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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Strongest Fibre

Dyneema, the trade name for extremely long-chain polyethylene that is also called high-performance polyethylene (HPPE), is considered the strongest fibre in the world. It is 15 times stronger than steel and up to 40% stronger than Kevlar, the polymer from which bullet-proof vests have traditionally been made. At the same time, it is a lightweight material. Having a density less than that of water, Dyneema floats on water.

Teaching Ideas

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

Ball's Up

This technique may be used to select a student for a task, such as reporting back to the class on his or her group's deliberations or to answer a teacher-prepared question, or to select a revision question for a student to answer. Using an ink marker, divide the surface of an inflatable, plastic beach ball into numbered panels (e.g., 1-32, to cater for a class of up to 32 students). Number the students in the class using corresponding numbers. You may be fortunate enough to find a ball that already has suitable, but not yet numbered, panels marked on it.

At the cry of Ball's Up by the teacher, the ball is thrown to a student who notes the number that his or her right thumb is touching. This number identifies the student who is then called upon to report back to the class or to answer a question. Alternatively, rather than identifying a student, the resulting number can be used to identify a question, from a list of revision questions prepared by the teacher, for the catcher to answer. While students should be led to believe that each number matches a specific question, this need not be the case, allowing the teacher to differentiate by choosing a question from the list that better suits a particular student.

Adapted from: Lock, R. (2008). The ball's up at the end of the lesson: Plenary fun with a vinyl football. *School Science Review*, *90*(330), 19-21.

Conservation of Mass

Evaluate the following procedure for verifying the law of conservation of mass during a chemical reaction:

Add some vinegar to a flask and some baking soda to a balloon. Stretch the opening of the balloon over the opening of the flask, allow the balloon to rest by the outside of the flask (i.e., the baking soda and vinegar are not mixed), and use a balance to determine the total mass of the set-up. Next, lift the balloon so that the baking soda falls into the vinegar, watch the balloon expand (as carbon dioxide gas is produced), and note the new balance reading after the reaction has ceased. Compare the before and after balance readings.

While such a methodology is commonly suggested to verify the conservation of mass during a chemical reaction, it is flawed because the final balance reading (the apparent final mass) must always be less than the original balance reading (Sarkar & Frazier, 2008). In fact, in the presence of excess vinegar, the apparent mass decrease will be proportional to the amount of baking soda used. Students might also incorrectly interpret the observed difference in terms of leakage of gas or experimenter error.

A decrease in balance reading should be expected under these circumstances, because a buoyancy effect is at play. As the balloon increases in size, it displaces more air in the atmosphere in which it is immersed and, in accord with Archimedes' principle, experiences an increasing buoyant force or upthrust. In normal air, this buoyancy effect produces an apparent mass decrease of 1.3 g for every litre of air that an object displaces.

An improved methodology would be to conduct the chemical reaction in a rigid reaction container that does not change size as the reaction proceeds and that can also withstand the increase in pressure due to the production of carbon dioxide gas, such as a 2-L soft drink bottle to which 20 g of vinegar and 2 g of baking soda are added. Initially, the vinegar can be kept from mixing with the baking soda by placing it in an open test tube that is standing up inside the bottle. Alternatively, with more advanced students this activity could be used as a discrepant event to stimulate student thinking about experimental design.

Reference

Sarkar, S., & Frazier, R. (2008). Conservation of mass and an unsuspected buoyancy effect. *Science Scope*, *31*(9), 52-55.

Students' Alternative Conceptions: Ultraviolet Radiation and Skin Protection

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:

a. Blistering sunburns during childhood can cause melanoma to develop later in life. (*True*. Overexposure to solar radiation can damage skin cells.)
b. The ozone layer blocks all forms of ultraviolet radiation (UVR). (*False*. There are three kinds of UVR, characterized by their wavelengths. Ultraviolet A radiation (UVA) has the shortest wavelength (320-400 nm) and is not blocked or absorbed by the atmosphere. UVB (290-320 nm) rays are only partially blocked by the atmosphere. UVC (100-290 nm) radiation is absorbed by the atmosphere.)
c. Overexposure to UVR can cause skin cancer, eye damage, and skin ageing. (*True*. UVR is carcinogenic.)
d. Sand, water, and snow have the ability to increase the Sun's intensity. (*True*. Each of these can act like a magnifying lens to intensify and reflect radiation.)
e. The greatest risk of sunburn comes during the hours 10 a.m. to 4.00 p.m. (*True*. Solar intensity is greater during this time period.)
f. UVR increases with altitude. (*True*. At higher altitudes, there is less atmosphere to absorb UVR.)
g. Sunscreens protect against all types of UVR. (*False*. Most sunscreens protect against UVB and contain zinc oxide and titanium oxide. However, broad spectrum sunscreens may provide protection against UVA and will contain chemicals such as avobenzone, octocrylene, oxybenzone, or Mexoryl.)
h. A sunscreen with a Sun protection factor (SPF) of 30 offers twice as much protection as one with an SPF of 15. (*False*. In general, the SPF refers only to the percentage of protection from UVB. While a product with an SPF of 30 will block 97% of harmful radiation, one with a SPF of 15 will screen out 93%.)
i. The active ingredient in sunscreen that blocks UVR is aloe. (*False*. The active ingredients commonly found in sunscreens are shown in Item g above.)
j. People with a dark complexion, or already having a tan, do not need to use sunscreen. (*False*. All people should use sunscreen, regardless of the tone of their skin.)
k. You do not need to apply sunscreen on an overcast day. (*False*. Clouds do not screen out all of the UVR that causes sunburn.)
l. If you do not enter the water, there is no need to reapply sunscreen. (*False*. Sunscreen should be reapplied 90 minutes after initial application, or sooner. This recommended time may vary with the length and intensity of solar exposure.)
m. The effectiveness of a sunscreen decreases beyond its expiry date. (*True*)
n. UVR does not penetrate glass. (*False*. Glass does not block all types of UVR.)
o. The American Academy of Dermatology advocates that the use of UV devices such as sunlamps, sun beds, and tanning beds should be banned for all but medical purposes. (*True*)

U. S. Environmental Protection Agency (2009) aims to educate about protecting ourselves from overexposure to the Sun. The content of the website includes lesson plans, videos, interactive maps, and PowerPoint downloads.

Reference

U. S. Environmental Protection Agency. (2009). *SunWise program*. Retrieved from http://www.epa.gov/sunwise/ .

Source: Farenga, S. J., & Ness, D. (2008). Developing Sun sense: Learning about protection from the Sun's rays. *Science Scope, 31*(9), 64-66.

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 Heart

We've focused on anatomy
In science class of late
It's been quite fascinating
I'm sure you can relate.

We've learned about the liver
It's function and position
The pancreas and kidneys
Each with their unique mission.

But of all the body's organs
The one that stands apart
As vital above all the rest
Must be the human heart.

It's not that it's the largest
In fact, it's quite compact
Each formed to fit its owner's chest
Fist-sized to be exact.

The heart is an organic pump
In fact it's two in one
It takes blood from the body
Back up to the lungs.

It does the opposite as well
As it works in dual mode
It powers the body's systems
With oxygen its load.

But while we've learned its structure
And of its chambers four
It has another function
That we all cannot ignore.

It has a special purpose
Distinct from the above
The heart's the only organ
In the body that can love.

Jack Burnham, 14 years
Australia

Editor's Note: This poem reflects the myth, initiated by Aristotle and Plato, about the roles of the brain and heart mentioned in "Myths Associated With Brain-Based Research" on p. 77 of this issue.

Ideas in Brief

Ideas from key articles in reviewed publications

Myths Associated With Brain-Based Research

Myths about learning have a long history. For example, Aristotle and Plato initiated the idea that while the brain controls our cognitive processes, it is the heart that controls our emotional processes, and this myth lingers in our language in the form of sayings such as “capturing hearts and minds.” Our understanding about how the brain works is increasing at a phenomenal rate, and myths about the application of brain-based research to the classroom may arise as a result of the oversimplification and over-interpretation of research findings, or even the desire to capitalize on often tentative research conclusions for monetary gain.

As an exercise, try to identify the myths in the following list:

a. Caffeine acts as a “pick-me-up” and improves alertness.
b. We use only 10% of our brain’s capacity.
c. Pupils are visual (V), auditory (A), or kinaesthetic (K) type learners.
d. Children need an enriched environment in the early years.
e. If we do not use our brain cells we lose them.
f. Students are left- or right-brained thinkers.
g. Brain Gym stimulates neural mechanisms.
h. An adult working memory can hold about seven facts.
i. There are critical periods of learning.
j. Functional magnetic resonance imaging (fMRI) shows neurons firing and hence thinking and learning.
k. Our capacity to learn is limited by our working memory.
l. The influence of the amygdalae ensures that everything has an emotional context associated with it.

Crossland (2008) suggests that all except the last two statements are myths. Detailed explanations relating to some of these statements may be found at Teaching and Learning Research Programme (n.d.). Like some of the others, Statement c has a kernel of truth, but as it stands it is a myth. References containing explanations related to the other statements may be found by typing the key words into a search engine.

References

Crossland, J. (2008). The myths surrounding ‘brain-based’ learning. *School Science Review, 90*(330), 119-121.
Teaching and Learning Research Programme. (n.d.). *Neuroscience and education: Issues and opportunities.* Available from http://www.tlrp.org/pub/commentaries.html .

Research in Brief

Research findings from key articles in reviewed publications

Museum Class Visits: Structuring the Experience

By: Yael Bamberger, University of Michigan, Ann Arbor, MI, USA yaelbamb@umich.edu

School visits to museums are a good opportunity for science learning through experience. The “Three Co’s”--*Co*nnecting knowledge, *Co*mmunicating knowledge, and *Co*ping with knowledge--are fundamental, research-based ideas for the development of meaningful science learning experiences in museums (Bamberger & Tal, 2007, 2008). Based on the Three Co’s, the following suggestions for structuring the museum experience were developed.

Connecting Knowledge

To prior knowledge. Connecting knowledge is strongly related to learning for understanding, and is thus an important component of meaning-making. Therefore, scholars emphasize the importance of connecting the museum experience to the school science curriculum, and highlight the importance of good preparation and follow-up activities in school. The teacher may embed the visit at the beginning, or in the middle, of a new curriculum unit, and should first equip the students with concepts they will face in the museum. For example, in school before the visit, the teacher may invite the students to look at a map of the museum or take a virtual tour in the museum's website. Exhibits to explore should be marked. In addition, many museums’ websites provide pre-visit activities that can be completed in class independently or in small groups, with some direction from the teacher. During the visit, a museum task can probe for previous in- and out-of-school experiences. The teacher should direct students in making connections between the museum experience and the content they learned in school, as well as general knowledge. For example, teachers may encourage students to come up with questions that relate the experience to the science done in school.

To personal experiences. Students often connect the museum experience to their own life experiences, although the museum activities usually do not direct this connection. These connections to the personal experiences are not forgotten over time, and the teacher may address the personal context of the visit in the follow-up activity. Teachers can invite students to go beyond the specific scientific content of the curriculum and share with the class any personal experience, related to their past or everyday lives, that the visit was connected with. For example, students can share their personal experience with the class by making presentations in small groups that focus on an object or an exhibit they explored and found interesting.

Communicating Knowledge

With adults. The teacher has the important role of mediating the museum experience for her students. The teacher is the only adult who knows the scientific content knowledge of the exhibition, the students’ prior knowledge, and the class social climate. Therefore, throughout the visit and exploration, the teacher should be actively involved with the students, drawing connections between school science and the museum exhibits and encouraging social interactions that could promote learning.

With peers. Peer interactions that promote learning are one of the most common outcomes of museum visits. Students and visitors consider the opportunities for sharing knowledge and thoughts as one of the enjoyable aspects of the visit. Hence, exhibits that are designed to enhance discussions among visitors are preferable. Examples of ways to enhance discussion include using comment cards or creating labels that include questions in addition to information. The teacher might direct students to explore in pairs or groups, by working on a common task, drawing what they see, and discussing questions that arise. In addition, live organisms are particularly good at evoking learning discussions and emotional engagement. Therefore, a teacher can direct students to explore live animals exclusively or in addition to other exhibits.

Coping With Knowledge

Interest, motivation, choice, and control. Learning in museums is based on curiosity, intrinsic motivation, choice, and control. All of these components are essential for developing lifelong learning skills. Actually, activities that provide limited choice--not free-choice exploration, with no limitation or direction, nor no-choice expository activities, like in a traditional classroom--develop the students' natural curiosity into substantial learning. Such tasks enable students to control their learning and suggest a variety of levels and opportunities for choosing what and how to explore. Limiting the choice possibilities to specific objects, subjects, or areas for exploration helps to direct students towards what to focus on, while still providing opportunities for choice and control of their own learning. Hence, in the museum, the students would explore the particular exhibit or exhibits for which they were prepared. Leading worksheets can also assist to direct learning, as can students' own questions developed during the pre-visit preparation. Such tasks enable students to control their learning and provide a variety of levels and opportunities for choosing what and how to explore. Students can thus be directed without losing their curiosity and interest.

References

Bamberger, Y., & Tal, T. (2008). Multiple outcomes of class visits to natural history museums: The students' view. *Journal of Science Education and Technology*, *17*, 274-284.

Bamberger, Y., & Tal, T. (2007). Learning in a personal context: Levels of choice in a free-choice learning environment in science and natural history museums. *Science Education*, *91*, 75-95.

Creationism is Alive and Well in American High School Biology Classrooms

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Despite decades of science education reform, numerous court rulings declaring the teaching of creationism (including "intelligent design") to be unconstitutional, numerous denunciations of "creation science" by professional scientific organizations, and the overwhelming evidence for evolution, creationism remains surprisingly popular in high school biology classes in the United States. Indeed, a variety of studies conducted throughout the U.S. for several decades have shown that 20-35% of biology classes include creationism.

Moore (2008) recently examined what, and how, creationism is covered by high school teachers who teach creationism. He surveyed 1,465 students from throughout the U.S., and particularly from Minnesota, about their high school biology classes and found that although most students' classes included evolution but not creationism, 24% reported that their high school classes included both evolution and creationism (22% included neither evolution nor creationism, and 3% included creationism but not evolution). Most (54%) students whose high school biology course included creationism reported that creationism was presented as a scientific alternative to evolution, and only 22% reported that creationism was presented as another explanation (not necessarily scientific) for life's diversity. Only 2% of the students reported that creationism was presented as a religious explanation for life's diversity.

There are innumerable creation stories; virtually every religion has one. Nevertheless, 83% of the students whose biology course included creationism reported that only the Christian story of creation was presented in their course. For comparison, only 2% reported that the course included the Islamic story, 1% the Hindu story, and 1% the Native American story. Approximately 13% claimed that their course's presentation of creationism included a generic creation story or several creation stories.

There are several "take home" messages from this study:

1. Creationism is alive and well in many U.S. high school biology classrooms.
2. Teachers who teach creationism are either unaware that doing so is unconstitutional and/or believe that telling students about their particular religious beliefs (but not other religious beliefs) is justified regardless of the law.
3. For most teachers, teaching creationism is teaching Christianity. The Christian creation story is usually presented as science. Other creation stories are usually ignored, implying that they are trivial or false.

Reference

Moore, R. (2008). Creationism in the biology classroom: What do teachers teach, and how do they teach it? *The American Biology Teacher*, *70*(2), 69-73.

Scientific Inquiry as Experienced by New Zealand Students: Two Case Studies

By: Anne Hume and Richard Coll, University of Waikato, New Zealand
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Scientific inquiry, where students have the opportunity to experience the procedural and conceptual knowledge required to carry out investigations like scientists do, has re-emerged as an emphasis in new science curricula that attempt to paint a more authentic picture of science (Carr et al., 2001). However, the international literature on the nature of inquiry-based learning experienced by students today suggests that practical work in school science bears little resemblance to inquiry as practised by scientists (e.g., Chin & Kayalvizhi, 2002; Hipkins et al., 2002; Nakhlel, Polles, & Malina, 2002).

Hume and Coll (2008) investigated the reality of classroom-based inquiry learning in science in the context of the New Zealand Science curriculum (Ministry of Education, 1993) that sought to promote students' engagement in authentic inquiry. The case studies were set in two large New Zealand secondary schools, River Valley Boys' High School and Mountain View High School (both pseudonyms). These studies involved Year 11 science classes where 15 to 16-year-old students were learning how to perform investigations for Science Achievement Standard 1.1: Carrying out a practical investigation with direction (SAS 1.1) towards their National Certificate of Educational Achievement (NCEA). The Year 11 context was chosen because, for many NZ students, this is their last opportunity for formal schooling in science, and likely to be a time when they form lasting impressions of the nature of scientific inquiry. These ideas and beliefs could have implications for their scientific literacy as future citizens, in terms of the extent to which they understand and appreciate the ways scientists work to produce scientific evidence, solve problems, and build knowledge. In each case study, the research focused on the learning experiences of a small group of 4-5 students.

The Findings

The findings revealed some minor variation in the overall timing and duration of the teaching and learning sessions at the two schools, but strong parallels in the sequence, pedagogy, and content of lessons. Each teaching and learning sequence could be divided into three distinct phases that were common to both schools: The preparatory phase (instructional sessions), the practice phase (the formative assessment), and the formal assessment phase (the summative assessment).

The preparatory phase. In this first phase, students in both classrooms were introduced to the requirements of SAS 1.1 and key concepts and skills associated with investigating relationships between two variables. Lesson content in these largely instructional sessions focused on:

- Terms, definitions, and procedures to do with fair testing.
- Specific skills such as making observations and measuring, tabulating and averaging data, plotting graphs, and the planning and reporting of fair tests using templates.
- How to meet the assessment requirements of SAS 1.1 as depicted in assessment schedule exemplars provided by the NZ Qualifications Authority (NZQA), the national governing body for qualifications in NZ.

The practice phase. In the second phase, students at both schools participated in a mock assessment known as the formative assessment, designed to give students practice at performing a whole investigation under test-like conditions. There were many commonalities in the formative assessment that occurred in the two case studies, as follows:

- The mock assessment took place over four lessons, with each lesson covering, in turn, the planning, data collecting, reporting, and feedback stages of the investigation.
- The science context for the investigations was the same (both teachers used the same exemplar materials for investigating the effect of factors such as temperature or concentration on the rate of reaction between magnesium metal and hydrochloric acid).
- Students worked in teams of 4 for planning and data gathering, but as individuals for the reporting.
- The format, timing, and reporting requirements of the mock assessment activity closely matched those of the summative assessment in Phase 3.
- Teacher direction was highly evident, including extensive and targeted feedback for students related to the assessment schedules for the task.

Formal assessment phase. In the third phase for their formal assessment, known as the summative assessment, students again performed fair test investigations in groups along similar lines to the practice investigation in the second phase. They initially planned as individuals, then collaborated as a group to produce a single plan and obtain data, and finally wrote up the reports individually. The planning and reporting templates were virtually identical in the two schools. However, the science contexts for the investigations were different. Students in the study group at Mountain View planned and executed their investigation with relative ease, whereas the study group at River Valley experienced difficulties carrying out their plan to investigate the relationship between the length of a pendulum and its period (i.e., the time taken to complete a full swing). They were unable to operate the pendulum successfully and consequently could not record sufficient data. However, they were very savvy of assessment techniques and showed adeptness at "playing the system," as the following excerpt shows:

> Within the closing stage of the practical session, the group scrambled to complete and record sufficient runs for their data processing and interpreting phase. The 4 group members frequently interchanged roles as they took it in turn to record their own copy of the results (which they needed for the write-up in the following session). All other groups had finished their data collection and were listening as Jenny (pseudonym for the teacher) covered points for the write-up. Martyn, Peter, Mitchell, and Eddie (pseudonyms) continued operating their pendulum and consequently missed hearing what Jenny was saying during her briefing. In their rush to finish, confusion set in: “Is this the third or fourth one?” asked Mathew, who was recording and calculating. When the pendulum continued to collide with the support arm, Peter commented “You’ll have to estimate,” while Eddie was convinced they should “make up the rest.” Mitchell agreed: “Lets make up the rest, and take 16 seconds as the average.” Martyn confirmed: “It will still give us our results.” Each group member had a complete set of written data by the end of the practical. Jenny allowed the class to view the background science notes before the end of the period before collecting in all papers to retain overnight. (Hume & Coll, 2008, p. 1213)

At the last minute, the students resorted to recording their remaining results from non-existent data and then used these fabricated results to complete the reporting section of the assessment.

The findings did demonstrate that some purposeful and focused learning was occurring, but students were acquiring a narrow view of scientific inquiry where the thinking was characteristically rote and low-level. The nature of this learning was strongly influenced by curriculum decisions made by classroom teachers and science departments in response to the assessment requirements of the high stakes NCEA qualification. At both schools, many decisions to do with classroom practice were not made by the individual teachers, but were made collectively at departmental level in the form of departmental guidelines. These guidelines were based on recommendations, including exemplary materials from the NZQA, that departments and classroom teachers were obligated to follow under school accreditation requirements. Thus at both schools, the content of departmental guidelines was very similar, and both case study teachers adhered closely to departmental guidelines in their teaching and learning programmes.

As a consequence of these decisions, students experienced structured teaching programmes in which they were exposed to programme content that limited the range of methods that scientists use to test fairly and to pedagogies that were substantially didactic in nature. In addition, the use of planning templates and exemplar assessment schedules tended to reduce student learning about experimental design to an exercise in “following the rules” as they engaged in closed, rather than open, investigations. Thus the resulting student learning was mechanistic and superficial rather than creative and critical, counter to the aims of the New Zealand Science curriculum that is intent on promoting students’ knowledge and capabilities in authentic scientific inquiry.

Note

Recently, the NZ Science curriculum has undergone revision, with the nature of science and authentic scientific inquiry being given an even greater profile than in the previous curriculum (Ministry of Education, 2008). Realignment of the achievement standards with the new curriculum has recently begun, and early indications are that more flexibility is being introduced into the investigation standard and support materials. There appears to be more recognition of the complexity of scientific investigation in the standard and more latitude for teachers to offer students some variety in their approaches to scientific investigation. A portfolio approach is being suggested as a means for gathering summative assessment information over a range of student investigations. On the surface, these changes should facilitate more authentic student inquiry, but their implementation into classroom practice cannot be assumed.

References

Carr, M., McGee, C., Jones, A., McKinley, E., Bell, B., Barr, H., & Simpson, T. (2001). *The effects of curricula and assessment on pedagogical approaches and on educational outcomes.* Retrieved March 14, 2003, from http://www.minedu.govt.nz/index.cfm?layout=document&documentid=5610&data=l .

Chin, C., & Kayalvizhi, G. (2002). Posing problems for open investigations: What questions do students ask? *Research in Science & Technological Education, 20*, 269-287.

Hipkins, R., Bolstad, R., Baker, R., Jones, A., Barker, M., Bell, B., Coll, R., Cooper, B., Forret, M., Harlow,A., Taylor, I., France, B., & Haigh, M. (2002). *Curriculum, learning and effective pedagogy: A literature review in science education.* Wellington, New Zealand: Ministry of Education.

Hume, A., & Coll, R. K. (2008). Student experiences of carrying out a practical science investigation under direction. *International Journal of Science Education, 30*, 1201-1228.

Ministry of Education. (1993). *Science in the New Zealand curriculum*. Wellington, New Zealand: Learning Media.

Ministry of Education. (2008). *The New Zealand curriculum*. Wellington, New Zealand: Learning Media.

Nakhlel, M. B., Polles, J., & Malina, E. (2002). Learning chemistry in a laboratory environment. In J. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical research: Towards research-based practice* (pp. 69-94). Dordrecht, Netherlands: Kluwer.

Readers' Forum

Inquiry Learning: Elements of Confusion and Frustration

Elements of confusion seem to accompany the use of the term *inquiry* in science education. Here, I wish to identify what I think are two such sources of confusion--the lack of a definition for inquiry and an inappropriate view of the importance of open inquiry--and also discuss how an inappropriate view of the role of open inquiry may be causing unnecessary frustration.

A Definition for Inquiry

I find it rather strange that the science education community continues to engage heavily in discussion of aspects of inquiry learning in the apparent absence of a definition for the term (e.g., Abrams, Southerland, & Silva, 2008; Johnson and Smith, 2008). How can there possibly be a fruitful conversation about a term if there is no guarantee that the participants in the discussion share the same meaning for it? Certainly, descriptions of the features of inquiry have been made available (e.g., National Research Council, 2000), but if such frameworks were sufficient we surely wouldn't have such a "lack of agreement about what constitutes an inquiry-based approach" (Buck, Bretz, & Towns, 2008, p. 52).

What is inquiry in the context of science education? In particular, how can we tell if a learning experience in which students are engaged can be considered an inquiry activity or not? In a recent journal conversation, I have suggested that "an inquiry activity is one that requires students to answer a scientific question by analysing raw, empirical data themselves" ("Inquiry [Continued]," 2008, p. 31). I tend to take it for granted that, if students are analysing data, they will also be drawing conclusions and be prepared to justify them. Also, I use the term *activity* in the broadest sense to include even projects that span an extended period of time. A detailed rationale for this definition may be found at "Inquiry Learning: A Discussion" (2007-2008), which is a freely available, online, composite reproduction of the ongoing journal discussion mentioned. I might briefly note here, though, that this definition precludes the answering of socioscientific questions, although scientific inquiry can certainly make a contribution to decision-making on socioscientific issues. It also follows that an activity such as the library retrieval of information that comprises the conclusions of others is insufficient to be regarded an inquiry activity. Does this definition provide the criteria necessary to alleviate confusion as to whether or not students are engaged in inquiry in the science classroom? Can it perhaps be improved?

Open Inquiry

In "Inquiry Learning: A Discussion" (2007-2008), I also made mention of inquiry being possible at any of four levels, depending upon which combination of question, method, and conclusion is supplied to students: Confirmation (Level 1), structured (Level 2), directed (Level 3), and open (Level 4). In the case of the latter, students answer their own questions using a methodology that they also devise themselves. Importantly, I distinguished between the amount of direction provided to students and the amount of guidance they receive, providing evidence for why unguided learning might be considered poor pedagogy.

With this as background, I then provided a rationale for doubting the role for open inquiry at higher (e.g., the post-compulsory) levels of education. My doubts were based mainly on my personal experience, over a considerable number of years, with offering open inquiry learning opportunities to high school students, and I noted that my stance would certainly be weakened if I could find examples of open inquiry being employed to teach science proper at the university level.

I was anxious to hear what others may have to say about this reasoning, as it appeared to be breaking new ground in so much as I had not seen others questioning the role of open inquiry in science education. So, it was with a feeling of some relief that I then found that Settlage (2007) had indeed also done just that, although in far more severe terms, when he asked us to speak out against open inquiry at all levels. He pointed out that it is a myth that open inquiry should sit at the top of the hierarchy of acceptable inquiry teaching approaches (i.e., that less-directed inquiry is the purest form of inquiry and something to be preferred), that methods textbooks inappropriately propagate the view of open inquiry as the ideal to be strived for, and that although many agree with this view, such an opinion is rarely expressed. He continued by saying that implementing open inquiry with any regularity is generally impractical and that there is negligible evidence to support a faith in it. Finally, he asserted that open inquiry occurs uncommonly, is pointless and misguided, and is a myth deserving of extinction.

Now, I think this raises a second very important source of confusion. Inquiry has been categorized by the assignment of levels based simply upon what is supplied to students (i.e., the level of direction provided to them). We make a grave mistake if we then interpret these levels in terms of "the higher the level number, the better," which is a completely different concept and illustrated nicely by S. Abell (personal communication, March 5, 2009):

> Why do science educators think that open inquiry--the highest level--is the best? Best for what is not clear. Is this the best way for students to learn science? What do students actually learn from doing open inquiry? I don’t think there is good empirical evidence here. Do students learn science concepts? Not usually. Do they learn the nature of science? Pretty much no. Do they learn how to set up experiments? Maybe.

Returning to the role for open inquiry, the only example of it being used at the tertiary level that I have found thus far is Johnson and Smith (2008). However, there is a twist; and a major twist at that. The questions students ask (e.g., How do the day and night evaporation rates from a grassy parade ground compare? How does indoor temperature in campus buildings vary with floor level?

How does grass root length differ between fertilized and unfertilized fields?) would be equally applicable to the elementary classroom, and the conclusions of these inquiries do not appear to be a part of the content of the course. Rather, open inquiry seems to be used to teach experimental design and data analysis (especially involving statistics) at the undergraduate level.

I tend to take (presently, at least) a more moderate approach than Settlage (2007), providing for the notion that open inquiry might be able to play a useful role at perhaps the primary and middle school levels where the equipment that students require to investigate their questions is typically more readily available, but doubting its value at higher levels, a position that also appears to be in accord with Abell's claim that open inquiry at the college level is "absolutely unobtainable" (Friedrichsen, 2008, p. 75). I make these comments in the context of open inquiry being used in standard science classes, as opposed to special opportunities that might be made available to students in the form of a science club or purposely-designed course (e.g., Schwebach, 2008).

At the same time, though, I'm seeking to clearly identify the benefits that might be associated with students doing open inquiry during the compulsory years of education, say. If open inquiry is not necessary for the development of cognitive outcomes, perhaps its impact can be in the affective domain, as suggested by Yager ("Inquiry [Continued]," 2008). Perhaps Yager, a passionate advocate of "science for all" and science/technology/society approaches, had it right some years ago when he likened science to sport:

> Unfortunately, however, our students rarely get to play--rarely get to do real science. . . . Instead, school science means 13 years of learning the rules of the game. . . . If potential athletes had to wait 13 years before playing a single scrimmage, playing a single set, a single quarter, how many would be clamoring to be involved? (p.77)

If open inquiry, then, is indeed more appropriate at some stages of education than at others, we can readily see why some teachers might be experiencing unnecessary frustration. Being pressured to implement a learning approach that neither they nor anyone else can justify for the particular stage of education at which they are working must surely be confusing and stressful. Perhaps we should indeed be satisfied, and even congratulating ourselves, if our classroom practices are such that Level 2 and especially Level 3 inquiry are prominent features.

I continue to deliberate on these issues, using as many means as possible to collect evidence, including seeking responses to this piece. For example, during the past couple of years I've been conducting Inquiry Learning workshops for practicing teachers across Australia. During these workshops I have shared thinking along the lines being presented here and am yet to find anyone who has seen reason to disagree.

I also recently shared my concern with MacKenzie, whose recent editorials (MacKenzie, 2008a, 2008b) appeared to be advocating the use of open learning in an unqualified way. I asked if she uses open inquiry in college/university science courses, if she is aware of colleagues or others who are doing so, and if she can point me to examples in the literature of open inquiry being used in university science proper courses, preferably with evidence supporting the practice. Interestingly, I have not received a reply, which appears to leave open the possibility that such writing is indeed promoting the rhetoric that Settlage (2007) warns us about.

References

Abrams, E., Southerland, S. A., & Silva, P. (Eds.). (2008). *Inquiry in the classroom: Realities and opportunities*. Charlotte, NC: Information Age Publishing.

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52-58.
Friedrichsen, P. J. (2008). A conversation with Sandra Abell: Science teacher learning. *Eurasia Journal of Mathematics, Science & Technology Education*, *4*(1), 71-79
Inquiry (continued). (2008). *The Science Education Review*, *7*, 27-36.
Inquiry learning: A discussion. (2007-2008). Available from http://www.scienceeducationreview.com/open_access/index.html .
Johnson, M., & Smith, M. (2008). Designing appropriate scaffolding for student science projects. *Journal of College Science Teaching*, *38*(2), 24-29.
MacKenzie, A. H. (2008a). The necessity of students & teachers as science researchers. *The American Biology Teacher*, *70*, 518.
MacKenzie, A. H. (2008b). Waiting for Godot: A reminder of the young adult learning experience. *The American Biology Teacher*, *70*, 455.
National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academies Press.
Schwebach, J. R. (2008). Science seminar: Science capstone research projects as a class in high school. *The American Biology Teacher*, *70*, 488-497.
Settlage, J. (2007). Demythologizing science teacher education: Conquering the false ideal of open inquiry. *Journal of Science Teacher Education*, *18*, 461-467.
Yager, R. (1988). Never playing the game. *The Science Teacher*, *55*(9), 77.

Peter Eastwell, Science Time Education, Australia www.ScienceTime.com.au

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

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

Newton's Laws of Motion

I am needing to teach Newton's three laws of motion to 14- and 15-year-old students, and I know they have many misconceptions, especially about inertia. Can you please suggest some good classroom learning experiences, including easily-implemented activities that require only simple and inexpensive materials (e.g., throwing a ball vertically upwards while walking)?

One of the introductory activities I do to demonstrate inertia is to show how mass and inertia are related. I use my computer desk chair and ask for volunteers. I purposely pick the biggest student in the class and the smallest student in the class (not letting them know that this is what I am doing). I then pick another volunteer who looks not particularly strong. I ask the heavier student to sit in the chair and ask my volunteer to give the chair a push. I then ask the lighter student to sit in the chair and ask my "pushing" volunteer to again give the chair a push, with the same amount of force. This time the smaller student usually goes flying across the room (with lots of giggles all around). I ask my pushing volunteer what she noticed about her experience. This leads to a discussion of how the more massive object resists being set in motion. It also leads to discussions of forces; what is a force? rolling friction, etc.

Suzanne Wolbers, Poly Prep CDS, Brooklyn, NY, USA

The best tried-and-true activity is the old pull-the-tablecloth-out-from-under-the-dishes stunt, but with a twist. The teacher uses heavy dishes; coffee mug, pyrex plate, and stainless steel silverware. The teacher will pull the tablecloth out, using a quick jerk, without a hitch. The students always want to try so I set up the student model. Their tablecloth has a paper setting so that there is no way they can be successful. Then it is up to the students to figure out why the teacher model worked and the student model didn't; the paper just doesn't have enough inertia so the friction between the paper and the table cloth causes everything to move in the same direction.

Inertia is a fun concept to “play” with. Everyone has, at one time or another, done the trick where a 3” x 5” index card is placed on top of a beaker and a quarter is placed on top of the card. The thumb and index finger are used to snap the card, the card flies off, and the quarter falls into the beaker because you applied a force to the card and not to the quarter. Try replacing the card with a piece of sand paper cut the same size. Will the added friction change the prediction? In this demonstration, my student model involves a card with the quarter glued to it. (I grab the card and quarter as soon as it flies off.) Remember, in science we have to be able to make predictions, so the students have to try to figure out why the student model didn't work as predicted.

One of my favorite activities is the bed-of-nails. I used a small board and drove large nails through it so that the points were sticking up about 2 cm apart on one side. Due to my own cowardice, I filed the point of the nails down a bit to make them a little less pointy. I can place the board on my chair with the nails sticking up and sit on it. While it isn't particularly comfortable, the nails won't go through. Since the force is spread out over the points of the nails, there is no pain. For the student model, which is displayed only but never used, the same size board has only two nails sticking up near the center about 30 cm apart. The students always want to try my seat-of-nails, but they are never interested in trying the student model.

Pamela Galus, Lothrop Science, Spanish, Technology Magnet, Omaha Public Schools, USA

A very simple yet effective practical we do for inertia is to take chairs outside the classroom (always a popular idea on a sunny day), set the seating up as bus seating, nominate your most active child as bus driver, and have them mime a bus ride at various speeds, corner turning, and stopping and accelerating. Students are required to model what happens to their bodies in these circumstances and then move on to predict inertia and discuss why it varies with objects of different mass. Very noisy, much fun, and gets the point across.

Barb Howard, Australia

If you have an elevator handy, riding it while standing on a scale is a good one. Also, AV carts can be ridden and pushed/pulled (mass vs force/overcoming inertia/no force during non acceleration/force during acceleration) or a bicycle or wagon can be used. Another really fun activity is to look at what happens when an object that is moving in a circular motion is suddenly released. Using a tennis ball tied to rope is especially good if some students can watch from above, from where they can see the arc better. I have also had students spin in a circle with a spring scale attached to a mass to determine acceleration in newtons. This activity is hilarious, and be sure to do it on a soft, grassy area.

Gina, Prince of Peace Lutheran, Cedar Crest, NM, USA

Newton’s third law can be demonstrated easily by a tug-of-war, where each side has a spring scale to measure force, or by having students play catch while standing on skateboards. It's especially obvious when playing catch with a bowling ball.

Jim Waters

I usually start with the following:

- A lab trolley moving along with a lab cart, or toy car, on top and stop the trolley suddenly.
- A coin on top of a sheet of paper on a beaker, and pull the sheet of paper out quickly.
- They love making a crash dummy out of playdough and designing a safer vehicle to reduce the impact on him on lab carts.

Lindy Piper, Australia

Jump from a small height without bending your knees. How does it feel? Now bend your knees while jumping. How does this compare? By bending your knees, the deceleration becomes less. This requires a smaller retarding force and your legs are not hurt. Similarly, a cricket player lowers his hands while catching a fast-moving, descending cricket ball. By doing so, he increases the time of contact and hence reduces the force.

Shyamala Muthusubramanian, MEASI College of Education, Chennai, India

When trying to explain the basics of mechanics, I use the bomber example. That is, if I drop a bomb (usually my house keys), will they land behind me, ahead of me, or exactly below me? Then I walk slowly and drop my bomb-keys. Then I do the same while running, and so on. They always land by my side. If anyone points out that air friction/compression slows down the real bombs, I tell them my virtual experiment is on the Moon. That's the way I explain that mass has inertia.

For the third law, I use this example. When you walk, what you are doing is making a force backwards on the floor. In a reaction, the floor makes a force on you, which moves you forward.

Juan Manuel Lleras, Museo de los Niños (Children's Museum), Bogotá, Colombia

This is an activity for the first law (inertia). You need two large, hefty, plastic, disposable plates and a marble. One plate needs to be cut so that one quarter of it is removed. Students roll a marble around the uncut plate and notice that the marble continues to move within the confines of the plates ridge or lip. Then they roll the same marble on the inside of the cut plate, to again follow the contour of the inside of the plate, and observe the path the marble takes when exiting the plate. It should continue traveling in a straight path when it exits. (This question has always been included on our State Science Exam.) This visual activity helps students apply the concept to other scenarios such as a tether ball when the string breaks.

Susan Olive, Neal Middle School, Fowler, OH, USA

Use cotton thread to hang a 1-kg mass from a secure support. Attach cotton thread to the bottom of weight as well. Pull slowly and the top thread breaks. Pull quickly and the bottom thread breaks. Discuss why this is so in terms of the forces on the thread and the concept of inertia.

John Cartwright, United Kingdom

Two students are standing on roller skates and holding a piece of rope 3-4 metres long. Regardless of who pulls the rope (one student at a time, or both), motion in the opposite direction always takes place. This is a good activity, since they can see that forces act in pairs; action and reaction act on different bodies, etc.

Yannis Hadzigeorgiou, University of the Aegean, Rhodes, Greece

Rather than comment on activities, I would like to consider some dangers in presenting inertia. Never ask: “Why does an object keep moving once it is started.” This implies that there is a reason and so the student looks for some reason. In fact, there is no reason an object keeps moving. A better approach would be to ask: “Why doesn’t an object stop once it is moving?” This leads the student to look for a cause of change in motion, which of course does exist. So, never suggest that an object keeps moving because of its inertia. Inertia is a principal, not a physical property.

Don Yost

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.

#7 of 40. *Require all staff members to read the appropriate safety manual. Require students to read the institution’s laboratory safety rules. Have both groups sign a rules agreement. Keep these statements on file in the department office.*

This does several things. It makes you decide what the rules and policies are going to be. It shows everyone that you are concerned about health and safety. It keeps a permanent record of your safety standards.

This is important for staff. It makes the expectations very clear. Safety is part of good science and here's what we expect at our institution or company. Safety is part of doing any job right. It is particularly important for new employees. It sets the standard right from the beginning.

A good rules agreement consists of six parts: (1) the rules, (2) the signed statement that you read, (3) understood, (4) agreed to follow, (5) realize that failure to follow the rules can result in termination, and (6) a cover letter signed by the organization’s president or superintendent confirming that not following the rules can result in termination.

To get started, it is not necessary to write your own set of rules, policies, and procedures. Take some from the LSI Publications, Teacher's Resource Books, State Guides, NSTA, or ACS publications. "Safety in Academic Chemistry Laboratories" would be a good starting point. Several states and school districts have good models to adopt or adapt. Check with your state Department of Education. The ACS Committee on Chemical Safety has just produced a safety guide for small businesses. Single copies of this, or the original version, are available for a nominal charge.

At the Dow Central Research New England Laboratory, I was given a 500-page safety manual on Day 1. I was asked to take it home and read it that night. When I returned in the morning, I was expected to sign a statement in the front of the manual indicating that I had read, understood, and agreed to follow those procedures. I guessed they were serious about safety.

LSI has prepared the K-12 science safety manual for major USA school districts and has a model that is available for purchase. Do you have a good safety manual? Please send a copy so others can learn from it. The lab safety manual "Laboratory Safety in Practice," published by Van Nostrand Reinhold, is now available from LSI. LSI helped to produce and publish an excellent Model Chemical Hygiene Plan. If your labs need a chemical hygiene plan or safety manual, email or call today to discuss LSI publications and development services.

Further Useful Resources

MakeBeliefsComix.com (http://www.makebeliefscomix.com/) Create comic strips in any of seven languages. Tools include characters, emotions, and talk and thought balloons, as well as provision to print and email.

Error Propagation Calculator (http://physics.gac.edu/%7Ehuber/error%5Fcalc/) A free downloadable Windows calculator for propagating uncertainties in calculations. The program does error calculations, weighted averages, tails of Gaussians, and similar analysis chores.

The Apple Genomics Project (http://www.four-h.purdue.edu/apple%5Fgenomics/) Using the apple as the model organism, this website features genomic information and computer animations that explain common genomic laboratory procedures.

The Use of Science Kits in the Professional Development of Rural Elementary School Teachers

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Abstract

This study reports on a science professional development initiative with elementary school teachers in Canada. Grades 4 and 5 teachers were involved in the implementation and modification of science kits, together with corresponding professional development activities. Each kit was aligned to specific outcomes in the curriculum and provided a complete set of materials and guidelines for classroom use. Teachers describe, through surveys and interviews, the benefits of using the kits and share a new confidence for teaching science.

This study reports on a science professional development initiative with elementary school teachers in Canada. Many elementary teachers, particularly at the upper grades, feel challenged with science teaching (MacDonald & Sherman, 2007). Professional development can have a positive impact on teachers' pedagogical content knowledge (MacDonald & Sherman, 2006), especially when it occurs on a continuous basis (Koch & Appleton, 2007). In this study, rural Grades 4 and 5 teachers were involved in the implementation and modification of science kits, as well as corresponding professional development activities.

Challenges for elementary science teaching. Research has identified challenges involved in teaching elementary science. One challenge for many elementary teachers is a lack of previous experience with hands-on science (MacDonald & Sherman, 2007). Furthermore, many tend to make limited use of hands-on or inquiry activities in their classroom teaching (Goodrum, Hackling, & Rennie, 2001). Many pre-service teachers enter teacher education without much confidence about science teaching, believing they lack the content knowledge needed to teach even lower elementary grades (King, Shumow, & Lietz, 2001). Guillame (1995) and Bryan (2003) noted that poor experiences with science and/or a general lack of engaging science experiences affects the belief system each teacher has about her/his own science teaching. Harlen (1995) identified a lack of background knowledge as a challenge for elementary teachers. Even when teachers have a successful teacher education experience with science, and meet governmental teacher licensing requirements, many feel they lack the science content needed to teach science (Sherman & MacDonald, 2008).

Many teachers indicate science is the subject area they least enjoy teaching, in part because they hold little confidence in their science content knowledge and are afraid their classroom teaching/learning activities will yield results they do not understand and cannot explain to students (MacDonald & Sherman, 2007). In addition, teachers feel challenged to acquire the resources needed to create the kind of science learning environments they consider appropriate. When teachers are able to find resources, they are challenged when asked to set up the equipment in ways accessible to the students. Many are exasperated and claim they don't even know where to start (MacDonald & Sherman, 2006). Murphy, Neil, and Beggs (2007) found that approximately one half of the teachers in their study identified lack of confidence and ability to teach science as the major challenges they faced in their classrooms.

Professional development for elementary science teaching. In light of these challenges, it seems important to examine how professional development can support elementary teachers' capacity to teach science. Several professional development (PD) approaches with science teachers have been reported (Loucks-Horsley & Matsumoto, 1999). In some research, the focus has been on the teaching of elementary teachers (Craft, 1996; Garet, Porter, Desimone, Birman, & Suk Yoon, 2001). Harris (2001) examined face-to-face professional development in rural settings, while Falvo (2003) explored distance approaches with rural teachers. The PD needed to make the transition from pre-service to in-service teaching in science was described by Mulholland, Dorman, and Odgen (2004). Stein, Ginns, and McRobbie (2003) argued that PD in the first year of teaching is critical. Annetta and Shymansky (2006) recommended a blended approach to PD in rural settings, using both distance and face-to-face approaches. In a 3-year study of face-to-face PD, focusing on scientific inquiry and inquiry-based instruction, research showed an improvement in teachers' science pedagogy as determined by the researchers (Akerson & Hanuscin, 2007). However, evidence shows PD providers must be cautious about the focus of their PD. Jarvis and Pell (2004) reported that elementary teachers, provided with an intensive PD program with follow-up classroom visits, showed an increase in confidence and enthusiasm for teaching science, but that their scientific misconceptions persisted.

Harland and Kinder (1997) suggested that the effectiveness of PD should be judged by its impact on teachers' classroom practice. Murphy, Neil, and Beggs (2007) identified five key PD approaches that increase teacher confidence and knowledge about science teaching. These include in-class support, distance/technology support, approaches that increase pupil interest in science, out-of-class intensive workshops, and production of materials. The study described in this article includes aspects of professional development related to in-class support, approaches that increase pupil interest, out-of-class intensive workshops, and the production of materials. During the workshops, materials are examined and manipulated, pedagogical approaches are examined and practised, and misunderstandings about content are clarified.

The Project

This research is part of a Centre for Research in Youth Science Teaching and Learning (CRYSTAL) grant, sponsored by the National Science and Engineering Research Council (NSERC), a Canadian federal granting agency. The research examines perspectives about the learning of science through outreach projects supporting school science. One part of the project was to support elementary science teachers in a large, rural school board in eastern Canada. In eastern Canada, the term *school board* refers to the school jurisdiction or district. In this school board, most elementary schools are 50-100 kilometres away from each other. Kits were created by the researchers based on the Grades 4 and 5 provincial science curriculum outcomes. In Canada, each province sets its own provincial curriculum outcomes for each subject area. The provincial science outcomes are mandated by the province's Department of Education and all elementary teachers of science are required to teach to these outcomes in their classrooms.

The Grade 4 kits focus on light, sound, rocks, minerals and erosion, and habitats, while the Grade 5 kits deal with the human body, weather, simple machines, properties and changes in matter, and exploring forces. Appendices A, B, and C exemplify the contents of, and activities in, a kit. The kits contain materials and resources needed for hands-on inquiry science activities related to the curriculum. Sample lesson plans, matched to the provincial curricular outcomes, are included. Photographs of the kit materials set up in proper format are included, as are videotapes of experiments occurring using the materials. For many pieces of equipment, several different suggestions about uses are given so teachers can make choices based on their own students.

Materials vary depending on the topic covered by the kit. For example, the kit on weather includes apparatus needed to build home-made weather measurement instruments. The kit on sound includes a variety of tuning forks, small musical instruments (tambourine, castanets, bells, a small drum, and a rain stick), and a digital sound level meter.

The kits are housed at a local university and distributed to teachers through a large rural school board's courier system. Presently, a grant provides funding to restock consumables and a university BEd student is hired to update the kits. Once requested by a teacher, the university Resource Centre librarian distributes the kits. Because of their popularity, the number of kits and the area serviced by them is expanding. The school board is duplicating the kits and assisting with data collection about their use.

Each time the kits are used, teachers complete a participant survey and participate in interviews. To date, over 40 teachers have been interviewed and surveyed. Focus group interviews have also been conducted. Responses have described the impact on both practice and planning for science teaching. Researchers have visited schools and have provided full-day workshops for each kit. It is insufficient to provide the resources alone. It is important to provide guidance for the use of the resources and opportunities to engage with the materials in a way similar to how the students will be invited to engage with them (Stein, Ginns, & McRobbie, 2003).

The local school board is very supportive of teachers participating in the professional development that teaches them about possible uses for the kit materials. The local school board has released teachers during school times to attend the workshops. During the workshop sessions, teachers practise with the materials, setting up experiments, creating activities in much the same way their students will do, and talking through the science content related to each activity. For some new teachers, this is an introduction to the science content they are about to teach and for more experienced teachers it is meant to be a content refresher session. Some of these teachers explain to us that is the first time some of the science has been explained in a way that they truly understand. The teachers not only work with the materials, but also discuss pedagogical content knowledge for each kit and explore, with their colleagues, different strategies that might work as they introduce new concepts to their own students. The researchers act as the organizers and leaders of the workshops and use pedagogical strategies that are inquiry-based. Suggestions are offered in response to teachers' questions about ways to incorporate experience-based, inquiry-based learning strategies into science classes.

Teachers' Comments

Time and materials for science. Teachers described the impact of current math- and literacy-centric thinking on their science teaching. They admitted that less than 10 percent of their classroom time is typically spent in teaching science. The increased focus on mathematics and literacy has reduced the amount of time spent on science teaching. "We should be doing almost as much science as mathematics but it isn't happening." Teachers suggested they need to be both efficient and effective in the little time they have to spend on science because "most teachers are teaching science, but are they getting the required time per cycle? . . . I don't think so." Another teacher summarized as follows: "There is a tremendous push by the Department of Education and administrators to focus on specific tasks, activities, and outcomes related to math and especially language arts. Time for science is limited."

Teachers described increasing the proportion of class time they spent teaching science with the kits. Partially, they attribute this to the fact that everything they need for each topic is together in one large box. One teacher commented:

> Presently, it is difficult to make science fun and hands-on. There are no science materials in my classroom, except for science program and books. I have purchased items myself, but it is difficult to collect everything, put it together, and it is also costly.

Teachers suggested they have developed a greater understanding of the kinds of materials needed to support science teaching. They no longer have to struggle to find the materials needed, or worry about storing large quantities of resources and materials. "They are engaging activities with the outcomes tied in. The lessons planned are ready to go and the lesson sequence is clear. It saves time."

Another teacher described her school:

> Our school has a lot of materials but you are lucky if you find what you need. For a time we tried storing everything for the school in one place, but the school population grew and those areas are all classrooms now, so we keep our own materials, but that means keeping on top of it and having to know when you didn't have anything left.

A teacher in another school suggested:

> If you come up to my classroom you'll see my cupboards are full and the library is full of stuff, so I don't think I need to be keeping anything else in my classroom. You're on the right track with the kits because I order the kit, the kit comes in, I open it up, set up everything, then when we're done, I break it down and it's gone.

Teachers described a cost saving because expensive pieces of equipment are included in the kits and "accumulating more expensive items (tuning forks, prisms, etc.) is challenging." The kit activities are suited for use in a regular classroom.

> The fabulous thing is that it's not too often you get a resource that, if you didn't have anything at all, you could still go ahead and do the activities. Everything you need is there, especially if you were a new teacher coming out. If I was new and got that kit, I would think that was wonderful.

In addition, the materials selected for the kits are generally sturdy and "they are practical and easy to use and you don't worry about the kids breaking them or dropping them. They are manipulatives the kids can really handle."

Teachers identify finding resources as one of the biggest challenges in offering hands-on activities (MacDonald & Sherman, 2006). In this study, a Grade 5 teacher described the challenge:

> Before the kits, some aspects of the curriculum were easier to do than others. I found the weather unit to be easy to do because most books described the material you needed, the kids could collect it, and then we would build very easy weather instruments. But I found topics like simple machines hard to do and the pond study was difficult, except the day you went to the pond.

The number of times the kits were used depended on several things. Not only did they serve to fill a gap in the amount and kinds of materials available to teachers, but the number of teachers using the kits grew as teachers gained an awareness of them. As the school board's support grew, so did teachers' awareness. As teachers met and talked about the kits at the various PD events sponsored by the school board, the use of the kits was extended. The kits were used more extensively following the conduct of each workshop aimed at explaining the use of a particular kit and allowing the teachers to experiment with its use.

Curriculum alignment. Another benefit of the kits is their alignment to provincial curriculum outcomes. "The kits have wonderful activities already planned and supported with materials. The activities are directed at outcomes. The activities are engaging for children." Another commented that "having lesson plans and materials together and meeting outcomes all in a "box" is a great idea." The kits include materials, resources, and lesson plan ideas connected directly to outcomes. Photographs and diagrams of activities are included. Videos and web sites are also provided so teachers need only follow the prepared activities if they are unsure of how to meet the science outcomes. Because they are aligned to the curriculum, "you can sort of sit down at the beginning of the year and start to lay out your year, and get a sense of where each of the kits fit in." Once teachers became familiar with a kit, using it more than once, they described how they were able to modify activities. "I've added more reflection to the activities, where I get the kids to tell me what they have learned and then write about it."

Teachers who are more confident in science teaching have used the kits' activities to add to their repertoire of science learning experiences and described increased confidence as they enhance their science program:

> The kit helped me think about the outcomes. It caused a spark; an idea. As you're looking through some of the different lessons, some you'd look at and think yes, I'll use that, but others reminded me of something I'd done before, something I knew well, and so I'd prefer the lesson I'd already done last year.

Another teacher added: "The kits are formulated in such a way a teacher can look at it and say 'I'm going to use this one way,' and another teacher might use it in another way." Her partner teacher continued: "The material used for the actual experiments and activities are very adaptable and I think teachers are pretty ingenious when it comes to using materials to fit their style or approach."

Teachers said they were better able to integrate science with other curriculum areas because they were more confident with their science teaching:

> I have learned a great deal more about each science topic. I realize I was teaching these content areas before without knowing very much about the topics. The kits have really helped me gain a greater understanding. I see how the science relates to other subject areas now in a way I didn't see before.

Sometimes integration of curricula areas was basic, like using science journals as a place to talk about paragraph construction, a language arts outcome for Grade 4. In other cases, teachers were able to identify broader overlapping curriculum outcomes in areas like Math and Science. The kits include lists of children's fiction connected to science topics. Many teachers are using these to integrate Language Arts into their science teaching. Teachers encouraged us to include more suggestions about integration for teachers who have not yet had the opportunity to think about the ways the curriculum overlaps.

Impact on teacher thinking. Having resources available with carefully described activities can increase teachers' content knowledge and their confidence (Bianchini, Johnston, Oram & Cavazos; 2003). Teachers offered children "exciting things when sometimes [without the kits] teachers' confidence in their own knowledge level prevents that from happening." Not only have the teachers been enabled to include inquiry-based science activities in their classroom, but they have moved to a higher level of thinking that includes modifying and advancing the activities. This depicts a significant level of impact on teachers' practice and pedagogic reflexivity as described by Harland and Kinder (1997).

Teachers began to take ownership of the kit development process by suggesting modifications, developing alternate activities using kit materials, and accommodating specific needs of their students. As teachers took on the creation or modification of kit activities, changes in their thinking were noted. "I did the light activity as the introduction to the unit [even though doing this wasn't mentioned in the kit] and I would never have thought to do that first, but now that I've done it, it makes so much sense."

Inspiring children. Teachers described the enjoyment students gained from learning with kit materials. "The hands-on materials would excite the students and make the learning more meaningful as they would be experiencing and playing around with things and ideas rather than being a mere passive learner." Teachers suggested the children enjoyed "kit learning" as it focuses on inquiry-based activities. "It's something hands-on and they love the kits. When we get a new kit [in the classroom] they are all trying to see into it and want to find out what we're doing next as it's exciting for them." The teachers believed their students had become engaged, active learners when science teaching was supported by the kits. "They are really excited about the experiments and I hear them talk about them during student-lead conferences with their parents."

The kit activities encourage children to engage in collaborative science inquiry and generate multiple artifacts of their understanding of science. When children engage in science inquiry, the resulting artifacts enable discussions where children compare the effectiveness of their designs with the designs of their classmates. These discussions can be highly instructional and can extend beyond the classroom, especially for the teachers, when they talk about their student's experiences with colleagues.

One teacher commented:

> The kit activities helped the kids think more like a scientist. We would set up our experiments and then I would get them to think about what they thought might happen, they made their predictions, and then we observed what happened. They wrote their conclusions down and explained what they saw. They helped each other learn by showing their work to each other.

Without the kits, many teachers admitted they had their students read science textbooks rather than engage in science inquiry.

Conclusions

The participants described using prepared science kits in a positive light. The benefits include increased teacher content knowledge, pedagogic content knowledge, teacher confidence, and enthusiasm for science. Teachers also suggested that their students seem more excited about science class, asking when they can do the next activity and readily participating in activities presented by their teachers. The kits have helped teachers feel better prepared to offer an exciting approach to science and to integrate science into other curriculum areas. Teachers have modified the kits for their own classroom context and students' needs. Having an organized set of materials with suggestions for lesson plans has helped these teachers gain content knowledge and confidence. Practical issues of collection and storage of materials have been overcome and more time is available for relevant and meaningful activities. Children in these classrooms have increased opportunity to engage in meaningful science learning.

Teachers indicated that, as a result of using the kits, students are engaged in a wider variety of science activities that are more meaningful and relevant to them. The quality of the experiences is enhanced by the fact teachers have access to more information and ways of sharing that information with students.

Kits have been utilized in a school board that is geographically large. Sharing of resources in many rural schools is limited because they have only one teacher per grade level. In addition, elementary schools in this school board can be separated by a significant distance, which means meeting with another teacher of the same grade is challenging, especially on rural winter roads. The kits provide a connection to the curriculum and to what other teachers are doing in their classrooms. "I now contact other Grade 4 teachers I know in other schools and ask how they used the kits."

The kits have facilitated a new level of conversation amongst elementary teachers in this school board. Previously, little time was spent talking about science teaching, partially because of teachers' lack of content knowledge and confidence, and partly because the amount of time spent teaching science was limited. Teachers are now telling others about their success with the use of the kits and requests for the kits have gone up dramatically. Not only are teachers talking about the kits, but they are talking about how to use the materials in the most effective way, about modifications they have tried, and about ways to add other activities to the kits. The kits have also helped teachers become more generative in their thinking about how to support science inquiry learning. In creating new and alternate activities, teachers seem able to apply what they learn from using the kits to new teaching situations. The kits include a capacity-building component for the teachers, by allowing teachers to manipulate and create different activities depending on the demands of their own classroom.

The evidence provided by these teachers suggests there is a need for substantially increasing this type of science PD for elementary teachers. The kits have increased the propensity of teachers to think about classroom-based science teaching and learning events over an extended period of time. This kind of interaction has the potential to generate teaching resources that support the development of enhanced pedagogical content knowledge through continuous professional development. As this research continues, evidence is also being collected about student achievement. While teachers report enthusiasm amongst their students, it remains to be seen what effect these kits will have on student achievement. With better-prepared teachers who are more confident and knowledgeable, it is hoped that student achievement will also be improved.

References

Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching, 44*, 653-680.

Annetta, L., & Shymansky, J. (2006). A comparison of rural elementary school teacher attitudes toward three modes of distance education for science professional development. *Journal of Research in Science Teaching, 43*, 1019-1039.

Bianchini, J. A., Johnston, C. C., Oram, S. Y., & Cavazos, L. M. (2003). Learning to teach science in contemporary and equitable ways: The successes and struggles of first-year science teachers. *Science Education, 87*, 419-443.

Bryan, L. A. (2003). Nestedness of beliefs: Examining a prospective elementary teacher’s belief system about science teaching and learning. *Journal of Research in Science Teaching, 40*, 835-868.

Craft, A. (1996). Continuing professional development: A practical guide for teachers and schools. London: Open University.

Falvo, D. (2003). Developing professionalism in teaching through technology skill development among rural teachers. *TechTrends*, *47*, 21-25.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Suk Yoon, K. (2001). What makes professional development effective? Results from a national sample of teachers. *American Education Research Journal*, *38*, 915-946.

Goodrum, D., Hackling, M., & Rennie, L. (2001). The status and quality of teaching and learning of science in Australian schools. Canberra: Commonwealth of Australia.

Guillame, A. M. (1995). Elementary student teachers’ situated learning of science education: The big, Big, BIG picture. *Journal of Science Teacher Education, 6*, 89-101.

Harland, J., & Kinder, K. (1997). Teachers’ continuing professional development: Framing a model of outcomes. *British Journal of In-service Education*, *23*(1), 71-84.

Harlen, W. (1995). *Understanding and teaching science* (SCRE Newsletter No. 57). Glasgow: Scottish Council for Research in Education.

Harris, M. M. (2001). Lessons from prairie teachers. *Action in Teacher Education*, *23*, 19-26.

Jarvis, T., & Pell, A. (2004). Primary teachers’ changing attitudes and cognition during a two-year science in-service programme and their effect on pupils. *International Journal of Science Education*, *26*, 1787-1813.

King, K., Shumow, L., & Lietz, S. (2001). Science education in an urban elementary school: Case studies of teacher beliefs and classroom practices. *Science Education*, *85*, 89-110.

Koch, J., & Appleton, K. (2007). The effect of a mentoring model for elementary science professional development. *Journal of Science Teacher Education*, *18*, 209-231.

Loucks-Horsley, S., & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics, 99*, 258-271.

MacDonald, A. L., & Sherman, A. (2006). Children's perspectives on building science models. *Education 3 to 13, 34*(1), 89-98.

MacDonald, A. L., & Sherman, A. (2007). Pre-service teachers' experiences with a science education module. *Journal of Science Teacher Education*, *18*, 525-541.

Mulholland, J., Dorman, J. P., & Odgen, B. M. (2004). Assessment of science teaching efficacy of preservice teachers in an Australian university. *Journal of Science Teacher Education*, *15*, 313-331.

Murphy, C., Neil, P., & Beggs, J. (2007). Primary science teacher confidence revisited: Ten years on. *Educational Research, 49*, 415-430.

Sherman, A., & MacDonald, A. L. (2008). Instructional leadership in elementary school science: How can I be an instructional leader in a content area, like science, where I have little to no background experience or knowledge? *International Electronic Journal for Leadership in Learning*, *12*(Article 12). Retrieved from http://www.ucalgary.ca/iejll/sherman .

Stein, S. J., Ginns, I. S., & McRobbie, C. J. (2003). Grappling with teaching design and technology: A beginning teacher’s experiences. *Research in Science & Technological Education*, *21*(2), 141-157.

Appendix A: Contents of the Light Kit (Grade 4)

Materials (one each unless otherwise marked, and as shown in Figure 1)

Fibre optics lamp, microscope, telescope, magnifiers (5), periscope kit, binoculars, kaleidoscope, masking tape, wax paper, aluminum foil, push pins (1 box), candles (30), light sticks (9), watch with LED light, clock with LED light, flashlights (8), matches (1 large box), mirrors (7.5 cm by 12.5 cm) (37), concave lenses (class set of 25), convex lenses (class set of 25), 8.5 inch x 11 inch card stock (package of 50), Rive ray box, optics set for Rive ray box (10 mirrors and 10 lenses), laser pointers (8), utility knives (4), cylinders (10, such as soup cans and/or tennis ball cans), styrofoam cups(25).

Figure 1. Materials in the light kit.

Children's Literature

"The Magic School Bus – Color Day Relay" by Gail Herman
"Awesome Experiments in Light & Sound" by Michael A. Dispezio
"The Magic School Bus makes a Rainbow" by Joanna Cole
"Inventing the Electric Light" by Lisa Mullins
"Kingfisher Young Knowledge: Light and Sound" by Dr. Mike Goldsmith

Websites

http://www.learner.org/teacherslab/science/light/
http://www.proteacher.com/cgi-bin/outside.cgi?id=3131&external=
http://www.pticalres.com/kidptx_f.html
http://www.zephyrus.co.uk/lightsources.hml
http://www.fr.edu/fellows/fellow7/mar99/light/lesson1.shtml

Appendix B: Sample Activity 1

How Light Travels

Lesson Purpose

The overall purpose of this lesson is to use a simple set-up of common materials to help students understand that light travels outward in straight lines.

Student Outcomes

Students will be expected to:

- Make observations about how light is dispersed from a variety of light sources.
- Demonstrate that light travels in all directions away from a source.
- Conclude that light travels in a straight line based on evidence gathered through their own research and observation.

General Curriculum Outcomes

Students will develop an understanding of the nature of science and technology, of the relationships between science and technology, and of the social and environmental contexts of science and technology.

Specific Curriculum Outcomes

Students will be expected to:

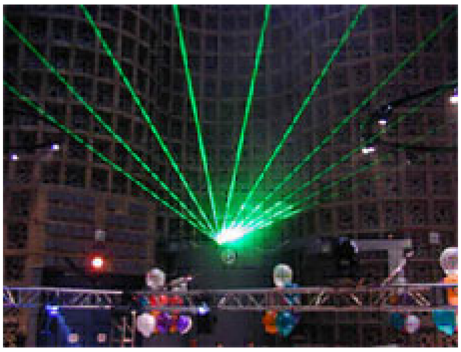
- Make observations and collect information that is relevant to a given question or problem.
- Plan a set of steps to solve a practical problem and to carry out a fair test of a science-related idea.
- Construct and use devices for a specific purpose.

Prior Knowledge

It is assumed students will have some understanding of how light travels (i.e., household light fixtures, spot lights, flashlights, etc.). Some may not know that light travels from a source to an object. Research indicates that children equate light with a state or with its source rather than understanding it as a distinct entity.

Lesson

Ask students what they already know about light. In a whole-class discussion, create a concept map based on their preconceived ideas. Ask students to view the two photographs, showing beams of light, of Figure 1. Ask them if they can see the beams of light in both photographs. Then have them look closer and explain how all the beams of light are similar (all of them are straight). Have them explain why they do not always see these kinds of beams in everyday life, such as in the classroom. Discuss with them that when we see most light (i.e., classroom lights), it is hard to see a single ray because it is too bright and the rays are not focused. Before discussing it with them, try to have them come up with a conclusion on their own by asking them open-ended questions.



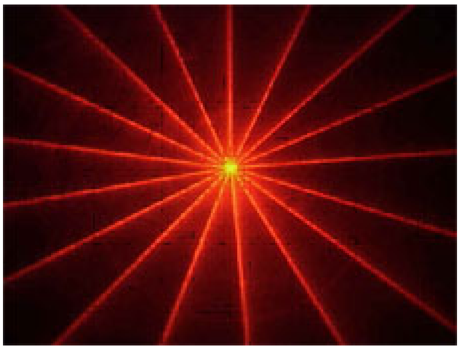


Figure 1. In what way are the beams of light in these photographs similar?

Now have them create a pinhole camera. Cameras work on the rule that light travels in straight lines. Make a pinhole camera to see if this is true. When they complete this, you can ask them how they can tell from the image formed by their pinhole camera that light travels in straight lines, and how would changing the length of the tube affect the quality of the picture they see?

Materials. Wax paper, aluminum foil, pencil, and an empty cylinder (i.e., a soup can, potato chip can, or a tennis ball can).

Procedure. Please follow these steps:

1. With an adult's help, remove both ends of the can and make your tube about 7-12 cm in length.
2. Tape, or secure with an elastic band, a piece of wax paper over one end of the container to form a screen.
3. Tape, or secure with an elastic band, a piece of foil over the other end.
4. Use your pencil point to make a small, tidy hole in the centre of the foil.
5. Presto; your camera is made (see Figure 2).
6. Point the camera with the pinhole end toward a window and look at your screen from about 15 cm away. To see the image better, put a jacket or a piece of fabric over your head and the camera screen.
7. In your notebook, draw the image you see.

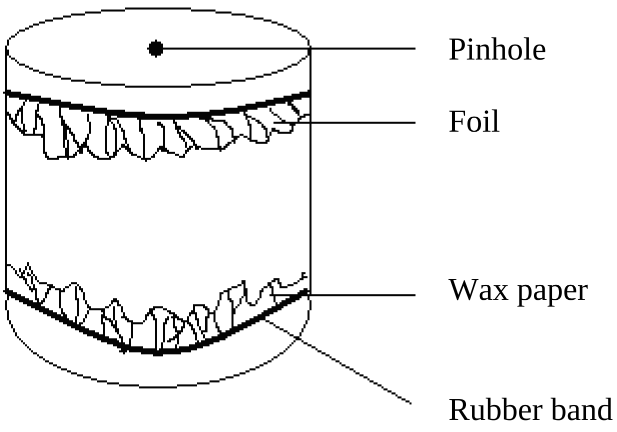


Figure 2. A pinhole camera.

Appendix C: Sample Activity 2

Lenses

Lesson Purpose

This lesson is intended to educate children about the function of lenses. The different types of lens in our world will be discussed (i.e., lens in human eye, cameras, binoculars, spectacles). The shape of the lens is important to the focusing of images, which helps us to see our environment clearly. There are two shapes that a lens can have: Convex and concave. Introduce these terms, as well as the terms converge and diverge. The function of these shapes will be expressed. Children will create a camera of their own so they can have a hands-on experience with lenses.

Student Outcomes

Students will be expected to:

- Describe examples of tools and techniques that extend our senses and enhance our ability to gather data and information about the world.
- Follow a given set procedure.
- Make observations and collect information relevant to a given question or problem.

Prior Knowledge

This lesson will be placed near the end of this unit on light. Students will therefore have knowledge about how light travels, refraction and reflection of light, and the parts and function of the eye. This information will help them understand the concept of lenses.

Children will have had experience with class discussions. Engage children in discussions to brainstorm and inquire about the function of a lens.

Lesson

Exploration phase. To begin this lesson, review the structure of the eye. Show the diagram of Figure 1 on an overhead. The students will have already seen this diagram in previous lessons.

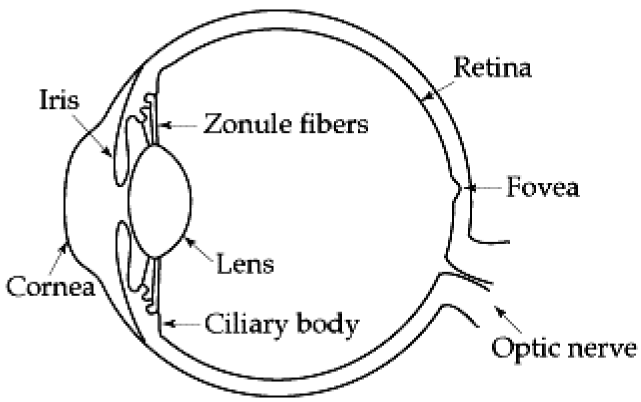


Figure 1. Structure of the human eye.

Discuss the function of each part of the eye briefly (i.e., what is the retina's function?). After becoming reacquainted with the parts of the eye, focus the lesson to the lens, giving more in-depth information about this structure. For example, sample discussion may go as follows:

> *Teacher*: You have just told me that light enters the eye cornea through the pupil and then passes through the lens. The lens in our eye is convex and helps to focus the light. Does anyone know what convex means [allow response time]. Convex is the type of shape that the lens is. Convex shape looks like this [draw on the board]. The convex lens of our eye is thicker in the middle and has an inward curve, like this [point to the drawing on the board, stressing the shape and curve of the convex lens]. If I pass light through this lens, what do you think will happen? Keep in mind that the lens' function is to focus light [draw a beam of light passing through the lens].

Convex Lenses

Materials

Convex lens (one for each child), flashlight (enough for sharing to occur), and white paper (one sheet per child). Give each student a convex lens to experiment with for several minutes.

Procedure (approximately 5-10 minutes)

1. Lie white paper flat on your desk.
2. Hold the convex lens over the top of the paper so the rounded part of the lens is facing downwards.
3. Shine the flashlight onto the lens.
4. Observe the direction of light onto the paper. Does the light seem to "come together" or spread apart?

After this short activity, ask the children what they found. Hopefully, it will be clear that the light comes together (introduce the term *converge*). Explain that when light passes through the lens of our eye, light is refracted and focused. This is what is known as convergence (i.e., light rays are focused to a sharp point of light). This magnifies the image. Next, introduce the other type of lens shape; concave.

Sample Discussion

> *Teacher*: Convex is not the only shape of a lens. A lens can also be concave. Can anyone predict what shape this might have?
> *Student*: It will be the opposite of convex.
> *Teacher*: Good predicting! The concave lens looks like this [draw on the board].

Concave lenses are sunken in the middle. They are thinner in the middle and thicker around the edges. Now let them experiment with concave lenses.

Concave Lenses

Materials

Concave lens (one for each child), flashlight (shared by children), and white paper (one for each child).

Procedure (approximately 5-10 minutes)

1. Lie white paper flat on your desk.
2. Hold the concave lens over the top of the paper so that the rounded part of the lens is facing down (demonstrate the proper way).
3. Shine the flashlight onto the lens.
4. Observe the direction of light onto the paper. Does the light seem to "come together" (like the convex lens) or does it spread apart?

Students should see that the light spreads apart. Introduce the term *diverge*. Now prompt a conversation about other examples of lenses in our environment:

> *Teacher*: So we now know that there are lenses in our eyes. Can anyone think of other lenses that we use?
> *Student*: There are lenses in my glasses!
> *Teacher*: Right; mine too! What do our spectacles do?
> *Student*: Help us see better.
> *Teacher*: Yup, I know when I take off my spectacles [do this] I can't see anything [squint]. Well, almost nothing. So what do we know about the function of lenses?
> *Student*: They focus light and help us see better!
> *Teacher*: Our eye lenses sometimes change shape, and when they do it changes our vision. The different lenses in spectacles help correct the shape of our eye lenses. Explain more fully the function of convex and concave lenses. Convex lenses converge light rays, this makes objects appear larger. Concave lenses diverge this makes objects appear smaller. Convex lenses help people who are farsighted (people who have trouble seeing close up). Concave lenses help people, like me, who are nearsighted (i.e., having trouble seeing far away).

Invention phase. In the following activity, students will construct and use a water lens.

Water Lens

Materials

Styrofoam cups (enough for each child), string, piece of plastic wrap (one piece for each child), water, coins, and various objects. Precut the bottom off the Styrofoam cups, as this will reduce time as well as any possible accident that may occur with cutting.

Procedure (approximately 20 minutes)

1. Obtain an Activity Sheet (see following).
2. Stretch the sheet of plastic loosely over the top of each Styrofoam cup and tie a string around the rim of the cup. There needs to be a little slack in the plastic so it sinks down a bit when the water is poured in.
3. Pour some water onto the top of the plastic sheet. The weight of the water stretches the plastic into a lens shape.
4. Place a coin on the palm of your hand and predict what you will see when you look at it through your water lens. Write your prediction on your Activity Sheet.
5. Do it, and record what you observe on your Activity Sheet. Find other objects in the classroom and look at them under the water lens, similarly recording your observations.
6. Complete the other parts of the Activity Sheet.

Activity Sheet

Making a Water Lens

Predict what you think will happen

Record your observations.

Did you make a lens with the plastic wrap and water?

How did this occur? Explain how water and plastic form a lens.

What kind of lens did you make?

What are Null Hypotheses? The Reasoning Linking Scientific and Statistical Hypothesis Testing

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Abstract

We should dispense with use of the confusing term *null hypothesis* in educational research reports. To explain why the term should be dropped, the nature of, and relationship between, scientific and statistical hypothesis testing is clarified by explication of (a) the scientific reasoning used by Gregor Mendel in testing specific hypotheses derived from his general inheritance theory and (b) the statistical reasoning used in applying the chi-square statistic to his experimental data. The Mendel example is followed by application of the same pattern of scientific and statistical reasoning to educational examples. A better understanding of the related, but separate, processes of scientific and statistical hypothesis testing, including the role of scientific hypotheses (i.e., proposed explanations) and scientific predictions (i.e., expected test results), not only reveals why null statistical hypotheses and predictions need not be stated, but also reveals how we can improve the clarity of our research reports and improve the quality of the research reported by insuring that alternative scientific hypotheses and theories are in fact tested.

P. Eastwell (personal communication, July 5, 2006) asked readers to consider the confusing and possible misuse of the term *null hypothesis* in the context of research reports. In Eastwell's words:

> We distinguish a prediction (an educated guess about the expected outcome of a test) from a hypothesis (a possible explanation for the observed facts and laws). Does it follow that science education researchers should now dispense with the use of the term null hypothesis in circumstances where it is really a null prediction that is being tested?

I think it would be helpful if science education researchers dispensed with use of the term null hypothesis under any circumstances, primarily because the term comes from the field of statistics and its relationship to scientific hypothesis testing is seldom, if ever, made clear. Hence its use in educational research often leads to confusion and may even limit research quality by restricting the number of scientific hypotheses generated and tested. As will become clear in this paper, the term null prediction is also not required.

Allow me to attempt to clarify by explicating important similarities and differences between scientific and statistical hypothesis testing in the context of a crucial experiment conducted by Gregor Mendel to test his classic inheritance theory. The example will consider Mendel's theory, the reasoning behind how he tested it, and how statistical hypothesis testing could have been used to determine the extent to which departures of Mendel's observed scientific results from his predicted scientific results were due to chance or due to faulty scientific hypotheses. The Mendel example (after Lawson, Oehrtman, & Jensen, 2008, with kind permission of Springer Science and Business Media) will be followed by some educational examples and implications.

Mendel's Experiment and the Reasoning Guiding Scientific Hypothesis Testing

As you may recall, Mendel's theory proposed that dominant and recessive genes exist in pairs (e.g., *YY, rr*) and that the genes of a pair separate and pass independently to egg and sperm cells (i.e., the gametes). Then during fertilization, the separated genes (e.g., *Y, r*) recombine randomly in zygotes (i.e., in fertilized eggs). To test these theoretical claims (we will call them scientific hypotheses as they are part of Mendel's more general and complex inheritance theory), Mendel conducted a two-part experiment with pea plants.

During the first part of his experiment, Mendel crossed/mated pure-breeding pea plants that produced yellow-round seeds (presumably with the dominant *YYRR* genotype) with pure-breeding pea plants that produced green-wrinkled seeds (presumably with the recessive *yyrr* genotype). All of the offspring from this cross produced yellow-round seeds (presumably with the mixed *YyRy* genotype). During the second part of his experiment, Mendel crossed the above offspring of the first generation. However, before these plants grew and matured to produce their own seeds, his scientific hypotheses (i.e., his explanatory claims) allowed him to make a very specific prediction (i.e., an expected result of a planned test given that his explanatory claims are correct) about the color and shape of the seeds that should be produced. Specifically his hypotheses led him to expect (predict) that the next generation seeds would appear with a 9:3:3:1 ratio of seed types (i.e., 9 yellow-round: 3 yellow-wrinkled: 3 green-round: 1 green-wrinkled).

When cast in the form of a hypothetico-deductive argument, Mendel's *If/and/then* reasoning looks like this:

> *If* . . . dominant and recessive paired genes pass independently to gametes and recombine randomly in zygotes (scientific hypotheses),
> *and* . . . pea plants presumably with the *RrYy* genotype for seed color and shape are crossed (planned scientific test),
> *then* . . . we should observe a seed color/shape ratio of 9:3:3:1 in their offspring (scientific prediction).

When Mendel collected, observed, and counted the 556 seeds that were produced in these offspring, he found that 315 were yellow-round, 108 were yellow-wrinkled, 101 were green-round, and 32 were green-wrinkled. These numbers constitute his observed scientific result.

What conclusion should Mendel draw from this scientific result? Were his scientific hypotheses supported? A quick calculation reveals that a 9:3:3:1 ratio of seed types should have produced about 313 yellow-round seeds, 104 yellow-wrinkled seeds, 104 green-round seeds, and 35 green-wrinkled seeds. These predicted numbers are very similar to the observed numbers. Therefore, Mendel concluded that the slight departures between his predicted and observed results were random in nature and that his scientific hypotheses (and the more general theory of which they were a part) were supported.

But were the slight departures between his predicted and observed results really due to chance? Or was there in fact something wrong with Mendel's hypotheses? Of course Mendel had no way of knowing because the process of statistical hypothesis testing, the way of knowing, had not been invented in 1865 when Mendel published his results. Consequently, let's briefly consider the reasoning guiding statistical hypothesis testing to see how it can answer this key question.

The Reasoning Guiding Statistical Hypothesis Testing

Consider testing a coin for "fairness." Assuming that one has a fair coin, when tossed, one would predict that it would land heads about half the time and tails the other half. So to test a coin for fairness (i.e., to test the statistical null hypothesis that you have a fair coin), you could toss it 100 times. Suppose it lands heads 47 times and tails 53 times. You probably would not be too bothered by this. Your observed ratio of 47:53 is quite close to the predicted 50:50 ratio. However, what would you conclude if your observed ratio turned out 35:65, if it turned out 5:95? Obviously, there will be some point when you no longer conclude that the observed result matches your prediction. Would you conclude that a coin that lands heads only 5 out of 100 tosses is fair? You probably would not. Said another way, you would probably reject the statistical null hypothesis that the coin is fair (i.e., that both probabilities are 0.50).

How then can we know when a departure from a predicted scientific result is due to chance or to a faulty scientific hypothesis? Although we can never know for sure, it turns out that, thanks to statistical hypothesis testing, we can nevertheless estimate the likelihood of various departures from predictions. In other words, even though we cannot be certain about the truth or falsity of any particular scientific hypothesis, at least we can estimate our degree of uncertainty.

Mathematicians have invented formulas to generate such uncertainty estimates. One formula, the chi-square formula introduced in 1900 by Karl Pearson (Walker, 1958), can be used in the present context. The chi-square formula calculates a single value (a statistic) that we can compare to values listed in a statistical table to tell us what we need to know. The chi-square value/statistic (i.e., χ^2) is calculated by comparing predicted and observed results. As observed results deviate farther from predicted results, the chi-square values increase. So a relatively large χ^2 value means that the results are probably not due to chance. For example, in a coin toss situation we have two categories of data with predicted numbers of 50 heads and 50 tails and observed numbers of 47 heads and 53 tails. So the χ^2 calculation looks like this:

$$\chi^2 = \frac{\left(47 \text{ heads } - 50 \text{ heads}\right)^2}{\left(50 \text{ heads}\right)} + \frac{\left(53 \text{ tails } - 50 \text{ tails}\right)^2}{\left(50 \text{ tails}\right)} = \frac{\left(-3\right)^2}{50} + \frac{3^2}{50} = 0.36$$

How does one interpret this value of 0.36? Suppose 100 people each have a fair coin. Suppose further that each person flips his/her fair coin 100 times and records the number of heads that turn up. If we now create a graph plotting these numbers versus their frequency, we will end up with a distribution most likely with around 50 heads (or 50 tails) as the modal value. Suppose further that each person calculates a χ^2 value for the results of his/her 100 tosses and we then plot the various χ^2 values versus their frequency. Because the smallest possible value is zero (obtained when observed and predicted numbers are the same), we will end up with a distribution of 100 chi-square values extending to the right of zero with increasingly large values being less and less probable. This is called a sampling distribution. Statisticians have compiled the probabilities associated with several such values and sampling distributions and listed them in statistical tables. Consequently, if we have a new coin and want to know if it is fair, we can toss it 100 times and count the number of times it turns up heads (or tails). We can then use the observed results and the chi-square formula to calculate a χ^2 value and compare it to the values in the appropriate statistical table.

To summarize, we have just tested a descriptive statement (i.e., a statistical null hypothesis) about an unknown parameter. In this case the statistical null hypothesis is that both probabilities are 0.50. And just like in causal scientific hypothesis testing, we used hypothetico-deductive reasoning to do so. That is:

> *If* . . . the probability of landing heads is 0.50 (fair-coin statistical null hypothesis),
> *and* . . . we flip a coin 100 times and compute a chi-square value for the result (planned statistical test),
> *then* . . . the chi-square value should fall well within the sampling distribution as reflected by the values and probabilities that appear in the appropriate statistical table (statistical prediction).

And . . . the calculated value of 0.36 derived from our result of 47 heads and 53 tails does fall well within the sampling distribution. More specifically, the appropriate table tells us that a value of 0.36 will occur due to chance alone between 50% and 70% of the time such a test is conducted (observed statistical result).
Therefore . . . most likely the probability of landing heads (or tails) really is 0.50. Thus, we can be quite confident that the coin is fair (statistical conclusion).

Calculating and Interpreting a Chi-Square Value for Mendel's Results

Let's now return to Mendel's experiment and use his predicted and observed results to calculate a chi-square value and see if the departures are likely due to chance. The calculated χ^2 value turns out to be 0.62. A quick check of the appropriate statistical table shows this value (with three degrees of freedom) associated with probabilities 0.80 and 0.90. This means that between 80% and 90% of the time, chance variations would result in a greater departure from a true 9:3:3:1 distribution than do Mendel's results. In other words, it seems safe to conclude that the difference between Mendel's observed and predicted results are due to chance. Therefore, not only is the descriptive statistical null hypothesis supported, but so are Mendel's causal scientific hypotheses and his general inheritance theory.

Table 1 summarizes both scientific and statistical hypotheses in terms of the *If/and/then* arguments in which hypotheses are tested through the generation of specific predictions. As you can see, both processes involve prediction generation followed by data collection and the comparison of predicted and observed results. However, the goal of scientific hypothesis testing is to test scientific hypotheses, which are causal in nature, while the goal of statistical hypothesis testing is to test statistical null hypotheses, which are descriptive in nature.

Note also that the scientific prediction (i.e., we should observe a seed color/shape ratio of 9:3:3:1 in the offspring plants) and the statistical null hypothesis (i.e., a seed color/shape ratio of 9:3:3:1 exists in the offspring) sound much the same. In the former case, however, we have a statement about how a scientific test should turn out assuming that a causal scientific hypothesis is correct, while in the latter case we have a descriptive statistical hypothesis about the nature of seed colors and shapes.

Educational Examples and Implications

In the first edition of their classic statistics textbook, Glass and Stanley (1970) discuss the evaluation of three teaching methods (i.e., textbook, programmed textbook, and computer-level program) on reading comprehension. The evaluation involves random assignment of students into three treatment groups, one group for each teaching method. Students are then administered a posttest to determine which method was most effective. During their discussion, Glass and Stanley state the experiment's null hypothesis as "the population means for the three teaching methods are equal." (p. 411)

As discussed, this statement represents a descriptive statistical hypothesis; not a causal scientific hypothesis. Unfortunately, in their example Glass and Stanley (1970) do not offer any causal scientific hypotheses. If scientific hypotheses were discussed, they would provide reasons/causes for the possible superiority of one treatment over the other(s) (e.g., programmed texts are better because they include frequent questions that provoke students to reflect on what they have read). Thus, an unmentioned hypothetico-deductive argument might go something like this:

If . . . provoking students to reflect on what they have read increases comprehension (scientific hypothesis),
and . . . some students read standard text while others read programmed text or a computer-level program and the three groups are then tested (planned scientific test),
then . . . mean test score of the programmed text students should be higher than those of the other two groups (scientific prediction). Or, stated as a statistical null hypothesis, the population means for the three teaching methods are equal.

Table 1
The Reasoning Guiding Scientific and Statistical Hypothesis Testing (Lawson, Oehrtman & Jensen, 2008)

Aspect of reasoning	Process	
	Scientific hypothesis testing	Statistical hypothesis testing
Hypotheses: *If . . .*	Dominant and recessive gene pairs pass independently to gametes and recombine randomly in pea plant zygotes (scientific hypotheses).	A seed color/shape ratio of 9:3:3:1 exists in the offspring (statistical null hypothesis).
Planned tests: *and . . .*	Cross pea plants presumably with the *RrYy* genotype for seed color and shape (planned scientific test).	Collect a sample of seeds and compute the value of our selected statistic (planned statistical test).
Predictions: *then . . .*	We should observe a seed color/shape ratio of 9:3:3:1 in the offspring (scientific prediction).	The value of the statistic should fall well within the sampling distribution (statistical prediction).
Results: *And/But . . .*	Of the 556 seeds, 315 were yellow-round, 108 were yellow-wrinkled, 101 were green-round, and 32 were green-wrinkled (observed scientific result).	The value for Mendel's observed results (Chi-square = 0.51, df = 3) falls well within the sampling distribution (observed statistical result).
Conclusions: *Therefore . . .*	Mendel's scientific hypotheses for pea plants and his general inheritance theory are supported (scientific conclusion).	The departure of Mendel's observed scientific results from the predicted scientific results are most likely due to random variation, so the statistical null hypothesis is supported (statistical conclusion).

This argument adds a critical component to Glass and Stanley's (1970) example; namely, a reason that one treatment is predicted to be superior to the other(s). Without such a reason, even if only implicitly held, the researchers would most likely not have conducted the experiment in the first place. Hence, by omitting discussion of possible reasons (i.e., scientific hypotheses), Glass and Stanley not only omit a critical aspect of the research process, they also fail to differentiate scientific hypothesis testing from statistical hypothesis testing.

Consider a second educational example. Suppose you are a high school biology teacher and have just taught a unit on Mendelian genetics. Upon testing your students you find that some of them did very well on the test while others did very poorly. Piagetian theory argues that intellectual development occurs in stages and that formal stage reasoning patterns are needed to understand theoretical concepts, such as many of those embedded in Mendelian genetics. Based on Piagetian theory, you suspect that some of your students may not yet have developed the presumably necessary formal reasoning patterns. Consequently, you generate the following causal scientific hypothesis, planned test, and scientific prediction:

Scientific hypothesis. Formal stage reasoning patterns are necessary to understand Mendelian genetics.
Planned test. Assess students' stages of intellectual development and compare their stages with their understanding of Mendelian genetics as measured by test performance.
Scientific prediction. The concrete operational students should be the ones who fail the test, while the formal operational students should be the ones who pass the test.

In terms of statistics, you are predicting that the collective scores of the formal students will be significantly higher than those of the concrete students, where significantly refers to statistical significance. When stated in the null form, we get the following: The mean test scores of the formal and concrete students should be equal. If we conduct the appropriate statistical test and find that the mean test score of the formal students is in fact statistically higher than that of the concrete students, we can reject the statistical null hypothesis. This in turn allows us to accept the causal scientific hypothesis. In other words, we have support for the scientific hypothesis that formal stage reasoning patterns are needed to understand Mendelian genetics.

What then would you make of a report in which the author states:

> The following hypotheses were postulated and computed at the 0.05 level of significance:
> *Hypothesis 1*: Students grouped in heterogeneous cooperative groups will perform significantly higher than those grouped in friendship cooperative groups.
> *Hypothesis 2*: Students grouped in friendship cooperative groups will perform significantly higher than those grouped in traditional groups.

Are these scientific or statistical hypotheses? Clearly they are statistical hypotheses. Accordingly, it becomes incumbent upon the author to clearly state what the scientific theories and/or hypotheses are and why they led him/her to predict such a statistical outcome. In short, a solid research effort and a well-crafted research report should clearly identify:

1. The puzzling observation in need of explanation.
2. The general theory or theories that may offer a possible explanation(s).
3. Specific hypotheses derived from those theories that the study aims to test.
4. The research design, including the *If/and/then* argument identifying the reasoning linking the scientific hypothesis and the design (i.e., planned test) to clearly stated scientific prediction(s).
5. In the case of quantitative research, the specific statistic(s) used to determine the match between the scientific prediction(s) and the result(s). Note that there is no need to state statistical null hypotheses as doing so is likely to confuse readers.
6. The research results and the extent to which they match the scientific prediction(s).
7. A conclusion about the status of the tested scientific hypothesis/theory (i.e., supported, contradicted) including, if possible, ad hoc scientific hypotheses and suggestions for future research.

The next time you read, or perhaps write, an educational report, see if it spells out these critical elements and their connections. The implication is that becoming more conscious of how to conduct and report research aimed at testing scientific theories and hypotheses--not just statistical hypotheses and statistical null hypotheses--should improve the way science educators conceive of, carry out, conduct, and report their research. This in turn should better inform and improve practice.

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References

Glass, G. V., & Stanley, J. C. (1970). *Statistical methods in education and psychology.* Englewood Cliffs, NJ: Prentice-Hall.

Lawson, A. E., Oehrtman, M., & Jensen, J. (2008). Connecting science and mathematics: The nature of scientific and statistical hypothesis testing. *International Journal of Science and Mathematics Education*, *6*, 405-416.

Walker, H. M. (1958). The contributions of Karl Pearson. *Journal of the American Statistical Association*, *53*(281), 11-22.

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