test the validity of the hypothesis, we devise and conduct new experiments. If a positive result is produced by the experiment, the hypothesis is reinforced, although not proved. If the experiment produces a negative result, the hypothesis may be revised or scrapped, with any new hypothesis being likewise subjected to testing.

Why are we exploring space? There are the obvious simple answers to this question such as "to see what is there." There are also deeper yearnings of curiosity tucked away in the crevices of our psyche. "Are we alone?" "Did life once exist elsewhere sometime in the past?" "Is the human race destined for the stars as it embarks upon a colonization of other worlds that is likely to first include the Moon and Mars?" Should we follow the advice of Dr Carl Sagan, the famous American scientist and champion of space exploration until his death, and aggressively start preparing for colonizing the Moon, Mars, and other planets?

Why do we send space probes to Mars? First let us answer "why do we send space probes to Earth in the form of orbiting satellites?" We image storm systems such as hurricanes and weather trends that allow us to predict and alert people to danger. Satellite images of our planet also help us analyze long-term trends such as deforestation, changing shorelines, and effects of erupting volcanoes and monitor levels of gases such as ozone. These capabilities did not exist just decades ago. We are exploring our planet not only to ensure our safety, both short-term and long-term, but also to learn more about our planet. And we, the educators, should take advantage of this and turn those events and images into teachable moments that help our students to better understand the solar system and the universe, and in turn the world in which we and our students live.

Web Links

Jet Propulsion Laboratory (http://www.jpl.nasa.gov/releases/2004/90.cfm) Discusses Mars rover finding that some of the surface rocks on Mars may have formed in the presence of flowing water.

Mars Global Surveyor (http://mars.jpl.nasa.gov/mgs/index.html) From NASA/JPL.

Malin Space Science Systems: Exploration Through Imaging (http://www.msss.com/) MSSS operates and processes data from instruments on planetary missions under contract to the National Aeronautics and Space Administration (NASA).

Science@NASA Stories About Mars

Unearthing Clues to Martian Fossils (http://science.nasa.gov/science-news/science-at-nasa/1999/ast11jun99_1/) The hunt for signs of ancient life on Mars is leading scientists to an other-worldly lake on Earth.

The Red Planet in 3D (http://science.nasa.gov/science-news/science-at-nasa/1999/ast27may99_2/) New data from Mars Global Surveyor reveal the topography of Mars better than many continental regions on Earth.

Search for Life on Mars will Start in Siberia (http://science.nasa.gov/science-news/science-at-nasa/1999/ast27may99_1/) NASA funds permafrost study to support astrobiology research.

Acknowledgements

We would like to acknowledge the help of the following reviewers for their valuable suggestions and recommendations that have made this paper more effective: Kevin Carlton, Peter Eastwell, David Geelan, Israel Kibirige, Heather Mace, Debra McGregor, Helen Meyer, and Marina Milner-Bolotin. Indeed, we have integrated a few phrases from the reviewers' comments and feedback into the final version of the paper. We would also like to acknowledge and thank all those colleagues at the high school and college levels who read the paper and/or tried the activity in their classrooms and provided us with very valuable feedback. We are very grateful for this assistance.

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The Science Education Review (ISSN 1446 - 6120) is published by Science Time Education, 570 Womina-Willowvale Road, Warwick, Queensland 4370 Australia.

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