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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Albert Einstein

The interpersonal relations and other conduct of enthusiastic and gifted thinker Albert Einstein would cause concern for university personnel departments today. Consider the following:

- Einstein was a womanizer who made shameless passes at his mistress's daughter.
- Confronted by both, he shrugged and asked them to decide which of them he should marry after he divorced Mileva.
- As a part of the divorce settlement, he arrogantly promised to give Milena the money from an as yet unearned Nobel Prize.
- When this award was subsequently made, he gave her only one-half the money.
- He let his alimony payments dwindle to intermittency.
- He threatened to use his fame against his university should they not provide him with a full-salary pension on retirement.
- He hid money from the taxation authority.
- He cut off his schizophrenic son, who died a "third-class" patient in a mental institution.

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 Snowball Questioning Technique

In the Snowball Questioning technique, Burk (2012) takes the Think-Pair-Share technique one step further. After the teacher asks a question, students are given 30-60 seconds to think silently about an answer to it. Students are then asked to pair with a classmate and discuss the question for 1 to 2 minutes. Then, pairs are invited to join together to form groups of 4, discuss the question for a further 1 to 2 minutes, and attempt to arrive at an agreed answer. The class seating plan aims to see each group of 4 comprising 2 proficient and 2 not-so-proficient students.

A spokesperson for each group of 4 then shares the group's answer with the whole class. The spokesperson may be chosen using a criterion such as the person wearing the most blue or having the nearest birthday. The teacher also questions each group as to whether members initially agreed, or differed, in their answers and about how the discussion within the group proceeded. Finally, the teacher shares the best answer, making sure that any misconceptions have been dispelled by the group and whole-class discussions. Burk (2012) has observed the Snowball Questioning technique to improve both the engagement of students and the quality of their answers.

Reference

Burk, I. (2012). The Snowball Questioning method. *The Science Teacher*, *79*(4), 64-65.

Ball in a Bucket: Inertia

Sit a student on a chair that is free to rotate and ask him or her to hold a tennis ball at shoulder height. Invite another student to rotate the chair, place a bucket on the floor a short distance away from the chair, and ask the rotating student to release the ball so that it lands in the bucket. Students will quickly come to realize that, after being released, the ball moves tangentially to its original circular path, thus helping to debunk the common misconception that the ball will continue to move along the circular path.

Source

Hancock, J. B. (II), & Fornari, M. (2012). Minds-on audio-guided activities (MAGA): More than hearing and better than seeing. *The Physics Teacher*, *50*, 288-291.

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 Da Vinci Ode

Anatomy was his hobby;
dissecting animals his pleasure.
He studied the insides of creatures
And took their organs away to measure.
The Vitruvian Man was
drawn by he.
It's one of his most well-known works--
apparently.

Sometimes he studied
a bird flying.
He wanted to fly too.

He wrote in mirror writing,
so his ideas couldn't be stolen.
His ideas were original,
And to none was he beholden.
Eventually his notes were deciphered,
after lots and lots of toil.
Today we take for granted
the mysteries he uncoiled.

Who is this great prodigy,
of scientific inquiry?
It can only be . . .

He never stopped trying.
He built a "helical air-screw"
that didn't work.
His "Ornithopter" crashed
after going berserk.

His notebooks detailed
plans for tanks and guns.
He later detested war,
but was happy when Good won.
He drew an armoured tank,
cannon and submarines.
His mechanical designs,
are found in today's machines.

Leonardo da Vinci!

Tara Sofia Jadwani-Bungar, 12 years
Australia

Air

It surrounds you and me
It's everywhere and it's free
It's invisible--we can't see
It's essential to all life like trees
Air

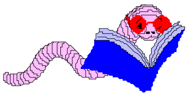
It's built up everywhere
And misuse it if you dare
You have to be aware
That we all breathe air!
Air

It's a mixture of gases
Like nitrogen and carbon dioxide dear lad and lasses
To protect and preserve it's a job for the masses
Air

Life as we know it will end
Without gases that we cannot lend
With all the pollution it is almost impossible to mend
And without a simple gas all we can say is the end

Air Air Air
Is it fair what we do to air?

Martin Xiao, 10 years
Australia



Research in Brief

Research findings from key articles in reviewed publications

Using Journals to Monitor Students' Development and Feelings

Erduran Avcı and Karaca (2012) (which is freely available online) had sixth- and seventh-grade students in Turkey write journals twice a week for 9 weeks. The researchers show how such journals allow teachers to monitor not only students' scientific understandings and academic development but also their thinking and emotional experiences.

Reference

Erduran Avcı, D., & Karaca, D. (2012). An investigation of students' academic development, views, and feelings through journals. *Eurasia Journal of Mathematics, Science & Technology Education*, *8*, 177-188. Available from http://www.ejmste.com/ .

Should we "Contaminate" Students With Alternative Ideas?

By : Patrice Potvin, Julien Mercier, Patrick Charland, and Martin Riopel,
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Many science teachers think that it can be counter-productive to proceed to an explicitation of initial conceptions (true or false) in class before learning occurs. It is often feared that proceeding in this way, like when public brainstormings are conducted, could produce a "contamination effect," suggesting false (among others) ideas to students who didn't adhere to them in the first place, possibly leading them to produce wrong answers at the final exams and therefore failing to achieve conceptual change.

Prior to our investigation, the science education research literature was not very helpful in solving this issue. Indeed, most studies exclusively use authority arguments (and not experimental ones) to include classroom explicitation of initial conceptions (CEIC) in their experimental designs. Furthermore, the measured effect of this operation is most of the time drowned within the complexity of suggested designs, such that isolating the effect of the single operation of CEIC from the effect of the entire design appears impossible.

Our experiment established a comparison between entirely similar learning paths, with the single exception that one of them included a CEIC operation. Students from both groups ($N_{\text{control}} = 676$ and $N_{\text{experimental}} = 199$) were submitted to a pre-posttest (eight conceptual questions about basic electricity knowledge) design, in laboratory conditions, with a 75-minute pedagogical treatment called The Electronic Challenge just before posttest. This treatment was a problem-based game, where students had to experimentally solve 20 challenges from the simplest "make a bulb light" to the most complex: "A bulb lights weakly without the need to push a switch. When switch A is pushed (and maintained as such), the light from the bulb increases, and when switch B is pushed, the light from the bulb increases even more." The CEIC used in the experimental group consisted of exposing all students to the conceptions of others by being asked by a moderator to identify, by raising their hands, the answers to the pretest questions (projected on a screen) they believed to be correct ones. For the two most popular answers to each question (therefore at least a wrong one), two justifications were elicited from the students, allowing the class to hear and to understand them.

The results showed that there was no contamination effect on the post-test due to CEIC. In fact, we recorded a very significant (but rather weak) positive effect, but only for girls. Boys seemed completely unaffected by the CEIC. This surprising result raises the question of the effectiveness on socioconstructivist pedagogical designs on boys. Are girls more prone to capitalise on other's ideas than boys?

These results have to be read with caution. It is possible that our design, which allows students to immediately verify if their hypotheses about electricity could be right (or not), might be optimal to avoid any contamination effect. It would be interesting to know if a contamination effect can occur with a more traditional, transmissive approach. However, our results suggest that a contamination effect by classroom explicitation of initial conceptions (CEIC) should not be feared, at least in contexts where these concepts can be tested by students with real materials (as was the case with all groups in our experiment) and that students are able to make the most of what they hear, even though the conceptions they are exposed to have the potential to be misleading.

Reference

Potvin, P., Mercier, J., Charland, P., & Riopel, M. (2012). Does classroom explicitation of initial conceptions favour conceptual change or is it counter-productive? *Research in science education*, *42*, 401-414.

Motivation to Learn Science: A Question of Gender or Cognition?

By: Albert Zeyer, University of Zurich, Switzerland albert.zeyer@ife.uzh.ch

A number of studies suggest that boys are more positive towards science education than girls (Osborne, Simon, & Collins, 2003). If, however, research focuses on students' interest and motivation to learn science, the situation becomes unclear. Glynn, Taasoobshirazi, & Brickman (2007), for example, were unable to find a relationship between gender and motivation to learn science among American students who were not majoring in science subjects. This ambiguity is also evident in studies where sub-dimensions of motivation, such as internal/external motivation and self-efficacy, are taken into account.

In this unclear situation, the so-called E/S theory that originally emerged from the field of autism research is of particular interest (Baron-Cohen, Knickmeyer, & Belmonte, 2005). It proposes two core cognitive dimensions: empathizing (E) and systemizing (S). These relate, respectively, to the consciousness of a mental world and the consciousness of a physical world. Empathizing is the ability to identify and perceive mental states. It is the drive to understand people and their psychological makeup. Systemizing describes a person's ability to perceive physical things and to understand these objects and their function in the context of a system. It identifies the rules that determine a system and understands how the behavior of a system can be predicted.

The basic assumption of the E/S theory is that all humans use both psychological dimensions. However, one of the two dimensions is generally dominant. A person who is more influenced by systemizing (S>E) is called a systemizer. Those who are more influenced by empathizing (E>S) are called empathizers. People who are equipped equally with both abilities (S<>E) are characterized as balanced. Psychometric studies have shown that females tend to be empathizers, while men are more often systemizers. This concept is known as the E/S model, and the E/S constellation is called the person's brain type.

Some years ago, Billington, Baron-Cohen, & Wheelwright (2007) showed that students of natural science tended to be systemizers, while students of the humanities were mostly empathizers. Moreover, the brain type proved to be a better indicator of the type of studies chosen than gender. Based on these results, we developed the hypothesis that generally differences in motivation to learn science are not primarily influenced by gender but by the brain type. Systemizers are generally more motivated to learn science than empathizers, and differences observed between the genders result from the tendency for girls to be empathizers and the boys to be systemizers. They are not a result of being a girl or a boy per se.

This hypothesis has been supported in research with Swiss students (Zeyer, 2010; Zeyer, Bölsterli, Brovelli, & Odermatt, 2012; Zeyer & Wolf, 2010) and recently also in a cross-cultural study (Zeyer, et al., 2011). Results in the latter study were remarkably stable across cultures, and structural equation modeling provided some interesting insights (Figure 1).

As can be seen in Figure 1, there is a so-called full mediation of systemizing between gender and motivation to learn science. This means that gender has no direct impact at all on motivation to learn science, but only through its impact on systemizing. In fact, systemizing explains more than

25% of motivation to learn science, which is a fairly high amount of explanation in social sciences. However, no relationship was found between empathizing and motivation to learn science. This partially modifies the hypothesis suggested in the work of Billington et al. (2007). An empathizer can be poorly engaged in science; however, the engagement of an empathizer can also be strong. It depends on whether they are high or low systemizers.

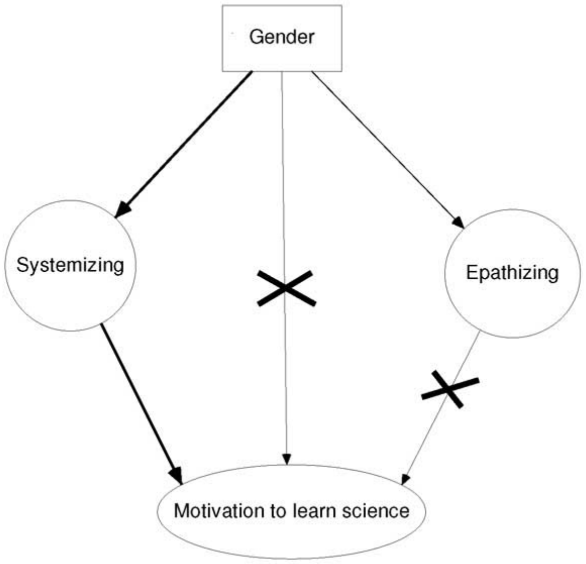

Figure 1. The diagram resulting from structural equation modeling.

Implications for science teaching. At the moment, it is too early to draw far-reaching conclusions for science teaching from these results. Nevertheless, we believe that they suggest, with due caution, some interesting points of view. First, students' gender seems to be not as important as it sometimes is considered to be. If a student's systemizing cognition is strong, then they will be highly engaged in science, independent of their gender, and vice versa.

Therefore, the challenge for school science seems to be how to deal with low systemizing students, be they good empathizers or not, and be they girls or boys. Successfully improving the systemizing dimension of these students' cognitive style could lead spontaneously to an improvement in their motivation to learn science. Research must show if, and to what degree, the initial level of systemizing can be improved and how this could be accomplished.

Third, the structural model suggests that empathizing does not influence a person's engagement in science. This can be interpreted in two different ways. One could argue that science simply has no link to empathizing and therefore it does not affect the empathizing cognition of a person whatsoever. Or, it is also possible that the empathizing dimension of students is not affected because of the particular way science is taught in the investigated schools. From the presented data, it is not possible to determine which interpretation is correct. Nevertheless, it is noticeable that there is no link to empathizing in all the investigated cultures.

Moreover, it is interesting to speculate about how science teaching must develop in order to meet the needs of students who are empathizers. At first glance, the answer seems to be simple: it must involve mental states. But what does this mean? It might well be, for example, that involving socio-scientific issues is an approach to meet the needs of empathizers; that is, scientific issues that are also subject to economic, social, political, and/or ethical considerations (Sadler, 2004). Generally, "talking science" (i.e., discussing the significance of scientific issues with peers [Rocard et al., 2007]) seems to be a promising approach. It may fit to the needs of students' empathizing cognition, because it always involves dealing with the minds and feelings of others. More research is required to understand these relations and their implications more clearly.

How to proceed in school? We believe that simply being aware of our results may have an impact on attitudes towards the teaching and learning of science in schools. For example, it may be that less attention need be paid to gender differences in teaching than is sometimes the case. Instead, types of cognition may come to the foreground. Actually, it is not difficult to develop an intuitive concept of systemizing and empathizing. Without necessarily classifying students as systemizers or empathizers, a teacher may take these concepts into account when teaching in order to identify different types of challenges that students may encounter when learning science.

Teachers who would like to develop more familiarity with the E/S approach and its possible consequences for science teaching may consider using the Baron-Cohen standard questionnaires provided at Autism Research Centre (2012). Two types of questionnaire are available. One type of questionnaire (EQ, SQ for adults) is self-reporting and can be given directly to the students. The other one (EQ-SQ Quotient for children) has been developed for parents to assess their children in terms of the E/S theory. This questionnaire can be used by teachers as well.

Of course, the results of these tests must not be overstated. However, they may provide a reference point for determining a students' individual constellation and, if the brain types of all the students are considered together, an overview of the classroom constellation a teacher has to cope with.

In a high-systemizing constellation, be it individual or collective, our results suggest a situation where there is a high science motivation (i.e., most of these students will be "potential scientists" who do not need to be especially encouraged in their willingness to cope with scientific issues). In a low-systemizing constellation, it may be worthwhile to particularly focus on systematic aspects of the science topic in question. If the teacher is able to explain these features in a plain, understandable way, this may encourage the motivation of low systemizers. On the other hand, improving the systemizing capacity of students may be a successful way of helping low systemizers to cope with the challenges of science education.

In the event that low-systemizers have a high empathizing quotient, it may be wise to approach a science topic using the "human factor" (i.e., by introducing the issue through narrative and contextual bridges that help to guide empathizers in the realm of science and open up their readiness to face scientific questions and find them interesting or even attractive). With high-empathizers, the student-teacher relation may also be particularly important for motivation.

At present we still know little, on a scientific level, about the validity of the approaches suggested here. More and careful research must be done to ground our suggestions in empirical data. It could also be very helpful to collect feedback from teachers who are working in various countries with the E/S approach. Therefore, on our blog (Universität Zürich, 2012) we provide a forum for teachers who wish to share their thoughts, experiences, and questions on this issue with colleagues, and readers of this article are very welcome to join the discussion there.

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Readers' Forum

Equal Male-Female Representation: A Myth

Reading Victoria FitzGerald's (2012) "Addressing the Lack of Girls in Physics" caused me to once again reflect on an issue that I have been pondering for some years. It is not uncommon to see a published paper in science education beginning along the lines of "there is a greater number of one sex than the other studying this course, or working in this profession, so we have a problem." However, I think such reasoning, based on the politically-correct myth that males and females are, on average, the same, lacks validity.

On average, men and women have different types of brains (Baron-Cohen, 2003). At the same time, though, there is quite a deal of overlap. Among men, about 60% have a male brain, 20% have a balanced brain, and 20% have a female brain, with women showing inverse figures (i.e., 60% of women have a female brain). On average, males tend to be genetically predisposed to systemize, analyse, be more forgetful of others, think narrowly, and obsess. Females, on average, are innately designed to empathise, communicate, care for others, think broadly, and take balancing arguments into account. As an education-specific example, it appears that girls are naturally more interested in biology and boys more interested in physics (Baram-Tsabari & Yarden, 2008).

Rather than focusing on equal numbers of each sex, I think we would be on much sounder ground if we were to focus on equal opportunity for all, and in this area there appears to be much that is yet to be achieved. However, at the end of the day and in a perfect world that featured equal opportunity for all, I cannot help but think that we might still find many more males in physics and civil engineering and many more females in literature and nursing, for example, and that this would be quite natural.

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Peter Eastwell, Science Time Education, Queensland, Australia

Getting More Science Teachers to Model "Doing" Science

Why is there not more attention given to getting all students (and teachers) actually "doing" science in every K-16 science classroom? The faulty assumption being made is that there is information thought to be accurate that all must "know" before really doing science. Most science teachers continue to use typical science textbooks and lab directions in excess of 90% of the time! Doing science means urging all to personally explore nature with attempts to explain the objects and events encountered. It also means exploring what others have done (and reported) as ways of evaluating their initial ideas as well. Science cannot be done in a vacuum! It takes doing, trying, creative thinking, and evidence gathering! Textbooks, lab manuals, and other quick fixes are all opposite examples of actually doing science.

Most professional development efforts invite persons with current understandings of science to tell, share, and encourage others to remember and repeat relevant research results. This view of doing science is what characterizes presentations for conferences and for most professional development efforts that are typically designed to influence the science that is taught. There should be major efforts to produce students who recognize and produce questions and then proceed to investigate them personally. Finally, it is important to establish the validity of their work using the actual evidence collected. Such actions would illustrate doing science.

Could not professional development efforts (including reports at conferences) start with problems/questions by the attendees followed by varied attempts by enrollees to answer them? An example might be reviewing the meaning of science followed with the idea that it could be used to indicate changes regarding the use of actually doing science with the attendees. Science always begins with questions. Students can be asked to offer questions that are personal, local, and current to their lives and communities that could involve science in problem resolution. These ideas could be shared with all attendees as they are encouraged to prepare for their own use along with plans for working on answers. These can also lead to identifying group projects to be organized as major foci for student interest in STEM careers. Again, it could be done with the professional development as illustrations of what they could do with students. A related effort could involve noting problems from local newspapers.

Attendees could be asked how these questions at the PD gathering could illustrate how they could be used with students when starting a new unit. This could lead to the collection of multiple responses and encourage the sharing of such evidence in science classrooms. Could there be some focus on results from students as well as changes in teaching noted? These could occur after actual professional development sessions or experience with conference presentations. We need more than happy attendees; we need reporting of new approaches to teaching that can be tried and evaluated after each professional development experience!

Science is typically taught by sharing the explanations and interpretations of others. These are then used to determine what is put in textbooks. Repeating this information is then used for evaluating student learning. Student ideas and involvement are not expected, nor are they welcomed. Science is too often like art or drama, where teachers admire and/or criticize the performances of their best students. Standardized tests too often require only students to repeat what has been presented or assigned by teachers. The information included in textbooks or directions for laboratories too often only focus on students remembering and/or duplicating performances with no use of questions, possible answers, real investigations, or interpretations.

Science can be done much better than this typical teaching scenario allows and made a part of efforts that illustrate real learning as an experience itself! Treating professional development efforts as science (i.e., questions about the objects and events in nature) should not only be a goal for reform teaching but an outcome of a real and personal experience with science.

Robert E. Yager, University of Iowa, Iowa, USA

The Place of Inquiry in the Reform of Science Education

The 1996 National Science Education Standards in the United States uses the word *inquiry* in two ways. It was to be a form of content while also being a way science must be taught. Some argue that the term inquiry needs to have *scientific* in front of it (i.e., scientific inquiry) before it has real meaning and use in science education. Such varying positions certainly can cause communication problems and often interfere with success with current reforms.

Inquiry was so important that the National Research Council (NRC) (2000) prepared a whole 202-page volume to clarify the use of inquiry in the reform of science education advocated in the 1996 National Standards. This new effort identified five essential features of inquiry and what it should mean for teachers, students, and model classes. These five features are: 1) learner engages in scientifically-oriented questions; 2) learner gives priority to evidence in responding to questions; 3) earner formulates explanations from evidence; 4) learner connects explanations to scientific knowledge; and 5) learner communicates and justifies explanations. The focus is clearly on learners!

Also of importance in the NRC document were the variations recognized as ways inquiry could be approached in science classrooms. In many respects teachers should know about the features that can justify changes in typical teacher actions that characterize traditional teaching. The list of essential features was followed by ways each feature could be used and four levels were indicated for accomplishing each feature. But why are the four variations for approaching the essential features considered to be important (necessary)? They start with a focus on student actions, but move finally to a focus on teacher actions.

Unfortunately, the fourth level for doing inquiry in classrooms identifies the teacher as the “guider” of inquiry in the classroom. Most teachers are content with such guiding and clearly relate it to the teaching they have always done. It requires minimal change in “teaching.” Do the other levels for realizing the features of inquiry really work? Or, are they but ways of lessening the real meaning of inquiry for students?

In several action research projects central to two major professional development efforts in Iowa over three decades, science teachers new to the notion of current reforms were polled. Over 90% were clearly at this fourth level, indicating what teachers often do to illustrate inquiry in their classrooms and labs; none were found in Level 1 (student-centered). They displayed stated actions for all five of the essential features. The specific descriptions of level four are: 1) learner engages in questions provided by teacher, materials, or other sources; 2) learner is given data and told how to analyze it; 3) learner is expected to provide evidence; 4) learner is asked to suggest possible connections; 5) learner is given steps and procedures for communication about teaching as inquiry. Ideally, reformers would hope to see much more use that would illustrate student-centeredness.

All of the variations in the teacher use of inquiry suggest ways teachers can achieve and encourage inquiry for their students, and the greatest success comes with teachers who give guidance (while not being too “directive”). But, is that an accurate/desirable evaluation of reform teaching? Does it achieve student-centeredness in terms of experiencing and carrying out inquiry? Does it make sense for teachers to set all parameters for what is taught and how?

If inquiry is to be recommended as essential content as well as a way of teaching to accomplish the current reforms, we once more need to focus on what changes are basic concerning teaching and less on it as information comprising the curriculum! It may be impossible to guide most students in the typical teacher-controlled classroom. Ideally, it means inviting and encouraging students to want/provide information to answer questions they raise. Perhaps inquiry for all teachers (and students) must exemplify what science actually is if current reforms are to succeed! Again, it starts with questions and varying attempts to answer them; by students, not teachers!

Reference

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Robert E. Yager, University of Iowa, Iowa, 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.

#17 of 40. *Allow Only Minimum Amounts of Flammable Liquids in Each Laboratory*

There seems to be a special law of nature that leads to the accumulation of chemicals in laboratories. When these chemicals are flammable, the safety of the lab's residents can be seriously compromised. Maintaining only those minimum amounts needed for the day's work is the best way to address this common problem.

The National Fire Protection Association (Batterymarch Park, Quincy, MA 02169) has developed guidelines for the amounts of flammable liquids that should be kept in laboratories. These guidelines are contained in their valuable publication #45, "Fire Protection for Laboratories Using Chemicals." Besides establishing limits for the total volume of flammables per 100 square feet of lab space, Code 45 recommends maximum container sizes and material of construction (glass, metal, etc.) for various classes of flammable liquids. Less is better.

There have been a regrettably large number of school science demonstration accidents where students have been burned. In almost all of them, the quantity of flammable liquid that was out on the demonstration bench vastly exceeded what was needed to perform the demonstration. In one case, the teacher needed about 0.5 milliliters and had a 1-gallon container on the bench.

Further Useful Resources

Virtual Genetics Lab (http://vgl.umb.edu/) An improved version of this highly successful genetics software is available. Provides for a simulation of transmission genetics that approximates, as closely as possible, the hypothesis-testing environment of genetics research.

Twig (http://twig-it.com/) Short films covering the science curriculum for 10- to 16-year-olds, accompanied by learning materials that include quizzes and lesson ideas.

Tox Town (http://toxtown.nlm.nih.gov/) Provides information on the everyday locations where you might find toxic chemicals, non-technical descriptions of chemicals, links to selected, authoritative chemical information on the Internet, how the environment can impact human health, and Internet resources on environmental health topics.

VoiceThread (http://voicethread.com/) Collect group conversations and share in one place. A VoiceThread is a collaborative, multimedia slide show that holds images, documents, and videos and allows people to navigate slides and leave comments in five ways: voice (with a microphone or telephone), text, audio file, or video (via a webcam).

Hypothesis, Prediction, and Conclusion: Using Nature of Science Terminology Correctly

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Abstract

This paper defines the terms *hypothesis*, *prediction*, and *conclusion* and shows how to use the terms correctly in scientific investigations in both the school and science education research contexts. The scientific method, or hypothetico-deductive (HD) approach, is described and it is argued that an understanding of the scientific method, which is about developing explanations for puzzling observations, is critical to an understanding of the nature of science, and that more opportunities need to be provided for school students to use it. Some advice is offered for improving science education research efforts and reports.

The terms *hypothesis*, *prediction*, and *conclusion* are often being used inappropriately in both the school and science education research contexts (Eastwell, 2010, 2012; Lawson, 2010a,b). This paper defines these terms as they apply to scientific investigations and shows how they can be used in a consistent manner across school investigations and research in both science education and science proper.

Definitions

This paper uses the following definitions:

A *hypothesis* is a proposed explanation.

A *theory* is a set of statements that, when taken together, attempt to explain a broad class of related phenomena (e.g., spontaneous generation theory, biogenesis theory, atomic-molecular theory). The distinction between a hypothesis and a theory can be somewhat arbitrary. While a hypothesis attempts to explain a specific puzzling observation (or group of closely-related observations), theories are more complex, more general, and more abstract. 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.

A *prediction* is the expected result of a test that is derived, by deduction, from a hypothesis or theory. The expected result is a logical consequence of assuming that the hypothesis or theory being tested is correct.

A *conclusion* is a statement or statements that summarize the extent to which a hypothesis or theory has been supported or contradicted by observed results.

Components of Different Investigative Reports

Table 1 contains three columns, with each column representing the core components of some different types of investigative reports. In this paper, these reports may be referred to as a column-1, column-2, and column-3 report. Let us consider each.

Table 1
Core Components of Some Different Types of Investigative Reports

Causal investigation (i.e., an explanation/reason and prediction are involved)		Non-causal investigation (i.e., no explanation/prediction involved)
Begins with a puzzling observation	Answer to non-causal question is predicted	
The Scientific Method (or Hypothetico-Deductive Approach)		*A Descriptive Study*
Puzzling Observation		
Question (causal)	Question (non-causal)	Question (non-causal)
Hypothesis or theory (proposed explanation)	Prediction (of answer)	
Prediction (deduced from the explanation)	Hypothesis or theory (reason for prediction)	
Test (method)	Method	Method
Results	Results	Results
Discussion and Conclusion	Discussion and Conclusion	Discussion and Summary (of results)

The Scientific Method

Of the three investigative approaches reflected by the columns shown in Table 1, it is the column-1 approach that has the most to offer school students in terms of facilitating an understanding of the nature of science. The approach is called the scientific method, or hypothetico-deductive (HD) approach (Lawson, 2000, 2005, 2010a, 2010b), and the steps that comprise it 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?).
3. One or more **hypotheses or theories** (i.e., proposed explanations) are advanced to answer the causal question.
4. A **prediction** is generated from each hypothesis, based on the assumption that the hypothesis or theory is correct.
5. A **test** is designed and conducted to check on each prediction.
6. The **results** of the tests are obtained.
7. The results are compared with the prediction from each hypothesis or theory and a **conclusion** is made as to whether the results of the test support or contradict the

hypothesis or theory. In the event that the one or more hypotheses or theories are contradicted, and the deductions of the predictions and the tests appear to be sound, there is the need to return to Step 3 and consider a modified, or new, hypothesis or theory. In this way, the scientific method becomes a cyclic process. Also, even if supported by multiple tests, a hypothesis or theory can never be proven absolutely correct because (a) subsequent evidence could always contradict it and (b) two different explanations may lead to the same predicted result.

Consider a classroom example. In the well-known activity of inverting a jar over a burning candle that is standing in water, students observe that the water level inside the jar is higher after the candle goes out than it was before, and are asked why the water level rose. They are invited to generate hypotheses (i.e., proposed explanations) for this puzzling observation that might include the following:

- Oxygen in the jar is used up, leaving a void into which the water rises.
- The burning process produces water vapour, which condenses and adds to the water inside the jar.
- While oxygen is used up, carbon dioxide is produced. However, the carbon dioxide produced dissolves in the water and creates a void.
- Smoke collects in the jar and attracts (pulls) the water up.
- The candle's heat energy causes the air around it to expand. After the candle goes out, the air cools, air pressure is reduced, and the water is pushed in by the greater air pressure outside.

Students can test each hypothesis by checking on one or more predictions that follow from it. For example, if the first hypothesis (i.e., oxygen is used up) is correct, then one would predict that using two candles would produce the same rise in water level inside the jar as when one candle only is used, because the amount of oxygen inside the glass is the same in both cases. When this test is performed it will be noted that the water actually rises higher when two candles are used, thus contradicting the hypothesis. Indeed, of the five hypotheses listed above, it is only the last one (i.e., the heating and cooling of the air inside the glass) that is supported by the results of testing. This explanation correctly predicts the effect of using more than one candle and, in another test, also predicts that bubbles due to expanding air should be seen as the jar is placed relatively swiftly over the burning candle, which is just what is observed.

We can now appreciate the importance of the scientific method to the field of science. At its core, science is about seeking explanations for natural phenomena and it is the scientific method that provides the mechanism for doing so. The scientific method is therefore central to the way science is done and to the way the field of science progresses, and an understanding of the scientific method is fundamental to an understanding of the nature of science. Let us not be side-tracked by those who would prefer to dismiss the notion of a scientific method (e.g., Osborne, 2011).

However, if the scientific method needs to be understood and honoured, how curious it is that school students are not being provided with opportunities to use it! Science textbooks generally outline the scientific method (or HD approach) at the beginning, stress how important it is, but then never provide opportunities for students to use it after that because the investigative questions posed throughout the text are non-causal ones, the treatment of which this paper will now proceed to address. This is surely no way to effectively communicate the centrality of the scientific method to how science is done and progresses as a field.

What is needed, then, is the more explicit and frequent use of causal questions in science classrooms, and this is not difficult to achieve. We need to look for opportunities for students to begin investigations by asking causal questions about puzzling observations. One technique is to simply take a common, non-causal question such as “does a seed require light to germinate?” and present it in the causal form of “why does a seed germinate?” or “what causes a seed to germinate?” Of the hypotheses that students might investigate, the need for light could be one, and one that would be contradicted by testing. Or, 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.

A Descriptive Study

Research questions may be categorized as either causal or non-causal. A causal question asks about the cause of a puzzling observation and examples are “why do the plants grow much better here than over there?” “why does a basketball go flat when used outdoors in winter?” “why does our local climate change?” and “why does the interest and enjoyment of students being involved in science change during the early years of secondary school?” Causal questions are answered using the scientific method discussed in the previous section.

In contrast, the type of investigative report represented by column 3 of Table 1 begins with a non-causal question and is found commonly in both school science and science education research. Examples are “what types of structures does a flower have?” “how does the solubility of this chemical vary with changing temperature?” “does eating spicy food cause your body temperature to rise?” and “how does the interest and enjoyment of students being involved in science change during the early years of secondary school?”

Because a hypothesis is a possible explanation, and a column-3 report does not contain an explanatory component, a hypothesis will not feature in such a report. It follows that a prediction and conclusion will also not feature in the report, because both depend on the existence of a hypothesis (or theory). An investigation such as this, which does not involve the generation of one or more hypotheses, is called a descriptive study. I have previously been critical of descriptive reports in science education that include both Results and Conclusion headings (Eastwell, 2012) because this creates confusion that can also easily lead to unnecessary repetition under these headings.

A Column-2 Report

Another common report format found in both school science and science education research is represented by column 2 of Table 1. Like in a descriptive (column-3) report, it begins with a non-causal question but sees the investigator making a prediction about the results of the investigation (i.e., predicting the answer to the non-causal research question) and providing a reason (a hypothesis) for this prediction before collecting data. While a hypothesis is a proposed explanation and can be generated in response to a puzzling observation (column 1 of Table 1), a hypothesis is also generated when one is asked to provide a reason for a prediction (Lawson, 2010a).

A major problem with the use of the column-2 approach is the failure of authors to distinguish between a prediction and a hypothesis (Eastwell, 2010; Lawson, 2010a,b). In particular, the term hypothesis is being used to describe what should be called a prediction. Note also that a conclusion is appropriate in a column-2 research effort, because the results of the investigation are used to determine whether the reason for the prediction (i.e., the hypothesis) has been supported or contradicted.

While it is fine for students to be asked to predict the answer to a non-causal question and provide their reasoning, I see no place for students being asked to make a guess about the outcome of such an investigation. So, if they are unlikely to have a conceptual base that is sufficient to allow a prediction to be made, they should be asked to use a column-3 (descriptive) approach. The same applies to students whose reasoning for making a prediction is along the lines of "I have heard the weatherperson say that such and such is the case" or "I have seen this before," as these are not reasons based on scientific conceptual reasoning.

Tying it all Together

It is instructive to analyse the scientific method (column 1 of Table 1) a little deeper and find that column-2 and column-3 investigations/reports are actually embedded within it. Consider what the fifth and sixth steps of the scientific method, namely designing and conducting a test and collecting the results, involve. As an example, let us return to the jar-over-the-burning candle activity and the testing of the hypothesis that the water inside the jar rises because oxygen in the jar is used up, leaving a void into which the water rises. The test of this hypothesis that requires checking on the effect of using more than one candle can be viewed as comprising the following steps:

- Ask the implicit, non-causal question "what effect will using more than one candle have on the height to which the water rises inside the jar?"
- Method
- Results

But these steps are the same as those of a column-3, descriptive study! What is more, in a column-2 report the investigator predicts the answer to a non-causal question and provides a reason for making the prediction before the investigation is performed, and this process maps onto Steps 3-7 of the scientific method (column 1). So, when viewed in this elaborated way, it appears that the scientific method is all we effectively need to represent scientific investigations, as long as we acknowledge that every investigative report need not contain all the steps, with different types of reports drawing on different subsets of the steps. It is this overarching applicability of the scientific method that causes me to present its steps in bold font in column 1 of Table 1.

The prominence of the scientific method in this discussion is no surprise. It is a pattern of reasoning that is not specific to science (Lawson, 2010a) and really just reflects the common-sense reasoning that humans use, even if implicitly, in their everyday lives. Our brains appear to be hard-wired for it. Importantly, it is the pathway to the development of shared knowledge. I say shared knowledge because, when it comes to ways of knowing, it appears to me that there are both shared and personal ways of knowing, but this is another story!

It may also be useful to point out that an investigator can enter the scientific method (column-1) process at any point; "as the person who initially made the puzzling observation, the person who came up with the proposed explanation, the person who figured out how to test it, the person who actually conducted the test, or perhaps the person who was able to analyze the results and draw a conclusion. The person could be the same one in all steps, different in all steps, or any other combination of these" (A. Lawson, personal communication, July 16, 2012).

For Science Education Researchers

While school science investigations are typically contrived, science education researchers can take the opportunity to report their research in a far more authentic way. The non-causal questions that are the focus of column-3, descriptive studies do not typically "appear out of the blue." Placed in the broader context, such questions usually have roots in attempts to explain puzzling observations (i.e., they are part of column-1 thinking), so where practicable researchers are urged to spell out the background to descriptive studies by specifying the underlying puzzling observations and hypotheses. This will result in far more genuine and complete reports.

Further, rather than regarding a column-3, descriptive study to be finished when the results of the investigation have been summarized, a researcher would do well to regard the results as a puzzling observation to be explained and, where practicable, proceed to implement the scientific method (column 1). This will involve the generation and testing of a hypothesis, a conclusion, and possibly even alternative hypotheses, predictions, and future planned tests. This would also add much to the completeness of a research effort. The results of a column-2 report, in the circumstance where the results conflict with the prediction that was made initially, can similarly be treated as a puzzling observation.

Summary

The main points made in this paper are:

- It is important that investigators correctly distinguish the terms *hypothesis* and *prediction* and recognize that a descriptive study requires neither.
- An understanding of the scientific method, which is about developing explanations for puzzling observations, is critical to an understanding of the nature of science, and more opportunities need to be provided for school students to use it.
- For an investigation that involves a hypothesis or theory (i.e., an explanation/reason) and a prediction, a conclusion is needed. On the other hand, an investigation that does not involve an explanation/prediction (i.e., a descriptive study) requires results only (no conclusion).

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The Magic of Science Through the Science of Magic

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Abstract

Magic tricks produce awe and wonderment. Why not use magic as a pedagogical approach? This paper presents the magic of science through the science of magic.

Abracadabra! Have you disappeared? Well, if the text below has not disappeared and you're still interested in adding a little magic to your courses, this paper might be just what you're looking for. In this paper I will share with readers the fun of creating and using magical demonstrations. To be able to use magic in your classes, I will show a simple way to convert good in-class demonstrations into awesome magic tricks. To illustrate the procedure, I'll describe how I transformed a couple of classical demonstrations into magic tricks that I have presented in classrooms and to many groups of science teachers.

Thwarted Expectations

Lady Astor is said to have once told Sir Winston Churchill: "If I were your wife I would put poison in your coffee!" To which Churchill answered: "If I were your husband I would drink it!" Churchill's reply is funny mainly because it is so unexpected. Thwarted expectation can give rise to interest and humour. Think about that B movie where the end was so predictable; not so interesting. Magicians make spectacular uses of unexpected events. Where does that leave the science teacher?

Good science demonstrations also reveal things that are unexpected. For instance, the outcome of a demonstration can be unexpected because of some student misconception. One knee-jerk reaction may be to explain away any misconceptions; but that may result in a demonstration that becomes expected or predictable. The magic proposal is different. Teacher-magicians build up an expectation and use the unexpected observation to engage students and maybe even feign magical powers. These magic tricks require no sleight of hand: the trick is only in the heads of those who find the demonstrations unexpected. There are many common misconceptions in science (Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhammer, 1992; Vosniadou & Brewer, 1992) that result in a variety of possible unexpected observations. This means that many of these demonstrations that result in unexpected observations can be dressed up as magic tricks.

Why Modify Demonstrations?

A demonstration can liven up a lecture. Students seem to perk up and pay closer attention. However, a study conducted at Harvard suggests that students simply observing a demonstration learn no more than those who have not seen the demonstration at all (Crouch, Fagen, Callan & Mazur, 2004). To be effective, students must be actively engaged during the demonstration. Effective demonstrations engage students by requiring them to make predictions about what will happen before they see the demonstration (Sokoloff & Thornton, 2004). Students become engaged and usually develop a vested interest in the outcome (i.e., "will I be right?"). If the outcome differs from their prediction, students pay closer attention to the outcome and try to figure out why they were wrong.

Magic demonstrations engage students differently. Instead of asking students to predict the outcome, the magician-teacher builds the demonstration around an incorrect expectation. Magic demos build on this incorrect expectation to maximize the effect of the unexpected observation. When the tension and drama are properly built into the trick, students become engaged: they pay close attention to the unexpected outcome and will try to figure out what is happening.

Making a Demonstration Magical

Two demonstrations are now presented: the double conic roller demonstration (center of mass) and the disappearing Pyrex in mineral oil (refraction). While these demonstrations may be familiar to seasoned teachers, the purpose here is to show a different mode of presentation; that is, not to sell the "salad" but its "dressing."

The Double Conic Roller

Among the great center-of-mass demonstrations available from most laboratory equipment providers is the double conic roller that is placed on an inclined wedge (Figure 1). When a pen is placed on the high side of the wedge (the left side in Figure 1), it rolls down the incline. However, when the wooden double cone is placed on the lower side of wedge (the right side in Figure 1) it rolls "up" the incline! How does that happen?

Figure 1. The double conic roller. The pen rolls down the incline from left to right. However, the double cone rolls from right to left, sinking inside the wedge.

The center of mass (COM) of both objects actually goes downwards as they roll. The COM of the pen follows a path parallel to the surface of the incline. However, the COM of the double cone is higher where the wedge is narrower (on the right in Figure1), even though this seems to be the lower end of the incline. The roller "sinks" into the wedge because the wedge becomes wider as the cone moves from right to left in Figure1. This gives the impression that the double cone rolls up the incline. In fact, it is rolling down into the wedge. Both objects fall in opposite directions: the pen moves down along the incline while the double cone seems to move up the incline (but really sinks into it).

Dressing up the demonstration as a magic trick. The inclined wedge and double cone are shown to the class. The cone and wedge are handed to 1 or 2 students for inspection, to make sure that there are no gimmicks (students often look for magnets). The teacher-magician shows students that one side of the inclined wedge is higher and lets a pen roll down from the top of the incline. With a deep breath and tremendous concentration, the teacher-magician explains that, with the mind's power, telekinesis will be performed, and the double cone will be dragged up the incline, against gravity! (Drum roll…) The double cone is then released from the lower end of the incline and it rolls "up" the incline!

As the double cone proceeds up the incline, the instructor's hands precede it as if magically pulling it upwards. When the double cone reaches the top, the instructor needs to quickly pick it up, because the "trick" would be spoiled if the cone just stayed there for some time. A long sigh is released, indicating that a tremendous mental effort was expended.

Students usually ask that this trick be performed again. The trick should be repeated once or twice, so that students can shift their focus to different aspects of the demonstration. Students often offer hypotheses (i.e., proposed explanations). These can be explored or systematically tested. The class is asked to debunk the trick through a structured inquiry process.

Deconstructing the demonstration. In this demonstration, a pen is rolled down an incline to show that one side is higher than the other. However, because the incline is also wedge-shaped, the lowest point for the double cone is inside the wedge. This demonstration forces students to rethink the concepts of high and low. The direction an object falls is only related to the path of its center of mass, not the contact surface it rolls along. Thus, two objects on an identical surface may have different "highs" and "lows" and may therefore fall in different directions. This observation is sufficiently interesting and unexpected to get students to wonder and ask about how things fall.

Pyrex and Mineral Oil: Now you see it, now you Don't

A Pyrex rod or test tube disappears when submerged in mineral oil because both have highly similar refractive indices. The same Pyrex tube is clearly visible in a beaker of water. Usually, this demonstration is used to illustrate the concept of refraction (or lack thereof) after the topic has been introduced.

Figure 2. A Pyrex rod becomes invisible when submerged in mineral oil because Pyrex and mineral oil have highly-similar refractive indices.

Dressing up the demonstration as a magic trick. A relatively-large beaker containing mineral oil is displayed. The instructor adds some more oil from an unidentifiable bottle while telling students that this is a "magic" liquid: This liquid binds broken pieces of glass back together!

The teacher-magician takes a Pyrex test tube and, after carefully wrapping it (usually in thick, brown, lab paper), proceeds to shatter the tube with a hammer. The teacher-magician then pours the Pyrex fragments into the beaker with magic liquid that, unbeknown to students, has a hidden, intact Pyrex tube submerged. The teacher-magician stirs and pulls out a fully "repaired" Pyrex tube! Note that, depending on the length of available test tubes, these may need to be first shortened by cutting to allow one of them to be fully immersed in the oil.

Note that a pair of tongs is necessary to navigate the sharp fragments and grasp the previously-inserted whole test tube. When the seemingly repaired Pyrex tube is pulled out, students are asked what they think: is it possible? Students usually volunteer explanations that can be tested. They are then guided through an inquiry cycle where the concept of refraction is constructed and the magic trick debunked.

Deconstructing the demonstration. Disappearing tricks are the bread and butter of professional magicians. What makes an object visible is the way it reflects or bends light. This demonstration shows that if two objects bend light in the same way (i.e., they have similar indices of refraction) then you cannot tell them apart. Most students do not believe that stirring Pyrex fragments in a fluid will weld them back into place. It is useful to combine the unexpected observation with students' incredulity as a means to explore what really happened and introduce the concept of refraction.

Summary and Conclusion

Many classical demonstrations can be turned into magic tricks. The first thing to do is to find a demonstration that is interesting because it produces an unexpected observation (e.g., lying down on a bed of nails will not hurt you). Then teacher-magicians can build up an expectation (e.g., nails are sharp, dangerous objects: pretend fearing nails, drop an apple on a bed of nails and pull it out punctured). Playing-up an expectation maximizes the effect of the unexpected observation. Finally, perform the magic demonstration (e.g., lying comfortably on a bed of nails) and wait for students to start asking questions!

I often view my mandate as a science teacher quite broadly: My goal is to get students to ask about the world that surrounds them. As best put by Marcel Proust, "the real voyage of discovery consists not in seeking new landscapes but in having new eyes." Like most science teachers, I take great joy in seeing students wonder and ask about the simple things most people take for granted. Magic is my preferred way to get students to wonder and ask about simple things.

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