Volume 10, Issue 2 - 2011

THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Isaac Newton

Isaac Newton is arguably the greatest genius who has ever lived. However, he also had a dark side. While he had few friends, he had many bitter enemies and was only too willing to fire a barrage of insults at, and ferocious attacks on, both the character and work of anyone who dared to challenge his scientific claims. Such a disregard for the notion of truth was also evident later in his life in his role of Master of the Royal Mint. Having a strong desire to curb forgeries, he was particularly punishing on alleged counterfeiters. Counterfeiting was a treasonable offence punishable by death, and Newton condemned many to be hanged, drawn, and quartered on the weakest of evidence, such as the testimony of a paid informant.

Source: Brooks, M. (2011). *Free radicals: The secret anarchy of science*. London: Profile Books.

Teaching Ideas

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

The World's Most Extraordinary Organism

This activity may be used at the beginning of a school year to promote students' curiosity and motivate them towards the study of biology. Announce that the first homework assignment for the class is an individual competition to find the world's most extraordinary organism; one that is unusual or incredible in some way. Students may make use of the school or community library, the internet, their experience from watching television, the textbook, or whatever to present a page-sized image, common name, scientific name, brief description of what makes the organism so special, and references.

Some choices can be made to best cater for a particular class. For example, will a written or oral presentation be used? What length (e.g., minimum 100 words or 1 minute)? What timeline (i.e., overnight, or over a longer period to allow for at least some students to receive guidance)? Should the competitive spirit, where the class votes for the winner, be replaced by declaring every student a winner?

Invite students to ask questions about any of the organisms and show them that these are the very types of questions that the course addresses by relating the questions to the course topics (e.g., origin, evolution, and behavior). Personalise the classroom by displaying the students' images and descriptions on a board or the classroom walls, even rearranging them during the study of taxonomy!

A question based on the student presentations may even be posed by the teacher to introduce the next topic. For example, the question "what do all these very different organisms have in common that leads us to consider them to be living things?" could be used to introduce the characteristics of living things. Revisit the presentations during the year, perhaps even using them to extend into a consideration of the scientists who study the organisms, how science is done, and biology as a career.

Source: Allchin, D. (2011). The world's most extraordinary organism *The American Biology Teacher, 73,* 358-358.

Using Technology to Assess Students

Aronin and O'Neal (2011) offer the following list of 20 types of technology-based assessments: Voice-over, PowerPoint games, comics and graphic novels, blogs, interactive online time lines, podcasts, posters/pictures, webquests, books and stories, wikis, public service announcements, graphic organizers and mind maps, presentations, vocabulary and basic knowledge acquisition, online videos, drawing in 3-D, surveying, graphing, word clouds, and stories.

In the figure provided at http://www.nsta.org/middleschool/connections/201107Table.pdf one finds websites and programs for each of these types of student assessments that may be used either formatively or summatively, together with suggestions for how to use them and, in most cases, an example and/or sample rubric.

Reference

Aronin, S., & O'Neal, M. (2011). Twenty ways to assess students using technology. *Science Scope*, *34*(9), 25-31.

Students' Alternative Conceptions: Astronomy

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Answer *true* or *fals*e for each of the following statements:

1. The Sun always rises at due East.
2. Astronauts in orbit around the Earth are weightless because there is no gravity in space.
3. The orbits of planets are perfectly circular.
4. Meteors are "shooting" stars falling out of the sky.
5. The Moon does not rotate.
6. Astronomy and astrology are basically the same.
7. The Sun is not considered a star because it is part of our solar system.

8. There is no gravity on the Moon because it is in space.
9. A full Moon always rises at midnight.
10. Because the asteroid belt is very crowded, spacecraft have trouble passing through.
11. The telescope was invented by Galileo.
12. Stars are white.
13. Seasons change because the distance between the Earth and the Sun changes.
14. During a solar eclipse, the Sun emits rays that are more harmful to your eyes than usual.
15. Saturn's rings are composed of solid objects.
16. The North Star is the brightest star in the sky.
17. Because it is closest to the Sun, Mercury is the planet with the hottest average temperature.
18. A scientific theory is an idea that has not yet been proved.
19. It is advantageous to locate telescopes on top of mountains because they are then closer to space.
20. Stars last forever.
21. The primary role of radio astronomers is to search for signals from extraterrestrial civilizations.
22. Black holes are giant holes that move through space and "suck in" everything they encounter.
23. Saturn is the only planet with rings.
24. While radio waves travel at the speed of sound, light waves travel much faster at the speed of light.
25. The shadow of the Earth on the Moon causes the Moon's phases.

The foregoing statements are adapted from LoPresto and Murrell (2011) and are all false. LoPresto and Murrell also contains a corresponding multiple-choice survey that might also be used as a posttest.

Reference

LoPresto, M. C., & Murrell, S. R. (2011). An astronomical misconceptions survey. *Journal of College Science Teaching*, *40*(5), 14-22.

Using Google Earth to Appreciate the Magnitude of Deep Time

A comprehension of the magnitude of geologic and/or evolutionary time is critical for an understanding of some scientific concepts (e.g., biological evolution). While commonly-used timeline analogies for deep time, such as a clock face or playing field, are fine for displaying the order of events, they fail to facilitate a sound comprehension of the magnitude of deep time.

To see why this is the case, we need to acknowledge that the distances most readily comprehended by humans are ones that can be experienced directly. The longest time a student has experienced is his or her lifetime; 18 years, say. Since this timespan maps onto commonly-used timelines as a microscopic distance that cannot be experienced, this typical mapping exercise simply changes times that cannot be comprehended to distances on a timeline that similarly cannot be comprehended, which is unsatisfactory.

What is needed is a timeline characterized by distances that can be physically experienced. So, taking the smallest apprehensible distance to be 0.5 mm, say, and equating it with the 18-year lifetime of a student (18 years) gives us a scale of about 37 million years per kilometer. On this basis, the age of the Earth (4.6 billion years) maps to about 125 km, a distance that is readily experienced. An upper limit for a distance that can be readily experienced might be 1000 km, say;

a driveable distance in 1 day (although larger distances might be used in some countries, and especially those where train travel is more common). We conclude, then, that the best timeline should be between about 125 km and 1000 km in length, and Parker (2011) has found Google Earth (Google, n.d.) to be ideal for this purpose. Indeed, it may provide the only timeline suitable for effectively teaching both the order of events and the magnitude of deep time, and also takes advantage of the fact that, as descendants of hunter-gatherers, humans are evolutionarily adapted to have a strong geographical sense.

To prepare a Google Earth timeline, one needs to select a landmark greater than 125 km from the presentation site (marked by a length of yellow tape on the floor), use Google Earth to establish a route between these two locations, and add markers representing historical events at appropriate places along the route. A spreadsheet containing key historical dates and that also provides for ready time-to-distance conversions is available at http://www.soton.ac.uk/~jdparker/Google%20Earth%20timeline.xls . PowerPoint images of the screen captures of maps can be made. More detailed preparation guidelines may be found at http://eprints.soton.ac.uk/154973/1/Parker_2011.pdf . A useful presentation technique is to ask all students to raise their hands and, as the route is traced on the screen, to lower their hands when they think a certain event has been reached. The class suggestion, as represented by the position along the route by which about one-half of the students have lowered their hands, can then be compared with the actual position for the event.

Adopting the scale, used as an example above, of 0.5 mm representing 18 years allows students to compare the biblical creationist age of the earth (represented by a distance of 16 cm from the yellow line) with the vastly different distance of 125 km suggested by science. Of course, students could be invited to construct such timelines themselves.

References

Google. (n.d.). *Google earth*. Available from http://earth.google.com/ .
Parker, J. D. (2011). Using Google Earth to teach the magnitude of deep time. *Journal of College Science Teaching, 40*(5), 23-27.

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 .

Discovering the Night Sky

Ancient civilisations distinguished between stars and planets,
They understood then, Moon phases and how the Sun rises and sets.
Through joining of the night sky stars they enabled navigations,
Using imaginary lines to make patterns (constellations).
The Egyptians created our calendar of 3 6 5 days,
Greeks discovered that reflected sunlight lit the Moon with bright rays.
Nicolaus Copernicus theorised that planets orbit the Sun,

By studying night skies, many important discoveries were won.

But it was not till Galileo, a famous astronomer,
First used a telescope to see the night sky, clearer than it were.
Then, scientific discoveries could more accurately be made,
And conventional views were challenged, and thus soon began to fade.
Galileo didn't just observe the fascinating night sky,
He also applied scientific methods to find out just why,
Using simple logical thinking and mathematical laws,
With his observations, to help discover the possible cause.

Galileo sighted some darkness on the surface of the Moon,
These dark areas amazingly grew and shrunk back rather soon.
Depending on their true position in relation to the Sun,
He deduced that these were just mere shadows, when next day there were none!
Cast by the Moon's odd-looking surface craters and mountains up high,
This was an important revelation - uncovered with a sigh,
As it was widely believed and also very commonly thought,
That the Moon's surface was quite smooth, as had previously been taught.

Most importantly, Galileo Galilei discovered then,
The four major, visible moons of Jupiter, in 16 10.
He observed that the surrounding moons of planet Jupiter moved,
And with further investigating and calculation he proved,
That around planet Jupiter the large rings actually revolved,
This was a major discovery - a curious mystery solved,
As it was previously truly believed by most common folk,
That all things in the universe revolved around Earth - what a joke!

Galileo's confirmation that planet Earth orbits the Sun,
Meant that the Copemican System's popularity was won.
Furthermore, the rings of Saturn that Galileo uncovered,
Are other fascinating phenomena that he discovered.
His observations motivated people to further explore,
Foremost, Galileo encouraged many people to be sure,
To always apply maths laws and logic to their observations,
In a quest to understand the universe and situations.

Many important, great discoveries were made throughout history,
By studying the night sky for the benefit of you and me.
Today, major advances such as the Hubble Space Telescope,
CCD imaging, observations in infra-red give hope.
Also, improved optical telescopes, ultra-violet, X-rays,
Continue to aid discoveries in more technological ways.
Future generations need no longer yearn or ask to know why -
Most questions can now be answered about the amazing night sky!

Ellysia Oldsen, 14 years
Australia

Research in Brief

Research findings from key articles in reviewed publications

Improving Students' Revision of Physics Concepts Through ICT-Based Co-Construction and Prescriptive Tutoring

By: Benson Soong, London Metropolitan University, UK and Neil Mercer, University of Cambridge, UK benson@cantab.net

For secondary school science teachers who are interested in helping improve their students' revision of physics concepts, there are not many interventions that both cover a wide range of physics concepts and have empirical evidence to support their claim of improved learning outcomes for students. Three such interventions include Mazur's Peer Instruction (e.g., Mazur, 2009), the Cooperative Group Problem Solving initiative at the University of Minnesota (e.g., Redish, 2003, chapter 8), and the Tutorials in Introductory Physics programme developed at the University of Washington (e.g., Finkelstein & Pollock, 2005). However, these three interventions were originally derived from research conducted in university settings. Given that secondary school and university environments are fundamentally different, there is a need for research work that stems primarily from a secondary school setting. After all, if students lose interest for science education in secondary school, then who is going to take science (e.g., physics, chemistry, and biology) in university? Our research study focused on designing, implementing, and evaluating a physics intervention programme in a mainstream secondary school in Singapore. The intervention was conducted as part of regular physics revision over a 1-year period and involved students who were taking their GCE O-level physics examination after immersion in the intervention.

Guided by sociocultural learning principles, the intervention changed the practice of how physics revision was conducted in a particular secondary physics classroom. The intervention comprised two interconnected components; a computer-mediated, collaborative, problem-solving (CMCPS) component and a teacher-led, prescriptive tutoring (PT) component. The CMCPS portion of the intervention required the students to follow basic "ground rules" (see Mercer & Littleton, 2007) for computer-mediated problem-solving of physics questions with other students, while the PT portion saw the teacher prescriptively addressing students' misconceptions, misunderstandings, and other problem-solving difficulties as captured by the discussion logs during the CMCPS sessions. During a CMCPS session, pairs of students working on individual PCs solve pre-assigned physics questions collaboratively using a shared text-chat and whiteboard application. Their collaborative problem-solving endeavours, comprising dialogue enabled by the text-chat/whiteboard software, are saved and reviewed by the teacher. During the PT session, the teacher discusses physics concepts based on what students themselves articulated. Said in a different way, the PT lesson is driven by students' problem-solving processes and not by students' answers, and because the teacher can now read how students think about physics instead of just seeing their answers, revision lessons are much more specifically focused.

The intervention was evaluated in two stages. First, a small-scale pilot study, which utilised a control group (CG)/alternate intervention group (AG)/experimental group (XG) with pre- and post-test research design, was conducted in order to evaluate whether the intervention was effective in promoting the improved learning outcomes of a small group of students. Given the success of the pilot study, a main study involving an entire class of students was conducted. This main study was evaluated by comparing the cohort's actual GCE O-level physics results with their expected grades (as given by the Singapore Ministry of Education based on the students' primary school results). Also, the students' O- level physics results were compared with the average physics results obtained by previous cohorts. The quantitative data indicated that the intervention for physics revision appeared to have been effective in helping the entire class of students revise physics concepts, resulting in improved test scores, while the qualitative data indicated that the students' interest in physics had increased over time. The physics teacher also reflected that the intervention had provided her with much deeper insights into her students' mental models.

Given the success of our intervention in this research study, we believe it offers secondary school science teachers a viable method for helping to improve students' revision of physics concepts. Should any secondary science teacher wish to attempt this intervention, we would be happy to assist.

Note. This piece comprises a summary of Soong & Mercer (2011) plus additional information that subsequently became available. For further information, please see Soong & Mercer (2011) or Soong (2010).

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Readers' Forum

Causal Questions

Sharkawy (2010) presents three types of investigable question; descriptive, relational, and cause-effect. These are all non-causal questions, and conspicuous by its lack of prominence in this paper is the causal question, which asks about the cause of a puzzling observation.

Science is about providing explanations for what we observe and, contrary to a misconception embedded in what I sense is the current mood, the scientific method (or hypothetico-deductive approach) is central to the way science is done and to the way the field of science progresses. An understanding of the scientific method is fundamental to an understanding of the nature of science, and the causal question is an integral part of the scientific method.

For an elaboration of the scientific method and the different ways in which causal and non-causal questions need to be investigated, please see Eastwell (2010b), which is freely available online. In particular, the answering of a causal question requires a hypothesis, whereas the investigation of a non-causal question does not require the scientific method and hence does not require a hypothesis. Further, the reports of investigations of causal and non-causal questions require different section headings, as explained in Eastwell (2010a).

What is more, when a causal question such as "why do mealworms move so slowly?" does appear in Sharkawy (2010), it is swiftly converted to related non-causal ones. This gives the impression that causal questions are not investigable when in fact, as Lawson (2010) has argued, the more explicit and frequent use of causal questions in science classrooms would be highly desirable for the better development of scientific literacy.

Finally, the answering of causal questions using the scientific method does not come easy for students, as the generation of hypotheses uses different brain networks than those used in tasks requiring simply an understanding of hypotheses, so practice is required (Lee & Kwon, 2011). Indeed, the advancement of hypotheses and the design of tests to check on the predictions that follow from them are the tasks that make science the highly-creative endeavour that it is. It is the levels of creativity displayed in these areas that distinguish exceptional scientists from good ones.

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Laboratory Safety Guidelines

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

#15 of 40. ***Require That all Accidents (Incidents) be Reported, Evaluated by the Departmental Safety Committee, and Discussed at Departmental Safety Meetings***

While having no accidents isn't necessarily a good indication that everything is ok, having them go unreported makes the matter worse. The reporting of all accidents is extremely important. Every accident is an opportunity to improve your safety program, to learn how to do a better job, and to protect your workers and facilities.

Since accidents happen relatively infrequently, particularly in smaller organizations, keep track of the incidents and close calls/near-misses as well. These are the events where matters of inches or seconds were the difference between nothing happening, a minor mishap, and a major disaster. The rule of thumb is that there are 300 minor incidents for each major one. Think of all you could learn from having a chance to review the close calls. When organizations provide an easy way for employees to self-report and share accounts of close calls and near-misses, the frequency of accident invariable goes down.

The safety committee should get copies of each accident or incident report and review it carefully. They should conduct an investigation of the event so that it can be correctly evaluated and the proper corrective action taken to prevent a reoccurrence. Don't go around looking for someone to blame. Looking to place blame is the quickest way to convince people that they shouldn't talk about what happened, to avoid telling the truth, or to have a loss of memory.

Then, the event should be brought to the attention of the rest of the people in your organization at a departmental safety meeting or by other means so that they too can learn from the experience. Photographs of injuries and property damage are graphic reminders of the consequences of carelessness, unsafe work conditions, and unsafe work practices.

At Cornell University, a review of the lab accidents for the prior several years revealed a pattern. There was one particular undergraduate lab experiment that was responsible for a disproportionate number of accidents. Changing the experiment helped to reduce the accident frequency.

Consider having an accident/incident report form for your employees and students to fill out. In the case of students, it will help them to develop an appreciation for this record-keeping aspect of safety. A sample accident/incident report form is available from LSI.

Further Useful Resources

Science Buddies (http://www.sciencebuddies.org/) Science Fair project ideas and help, including Ask an Expert, as well as information about careers in science and more.

The S'COOL Project (http://science-edu.larc.nasa.gov/SCOOL/index.php) Involves students in real science as they make, and report, observations of clouds to help validate NASA's CERES satellite instruments.

Ocean Explorer (http://oceanexplorer.noaa.gov/) A rich research data bank that students can use to ask their own questions about exploration, volcanoes, vent organisms, and plate tectonics on the seafloor and use the same data scientists do to find answers.

Pudue zipTrips (http://www.agriculture.purdue.edu/ziptrips/) Free, electronic science field trips. Students may participate either live and interactively or by watching an archived web stream.

Periodic Table Live! (http://www.chemeddl.org/resources/ptl/) This interactive periodic table is available from the Chemical Education Digital Library (www.chemeddl.org), which in turn is a part of the National Science Digital Library (http://nsdl.org). Worksheets to accompany Periodic Table Live! are available from www.nsta.org/highschool/connections.aspx .

Life Sciences Learning Center (http://lifesciences.envmed.rochester.edu/) Offers inexpensive, easy-to-prepare, hands-on, wet-lab simulations and manipulative models on a wide variety of biology topics. The simulations involve engaging, real-life scenarios and include blood typing, tissue typing, gel electrophoresis, chromatography, water testing, and growth factors involved in stem cell differentiation.

Songs for Teaching (http://www.songsforteaching.com/index.html) Children's songs, lyrics, sound clips, and teaching suggestions for promoting learning.

Bloom’s Digital Taxonomy (http://edorigami.wikispaces.com/Bloom's+Digital+Taxonomy)
An update of Bloom's Revised Taxonomy that attempts to account for the new behaviours and actions emerging as web technologies advance. Outlines the different taxonomic levels and provides digital taxonomy verbs as well as possible classroom activities and resources.

The Mismatch Among Students' Views About Nature of Science, Acceptance of Evolution, and Evolutionary Science Understandings

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Abstract

This study explored interrelationships among high school students' views about nature of science (NOS), acceptance of evolution, and conceptual understanding of evolution, and the extent to which these may have shifted from pre- to post-instruction on evolutionary theory. Eighty-one students enrolled in ninth-grade Biology responded to questionnaires measuring views about NOS and acceptance of evolution, and were tested on their conceptual understanding of evolution before and after a month-long instructional unit on evolution. Results revealed that students with more scientifically accurate views of NOS showed greater acceptance of evolutionary theory. Students' conceptual understanding of evolution significantly increased from pre- to post-instruction, but views about NOS and acceptance of evolution did not shift. No correlation was found between students' NOS views or evolution acceptance and their conceptual understanding of evolution. Findings imply that students may increase and refine their understanding of evolutionary theory without showing a change in their views about NOS or acceptance of evolution. (Most of this paper is a summary of Cavallo & McCall, 2008.)

Evolutionary theory has been the core of education and religious debate for well over a century (Brem, Ranney, & Schindel, 2003). This ongoing dispute compromises the very discipline of science, as non-scientists in positions of authority may have the capacity to remove or limit teaching evolutionary theory in our schools (e.g., National Center for Science Education, 2008). Yet the scientific community views evolution as a unifying theory in biology and recognizes that it is based on extensive and comprehensive evidence. The scientific community also asserts that controversial topics are critical to the scientific enterprise (National Research Council, 1996), as long as opposing positions have been subjected to the same show of evidence, rigor, and scrutiny as is the convention in science. Evolution provides, in fact, a classic example of the very nature of the scientific discipline where new evidence in science challenges current views and ways of thinking (Cavallo and McCall, 2008).

Beliefs About the Nature of Science

Though evolution is often headlined in the media, considerable public misinformation exists. Biology teachers find students hold opinions about evolution, yet have little scientific understanding of evolutionary processes. Along with pre-conceptions about evolution, students may not understand that scientific theory is based on substantial evidence and support, yet dynamic in light of new, authenticated findings. Thus, students hold misunderstandings of what defines scientific theory, as in the case of evolutionary theory, which in turn may impact their learning and understanding of scientific topics. Research indicates that promoting more scientifically accurate views of the nature of science (NOS) among students may impact their acceptance of evolutionary theory (Bybee, 2004; Cavallo & McCall, 2008; Dagher & BouJaoude, 1997). Recent research by Winslow, Staver, and Scharmann (2011) supports this approach by posing that if students understand NOS, this understanding "allows them to demarcate the boundaries of, and distinguish between, knowledge claims made by science and religion" (p. 1027). Thus, making the mental separation between what constitutes science and what constitutes faith may help students better understand, and be open to understand, scientific theories such as evolution that are addressed in school.

One way to address students' views of NOS is by means of a "unidimension framework" (Chen, Tsai, & Chai, 2011, p. 967), meaning that their views fall on a continuum with two opposing ends. According to this framework, students' NOS views on one end of the continuum may be characterized as dynamic and tentative, or on the other end, as static and fixed (Cavallo, Rozman, Blickenstaff, & Walker, 2003; Linn & Songer, 1993). Students who view science as dynamic and tentative consider science as constantly changing and understand that scientific conclusions are based on evidence. Students holding this view of NOS perceive science as intelligible, interpretable, and connected with what they already understand about the world (Cavallo & McCall, 2008). At the opposing end of the continuum, students hold the view that science is static and fixed and an assemblage of data and indisputable facts. Students with fixed or static beliefs may see learning science as something to be accomplished through memorization and as divested from their lives (Cavallo et al., 2003). Students who hold a static, fixed view also tend to believe that scientists always arrive, or attempt to arrive, at the "truth" (Linn & Songer, 1993; Saunders, 1998).

Beliefs About Evolution

One of the most influential factors regarding acceptance of evolution may be the students' worldviews. For example, religion may be the central framework in one's views of the world regarding origins of life. However, the scientific bases of evolution may conflict with these views. Dagher and BouJaoude (1997) suggest a strong connection between religious affiliation and personal views regarding the theory of evolution. In one study, beliefs were shown to interfere with students' ability to examine scientific evidence objectively, and the interference was even stronger when learned religious ideas conflicted with the information being taught (Sinclair & Baldwin, 1996). Lawson and Worsnop (1992) found that a substantial portion of students held a belief in creation and related non-scientific beliefs before their study began. These studies highlight the notion that science and religion both serve as ways of knowing about the world, but do so from very different frameworks of understanding (Sinclair & Baldwin, 1996). However, it is yet unclear how incongruous beliefs about evolution and NOS might impact students' acquisition of scientific understanding of evolutionary theory. Therefore, the research questions of this study were:

1. To what extent may views about NOS, acceptance of evolution, and understanding of evolution shift from pre-instruction to post-instruction during an instructional unit on evolution?
2. What are possible relationships among students' pre- and post- instruction (a) views about nature of science, (b) acceptance of evolution, and (c) understandings of evolution topics?
3. What differences may exist in students' achievement of scientific understanding of evolution according to their views of NOS (fixed, tentative) and acceptance of evolution (high, low)?

Method

This study was conducted on a suburban/rural ninth-grade campus located in the Midwestern United States. The students (mean age = 14.5 years) were those enrolled in three biology classes totaling 81 students, with 44 females and 37 males. The ethnicity of the participants was predominantly Caucasian and non-Hispanic, with less than 5% representing other ethnic groups.

Instrumentation and Instruction

The following three instruments were used in this study in a one-sample pre-test/instructional treatment/post-test design.

Science Knowledge Questionnaire (SKQ)

The SKQ measured students' views of NOS on a unidimensional continuum (Cavallo & McCall, 2008; Saunders, 1998). The SKQ used in this study was a 16-item Likert instrument. Students responded to questions about NOS by indicating a choice ranging from *Strongly Agree* to *Strongly Disagree*. The fixed/authoritative views of NOS items on the SKQ were reverse scored so a lower score on the instrument indicated a more fixed view and a higher score indicated a more tentative view of NOS.

Measure of Acceptance of the Theory of Evolution Instrument (MATE)

The MATE was adapted and used to measure students' beliefs about evolution (Rutledge & Warden, 1999). Questions on the MATE determined students' level of acceptance of the theory of evolution. Two additional questions were added to the questionnaire to evaluate overall student perceptions of evolutionary theory (Rutledge & Warden, 1999). The MATE used in this study was a 22-item Likert instrument that provided numerical values for analysis. A high questionnaire score indicated greater acceptance of evolutionary theory, so the scores obtained were termed the students' *acceptance of evolution*.

Understanding Biological Change (UBC)

Students' understanding of evolution was measured by administering the test, Understanding Biological Change (UBC), Version B, designed by Settlage and Jensen (1996). Four additional questions were selected from the questionnaire used by Sinclair and Baldwin (1996). All questions were in a two-tiered format with a question as the first tier and the explanation as the second. The students' response to both the question and the explanation/reasoning for the response were to be correct to receive credit for the item (scored as 1 or 0).

The instruction for the unit on evolution was a combination of active inquiry and discussion to help students gain understanding of the theory of evolution and its supporting evidence. The content of the unit was based on the text *Biology: The Study of Life* by Schraer and Stoltze (1999), with additional resources coming from the website series *Evolution* produced by WGBH/NOVA Science Unit and Clear Blue Sky Productions (2001). The topics for the 4-week instructional unit included the history of evolutionary thought, Darwin, evidence of evolution, and how evolution works through natural selection. Several online and in-class activities were used to help students gain an understanding of the evolutionary topics of this course.

Data Collection Procedures

Analyses on the first two research questions of this study used students' scores on the SKQ, MATE, and UBC to examine possible shifts from pre- to post- instruction, and to explore interrelationships among NOS, acceptance of evolution, and understanding of evolution. Analysis for the third research question used a median split with students placed into low- or high-scoring categories according to responses on the SKQ and MATE. The low-scoring group on the SKQ held more fixed, authoritative views of NOS and the high-scoring group held more tentative, dynamic NOS views. The median split on the MATE provided two groups with either a low or high acceptance of evolution.

Results

Shifts in Student's Views of NOS, Acceptance of Evolution, and Understanding of Evolution

A paired samples *t*-test was used to explore possible shifts in students' views of *NOS*, acceptance of evolution, and evolution understanding from pre- to post-instruction. Results of this test revealed no significant change in students' views of NOS, or acceptance of evolution, from the pre- to post-instruction ($p > .05$). However, there was a significant shift in students' biological understanding of evolution between pre- and post-instruction on evolution ($t = 7.25$, $df = 75$, $p = .000$).

Relationships Among Students' Pre- and Post-Instruction Views About Nature of Science, Acceptance of Evolution, and Understanding of Evolution

Correlation analyses were used to explore the relationships between students' pre- and post-instruction views of NOS, acceptance of evolution, and evolution understanding. Significant positive correlations were found between students' pre-test views of NOS and pre-test acceptance of evolution scores ($p < .05$). This finding indicated that students with a more tentative view of NOS also tended to have a higher acceptance of evolution, and those with a more fixed view of NOS also had lower acceptance of evolution. The correlation between post-test views of NOS and post-test acceptance of evolution scores also tended toward the same positive correlation ($p = .05$). A significant positive correlation was found between students' pre- and post-Evolution Understanding scores ($p < .01$).

Differences in Students' Understanding of Evolution Topics According to Their Views of NOS (Fixed, Tentative) and Evolution Beliefs (High, Low)

Paired samples *t*-tests explored differences in post-test scores on students' evolution understandings with respect to views of NOS grouped as fixed or tentative, and their acceptance of evolution grouped as high or low. No significant differences were found in students' understanding of evolution according to these opposing views of NOS or acceptance of evolution ($p > .05$). Notable, however, was that the difference between tentative and fixed NOS groups approached significance in understanding evolution, favoring students holding more tentative views ($t = 1.89$, $df = 73$, $p = .06$). More research is needed to determine the salience of this finding.

Summary and Discussion

This study explored patterns and interrelationships among students' views of the nature of science, acceptance of the theory of evolution, and their conceptual understandings of evolution. It revealed that students' views of NOS and acceptance of evolution did not shift during the month-long evolution unit, yet students' understanding of the concepts related to evolutionary biology increased. This finding corroborates the literature that reports beliefs as being deeply entrenched in one's persona and unlikely to change in a short period of time (Blackwell, Powell, & Dukes, 2003), yet in the same timeframe students were able to improve their understandings of the scientific concepts.

The results of this study show a positive relationship between students' views of the tentative nature of science knowledge and acceptance of evolution. In both pre- and post-evolution instruction, if students viewed science as a tentative/dynamic process, they were also more likely to accept evolution; the more the students viewed science as fixed and authoritative, the more likely they did not accept evolutionary theory.

For many, science may be considered a subject to be memorized and an authoritative source of knowledge rather than something that is changeable and dynamic. This is clearly not the view of the scientific community, which supports the position that scientific ideas are subject to change, and presumes that "even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works" (American Association for the Advancement of Science [AAAS], 1990, p. 2). It is important to help students realize that increasingly accurate approximations in science demand evidence, and arguments must be based on logic and reasoning (AAAS, 1990).

Clearly, students enter classrooms with certain worldviews and perspectives that may seem counter to current scientific theory. These worldviews are important for teachers to know prior to instruction, especially when instruction may challenge these views. Matthews (2009) highlighted the perspective of biologist, educator, and Anglican priest Michael Reiss by stating: "Unless science teachers take into account [existing beliefs] school science will fail to enable students to learn much of these areas of science [explanations of biodiversity] at more than a superficial level or to engage students with science" (p. 659). By viewing science as a dynamic process, students may actually be more open to highly charged scientific ideas such as evolution.

The question is not about the teaching of evolution; it is about the manner in which evolution is taught. Too often, the teaching of evolution is conscripted into a philosophical or religious topic, when it should not be; evolution is firmly grounded in the scientific discipline. This study provides no evidence that students' acceptance of evolution relates to their understanding of evolutionary theory: Students will understand the theory even if they do not accept its philosophical or religious implications. Therefore, as scientists and educators, rather than focus on acceptance of evolution, our responsibility should be to promote understanding of scientific processes as well as the body of knowledge accumulated through the processes of science. It is most important that students understand, and are able to practice, the processes of science, experience its tentativeness, and logically analyze evidence gathered today or throughout history so they are prepared to support or refute any scientific theory.

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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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