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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Newton's Remark

Isaac Newton (1642-1727) once said: "If I have seen farther, it is by standing on the shoulders of giants." This is often assumed to be an indication of modesty and an acknowledgement of the contributions of those who had come before him. However, this may not be the case. Newton feuded bitterly over precedence with Robert Hooke (1635-1703) and Gottfried Wilhelm Leibnitz (1646-1716), and Hooke was a rather short person, so Newton's remark may have been a cruel barb aimed at ridiculing Hooke (Gribbin, cited in Ben-Ari, 2005).

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

Teaching Ideas

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

Science Story: Vaseline

In 1859, and in a business that relied on obtaining sperm whale oil for use as a fuel, chemist Robert Chesebrough struck troubling times. Petroleum, a much cheaper fuel, was becoming widely available and demand for whale oil was declining significantly. Deciding to move with the times, he visited the oilfields of Pennsylvania, USA to seek new business opportunities. He observed that oil workers often stopped to remove a greasy, viscous substance called rod wax from the drilling equipment. However, on the positive side, the workers also said that this nuisance substance worked wonders on cuts and burns, soothing the pain and speeding the recovery process.

Chesebrough took a quantity of rod wax to his lab in Brooklyn, New York and, after much trial and error, turned it into an odourless, tasteless, colourless, translucent substance that he called Vaseline (also called petroleum jelly by others). He tested its healing power by cutting, stabbing, and burning his own skin, and then promoted it by travelling the country in a wagon, displaying his healed wounds as evidence for its properties and giving away free samples. Demand from the public soon saw Vaseline established as a staple in medicine cabinets and making Chesebrough a very wealthy man.

Vaseline provides an effective barrier to water, sealing a wound and preventing the entry of bacteria. It also seals in the skin's moisture, preventing the skin from drying out. Vaseline has many uses, including making an excellent fire starter after being applied to cotton balls.

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

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 .

Tsunami

The moon is up, the stars are bright, the sea flows clear and blue,
The wind is still, the air is fresh, the waves shine every hue.
A ship comes plowing into the bay, the moon glinting off the mast,
The atmosphere is peaceful, but alas, this cannot last.

The town on the shore lies nestled in amidst the land,
Everything is quiet but disaster is at hand.
A chilly wind springs up out at sea, unease enters the air,
Down on the seabed something stirs, like a giant in his lair.

A tremor and a jolt, there's something very wrong,
A jitter and a shake, and the sea's mournful song.
Of quarrelling currents, and then a mighty roar,
Like that of no creature ever witnessed before.

The seabed shivers and quivers and quakes and jumps about like a mad thing,
And the water throws up its proud blue head and loudly begins to sing.
The song of misfortune, destruction and death and the song swiftly reaches the town,
Everyone pulses, unsure what to do, then panic has gulped them all down.

They know this song, the song of misery, the song of a harbour wave,
It galvanizes them into action, doing what they can to save
Their brothers and sisters, their husbands and wives,
Relatives and friends, belongings and lives.

The song has turned into an evil hiss, across the ocean it plows,
A giant shock wave has triggered it off, there's no stopping it now.
The force of the earthquake way out at sea has thrown up this maritime beast,
It pounds across the ocean mercilessly, devouring greatest and least.

The massive wave soon reaches the land, it booms as it pounds on the shore,
This is a scar the land will suffer, it will last forever more.
The land is overthrown and turns into a sea, bits of debris and wreckage here and there,
The sea's song of mourning, depression and death is heavy in the air.

Kate Olver, 12 years
Australia

Ideas in Brief

Ideas from key articles in reviewed publications

A Pedagogy for Using Classroom Response Technology

Beatty and Gerace (2009) offer technology-enhanced formative assessment (TEFA) as a research-based pedagogy for instruction that uses a classroom response system (CRS) (e.g., "clickers"). TEFA is based on the following four interlocking principles that reinforce each other:

1. Question-driven instruction focuses and motivates students.
2. Dialogical discourse (i.e., small-group and whole-class discussions) develops students' understanding and scientific fluency.
3. Formative assessment informs and adjusts learning and teaching.
4. Meta-level communication (i.e., discourse about learning the content as opposed to the predominant classroom discourse about the science content and administrative matters) helps students develop metacognitive skills and cooperate in the learning process.

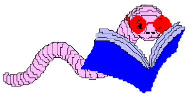
These principles are implemented by iterating through the following question cycle three or four times during a 50-60 minute period of TEFA instruction:

1. Pose a question or problem to the class. (TEFA asks questions first and uses them as a context for learning, rather than teaching first and then asking questions about what has been taught.)
2. Have students ponder the question--individually, in small groups, or both in succession—and decide on a response.
3. Use the CRS to collect and display the responses of all students.
4. Elicit students' reasoning for their chosen responses, but without indicating which, if any, is correct.
5. Develop a student-dominated discussion that enables students to practice talking science and that increases their understanding of the ideas involved. (Phases 4 and 5 usually blend together.) A second answer-collecting round might be included here.
6. Provide a closure (e.g., a summary that includes meta-level comments). (The class should now be willing to accept the message and integrate it with other knowledge.)

Elaborations, such as demonstrations, may be incorporated as appropriate. The TEFA question cycle is designed for whole-class teaching opportunities and will therefore complement other course components such as pre-class reading (for introduction to ideas), post-class homework (for more intensive problem-solving work and skills practice), group projects (for extended explorations), and laboratory exercises (for hands-on opportunities and experience "doing" science). While there is nothing about TEFA that demands the use of a CRS, its use does provide a very efficient way for all students to participate anonymously, thereby tending to increase their engagement and participation.

Reference

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology*, *18*, 146-162.



Research in Brief

Research findings from key articles in reviewed publications

Audience Response Systems in Secondary Science

Using remote devices, an audience response system (ARS) allows students to answer multiple-choice questions and displays this feedback for discussion. While ARSs have proved popular and effective in higher education, almost no research exists on their use at the secondary school level. Kay and Knaack (2009) conducted a formative study that involved 213 Canadian Years 10-12 students taking biology, chemistry, physics, and/or general science who had used an ARS in a limited way; namely, once or twice during a 1-month period. The analysis of survey and open-ended questions led to the following benefits and challenges being identified:

Benefits

- Increased student engagement, participation, and, to a lesser extent, attention paid in class.
- Effective formative assessment of student understanding.

Challenges

- Resistance, stress, and decreased student involvement and learning performance when used for summative assessment. (Twenty-one students felt that performance was hampered when an ARS was used for summative assessment.)
- Occasional technological malfunctions (e.g., flat battery).
- Resistance to using a new method of learning (reported by less than 2% of students).
- Increased stress due to time constraints when responding to questions.

To overcome resistance to the use of a new learning method, the ARS may be used in fun, practice sessions before it is used for teaching. In addition, both the rationale for its use and the intended benefits for students might be explained. While this study is seen as a starting point only for investigating the use of ARSs in secondary science classrooms, it is suggested that it might be best to use an ARS for formative purposes rather than as a test-taking tool. Also, teachers should be aware that an ARS can take time to set up and that the creation of effective questions can be very time-consuming.

Reference

Kay, R., & Knaack, L. (2009). Exploring the use of audience response systems in secondary school science classrooms. *Journal of Science Education and Technology*, *18*, 382-392.

The Affective Value of Practical Work

Affective outcomes refer to emotions and feelings students develop towards science. Practical work is often claimed to increase students' longer-term personal interest in science and/or motivate students to study science post compulsion, but is this so? Abrahams (2009) investigated this question using a study based on 25 multi-case studies involving practical lessons undertaken by 11- to 16-year-old English students in non-selective schools.

While practical work increased students' situational interest, which is unlikely to endure beyond the end of the particular lesson, it was found to be relatively ineffective in generating longer-term affective outcomes, implying a need for a more realistic appreciation of the limitations of the impact of practical work in the affective domain.

The results help to explain why students need to be continually re-stimulated by the frequent use of practical work. Students do like practical work because they see it as preferable to other learning experiences, and particularly those involving writing. However, a student can claim to like practical work yet have little, if any, personal interest in science or any intention to continue to participate in it post compulsion.

Reference

Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education*, *31*, 2335-2353.

Inquiry-Based Learning: Questions Posed and Left Unanswered

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Inquiry-based learning is defined as a method of teaching and learning that investigates questions using facts and observations that are gathered by the student or student group (Eggen & Kauchak, 2001). Once an inquiry activity is assigned to students, either individually or as a cooperative learning group, the students move through a series of steps such as making guesses, gathering data from observations, using this data to evaluate their guess, developing a conclusion, and generalizing to other situations. This approach to learning is not without concerns, or at least things to consider when using inquiry-based lessons. Questions may frequently come to mind about support and learner readiness. For example, how much help should be offered to students? How much guidance and structure should be provided? How much is too much? And when is it not enough? In addition, how does the background knowledge of the learner influence his or her performance on inquiry-based tasks? Even after deciding the amount of support or structure, teachers are often faced with an obvious difference in student work (O'Neill & Polman, 2004; Polman, 2000).

The Study

Tai and Sadler (2009) looked at the influence of inquiry-based learning on performance beyond the immediate learning task. They considered the pressure on science teachers to both prepare their learners for college and ignite their interests in science. Therefore, how well students perform in college science courses is one way to measure the long-range impact of inquiry learning. Grades in introductory science courses (biology, chemistry, and physics) for science or engineering majors were selected as the outcome variable, or measure, of the long-range impact of inquiry-based learning activities in high school.

High school grades, standardized test scores, and the number of advanced high school courses were chosen to represent the academic backgrounds of students. Students who enter college science courses with a tighter grasp on content, as indicated by prior performance and achievement, are likely to be better off in these courses. For the level of inquiry-based learning, the researchers looked at the number of student-designed projects and the level of freedom the students had in laboratory investigations.

The Usefulness of This Data

What makes this data so unique and useful is both the number of participants (2,754 biology surveys, 3,521 chemistry surveys, and 1,903 physics surveys) and the representation of 128 different first-semester college science courses (i.e., in biology, chemistry, and physics) from 55 4-year US colleges and universities. The results were not influenced by the fact that people who participated wanted to do so and were somehow different from those who did not want to participate. This is particularly important in self-report surveys if those who do participate possess some quality that not only increases their chances of participation but also interacts with the outcome of the study.

The Analysis

The data were analyzed using multiple regression analysis. Multiple regression analysis looks at the impact of multiple independent variables (i.e., number of student-designed projects, freedom in laboratory activities, standardized test scores, high school grades, and the number of advanced courses in high school) on a single dependent variable such as the grade in an introductory college science course. To ensure that no single group (biology, chemistry, or physics) was significantly different from the others, descriptive statistics were also evaluated. The three science groups were very similar with only one expected exception. In general, students enrolled in college physics had higher mathematics achievement scores. This is no surprise in that the mathematical demands in physics are different from the other two and may attract the more mathematically fluent student.

The results of the analysis can be summed up as follows: “Students with lower levels of high school mathematics attainment had greater success in college science when they reported more structured laboratory experiences. Students with higher high school mathematics attainment did not show much variation with differences in laboratory structure” (Tai & Sadler, 2009, p. 693). The results for introductory college physics students were somewhat different from the other two disciplines in that the degree of freedom in a laboratory setting seemed to have no impact on grade predictability, regardless of the most recent high school mathematics grade. This likely has to do with the mathematical expectations of physics more than anything else.

Teaching Implications

With the ever-increasing push for research-based practice in education, an important question for practicing teachers is how to use this research in deciding when to use inquiry-based instruction and then how much support to provide during the process. These results do not suggest that inquiry-based learning is a waste of time and should not be used. Instead, it prompts a line of thinking about what to expect from inquiry-based learning and its overall purpose. It begs for the separation of learning content from learning the scientific process. It is often assumed, these authors included, that students can learn content and process simultaneously. To dispel that idea is beyond the reach of a single study. However, these results seem to suggest that certain teaching activities are effective for content, some are effective for teaching processes like scientific inquiry, while others are effective at teaching both. Inquiry is the foundation of the scientific process and is essential in developing scientists. Allowing students to participate in such an academic endeavor may not only teach the process of science, but also motivate the interests of future young scientists. This leads directly to the idea that inquiry learning may not be as effective a tool at teaching content, but more effective in teaching process. Simply put, these results suggest that inquiry-based learning may not provide the growth in content knowledge that it is often expected to. That objective may be better reached through more structure learning environments. Furthermore, when inquiry is implemented in a science classroom, these results also suggest that the academic background of a learner should be considered in deciding how much support to provide and the degree of freedom to allow.

As a future, or current, teacher reading this article, I would want to know what suggestions or helpful pieces of information I could take away from this study. Here are the pieces of information that may provide clearer answers on inquiry-based learning activities. First, the academic background or aptitude of students seems to play a role in the effectiveness of inquiry-based learning. Second, students with “weaker” academic backgrounds appear to be better suited for highly-structured laboratory activities. Next, inquiry-based learning seems to have no impact on the academic performance (grades) of students with strong academic backgrounds. This last piece of information seems to suggest that for learning new content, inquiry-based learning may not be the most effective strategy. Finally, inquiry activities seem to have a place in science education. That place is in the development of independent thinking, a necessary skill for success as a scientist. Developing that skill is important and warrants the use of inquiry learning. In closing, the use of inquiry activities requires a careful consideration of the learners participating in the activity as well as the objectives of the activity. Whether one has high-background learners, low-background learners, or a mix of both will influence the nature of the activity and how the teacher might differentiate within his or her classroom. Additionally, the objectives of the lesson--whether they focus on content or process--will also inform the use of these activities.

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Readers’ Forum

What is a Theory?

Much writing appears to be communicating an incorrect idea about the notion of a scientific theory and, since a theory represents the pinnacle of the scientific endeavour (i.e., the very best that science can achieve), I think this is an issue that needs addressing. Consider the following descriptions, for example:

- "Some scientific explanations are so well established that no new evidence is likely to alter them. The explanation becomes a scientific theory. In everyday language a theory means a hunch or speculation. Not so in science. In science, the word theory refers to a comprehensive explanation of an important feature of nature supported by facts gathered over time. Theories also allow scientists to make predictions about as yet unobserved phenomena" (National Academy of Sciences, cited in *Theory*, 2010)
- "A scientific theory is a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. Such fact-supported theories are not "guesses" but reliable accounts of the real world. The theory of biological evolution is more than "just a theory." It is as factual an explanation of the universe as the atomic theory of matter or the germ theory of disease. Our understanding of gravity is still a work in progress. But the phenomenon of gravity, like evolution, is an accepted fact" (American Association for the Advancement of Science, cited in *Theory*, 2010)
- A theory is "a well substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses" (McComas, 2003, p. 143).

Now certainly, a theory plays an explanatory role, but there is another common feature of these descriptions that I think is problematic: Why does a scientific theory need to be an explanation that is well-established, is well-substantiated, has withstood repeated testing, or the like? This idea is to be found frequently across much of the literature where, in the same vein, we even find that "a superseded, or obsolete, scientific theory is a scientific theory that was once commonly accepted, but that is no longer considered the most complete description of reality by a mainstream scientific consensus" (*Superseded scientific theories*, 2010, ¶ 1).

Can't we have a theory with little support that is rejected? The spontaneous generation theory consisted of three basic components: Living things arise spontaneously from nonliving materials when an unseen life-giving vital force enters the nonliving material, different kinds of nonliving materials give rise to different kinds of living things (e.g., rotting meat gives rise to flies, while old rags give rise to mice), and spontaneous generation has occurred in the past and occurs today. Now, this theory may have been rejected, but surely it is still a theory? Can't we have a theory that is yet to be tested, and that even perhaps goes on to become a widely-accepted explanation? And so on. The idea that a theory needs to be an explanation that has stood the test of time, or similar, appears erroneous.

The definition I'm presently using is as follows, and comes largely from Lawson (2008): A scientific theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena. Examples are spontaneous generation theory, biogenesis theory, and atomic-molecular theory. The distinction between a hypothesis (a possible, or proposed, scientific explanation for the observed facts and laws) and a theory can be somewhat arbitrary. While a hypothesis attempts to explain a specific puzzling observation (or group of closely-related observations), theories are more complex, more general, and more abstract. Some theories have been modified or rejected, while others--the most useful ones--are standing the scientific test of time, which gives us increasing confidence in them.

We might also ponder about how the term *theory* may have come to be ill-defined in this way. To date, the only thought I've heard is the following: "In math a conjecture when 'proven' becomes a theorem. I suspect someone in the past may have mistakenly transferred this idea to science and stated that 'a hypothesis when well supported (proven) becomes a theory' (A. Lawson, personal communication, December 10, 2009). So, if you have a thought about this, do please submit it to the journal.

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A Teacher's Guide to Facilitating Conceptual Change

Several decades ago, few research studies were devoted to exploring children's ideas of the scientific world. These early studies demonstrated that children's minds were not the "blank slates" they were once perceived to be, but instead filled with ideas and explanations about natural phenomena that were often different from accepted scientific knowledge. The discoveries that resulted from these studies would become the foundation for thousands of future studies exploring children's alternative science conceptions and their implications for science education. The rapid growth of research about alternative conceptions can be illustrated by the expansion of the Pfundt and Duit (1985) bibliography, which saw a 12-fold increase in 24 years (700 references in its first edition compared to 8,000 references in its last edition [Duit, 2009]). The body of literature in this field describes hundreds of alternative conceptions in almost every area of science, and also offers suggestions for instructional strategies that may facilitate conceptual change (i.e., strategies designed to help students overcome their alternative conceptions). But are the suggestions offered in these research studies working?

Despite the vast amount of research that exists regarding conceptual change, recent evidence suggests that teachers are relatively unaware of the research and thus do not use the recommended instructional practices in their classrooms (Gomez-Zweip, 2008). Furthermore, several studies have demonstrated that teachers sometimes possess alternative conceptions about science that are similar to those held by students (e.g., Burgoon, Heddle, & Duran, in press). As a result, teachers may be less likely to effectively facilitate conceptual change in their classrooms, and students may retain their alternative conceptions throughout their academic careers, and even into their adulthood (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Keeley, Eberle, & Farrin, 2005). In fact, it has been well documented that changing students' prior conceptions is difficult, due to the often idiosyncratic and resilient nature of alternative conceptions (Wandersee, Mintzes, & Novak, 1994). So, what can teachers do to effectively address their students' alternative conceptions and promote conceptual change? Here are some general suggestions for teachers to identify and address their students' alternative conceptions in science topics.

The first step in facilitating conceptual change is for teachers to become aware of their own alternative conceptions and how those conceptions relate to those commonly held by students. This step is important because teachers who have alternative conceptions may unknowingly reinforce students' existing alternative conceptions or propagate new alternative conceptions during science instruction (Sanders, 1993; Soyibo, 1995). Examples of alternative conceptions that have been demonstrated by both teachers and students include:

- Gravity increases as objects increase their height above the ground.

- All metals are attracted to magnets.
- Some objects are inherently warmer or colder than other objects (e.g., metal objects are colder than wooden objects).
- Gases are "lighter" than solids or liquids.

There are several ways by which teachers can become aware of their own alternative conceptions. First, attending professional development programs that are science content-focused generally helps to improve teachers' science content knowledge. Second, there are several teacher-friendly books devoted to improving teachers' content knowledge in science. William Robertson's *Stop Faking It!* series, with several books on concepts such as Force and Motion (Robertson, 2002b) and Energy (Robertson, 2002a), is an excellent resource for teachers to reflect on and improve their conceptual understanding of several science concepts. Third, the Uncovering Student Ideas in Science series (Keeley et al., 2005) offers a total of 100 formative assessment probes designed to elicit students' alternative conceptions in science. Since teachers and students often have similar alternative conceptions, teachers could answer the probes to make themselves aware of the alternative conceptions they possess and how those conceptions relate to those commonly held by students.

The second step in facilitating conceptual change is for teachers to become aware of the alternative conceptions held by their students. Teachers can do this in two different ways. One method is to engage students in formative assessment activities, such as those found in the "Students' Alternative Conceptions" section of *The Science Education Review*. Formative assessment activities can take many forms, including written probes, sorting activities, drawing, and classroom discussions. Regardless of the format, formative assessment activities should elicit students' ideas about the science concept being assessed. Therefore, true and false or multiple-choice questions, for example, are maximally useful if they are coupled with an open-ended component. An example of a useful resource for formative assessment activities is *Science Formative Assessment* (Keeley, 2008), which includes 75 different formative assessment strategies.

Another method for identifying students' alternative conceptions is to consult the past research that has been done regarding students' alternative conceptions in science. The reason this method is useful is because "the set of common alternative conceptions for a given science topic is relatively small" (Wandersee et al., 1994, p. 181). Therefore, if an alternative conception has been frequently documented in past research, chances are that some of the students in a given classroom will also possess that conception. There are several books that identify the common alternative conceptions for different areas of science, including *Making Sense of Secondary Science: Research Into Children's Ideas* (Driver et al., 1994) and Chapter 15 of *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993). It is pleasing to see students' alternative conceptions being included in commercial curriculum materials (e.g., Beyer, Delgado, Davis, & Krajcik, 2009).

The third and final step in facilitating conceptual change is addressing students' alternative conceptions. According to Scott, Asoko, and Driver (1991), conceptual change strategies generally belong to one of two categories: 1) strategies based on cognitive conflict and its subsequent resolution, and 2) strategies that extend students' previous conceptions towards the accepted scientific viewpoint. Regarding the first category, teachers can promote cognitive conflict in their classrooms by engaging the students in demonstrations or activities that directly challenge the students' existing conceptions. After the students' initial conceptions are challenged, the cognitive conflict can be resolved by presenting the scientific viewpoint, and giving the students opportunities to apply the new conception in several contexts (Cosgrove & Osborne, 1985).

Regarding the second category of conceptual change strategies, teachers can extend students' existing conceptions toward the scientific viewpoint by using analogies that appeal to the students' intuitions. For example, students struggling to understand how a table can exert an upward force on an object like a book might benefit from an analogy to a more familiar situation, such as a hand holding up a book (Brown & Clement, 1989). If students have difficulty connecting the base of the analogy (hand holding up a book) with the target (book on a table), several more analogies can be used, with each progressively being a closer representation of the target, to extend students' conceptions toward the scientific viewpoint. For example, after presenting the "hand holding a book" analogy, teachers could use several bridging analogies, such as a book on a spring, a book on a piece of foam, and a book on a flexible board, to connect the first analogy to the scientific view (Clement, 2008).

For more than 30 years, research has documented that students' alternative conceptions are major barriers to science learning. Therefore, it is imperative for teachers to make conceptual change a priority in their classrooms. However, evidence suggests that teachers are not prepared to facilitate conceptual change, most likely due to the fact that teachers are unaware of the most effective strategies and resources. Although changing students' conceptions can be difficult, teachers should take advantage of the existing body of research and also follow some of the general suggestions that we are providing here to begin addressing the alternative conceptions that hinder the scientific development of their students.

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

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

Molecular Collisions

Does the frequency of collision of a molecule of a gas with other molecules of the gas in a closed container change as the temperature of the gas is lowered under isobaric (i.e., constant pressure) conditions? If so, how?

My answer is that the frequency of collisions will increase as the temperature is lowered. Consider a gas molecule of scattering cross-sectional area A moving with an average speed v. In time t it will sweep out a volume given by Avt. The number of collisions it will suffer in this time is equal to the number of molecules to be found within this volume, say N.

The frequency of collisions is N/t. So:

- If the volume is quartered, there will be four times as many molecules per unit volume.
- If the temperature is correspondingly quartered (as it would need to be at constant pressure), the average speed of the molecules is halved. (T is proportional to the mean of the average speed squared.)

Although the first bullet point would tend to quadruple the frequency by quadrupling N for a fixed volume, the second bullet point would halve the volume traced out per second and hence the frequency. The effect of both together would be to double the frequency of collisions.

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One may assume ideal gas behaviour (in the sense that the equation $pV = nRT$ is valid). This problem is addressed in Atkins and De Paula (2006). Here the authors show that the collision frequency, z, in a gas is given by the equation

$$z = \frac{\sigma \bar{c}_{\mathrm{rel}} p}{kT}$$

where $\sigma = \pi d^2$ is the collision cross-section of the molecules (d is the collision diameter), k is the Boltzmann constant, p is the pressure, T is the thermodynamic temperature, and $\bar{c}_{\mathrm{rel}}$ (the relative mean speed; that is, the speed with which one molecule approaches another) is given by

$$\bar{c}_{\mathrm{rel}} = \left(\frac{8kT}{\pi\mu}\right)^{1/2} \quad \text{and} \quad \mu = \frac{m_{\mathrm{A}} m_{\mathrm{B}}}{m_{\mathrm{A}} + m_{\mathrm{B}}}$$

providing the molecules are diatomic, composed of atoms A and B. Combining the two equalities, one gets

$$z = \frac{2\sqrt{2}\sigma p}{(kT\pi\mu)^{1/2}}$$

Thus it is obvious that, providing p = constant, the collision frequency is proportional to the inverse square root of the thermodynamic temperature

$$z = K\,T^{-1/2} \qquad K = \frac{2\sqrt{2}\sigma p}{(k\pi\mu)^{1/2}}$$

meaning that the collision frequency increases with decreasing temperature, which may not be what one might expect.

Reference

Atkins, P. W., & De Paula, J. (2006). *Physical chemistry* (8th ed.). Oxford: Oxford University Press.

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Laboratory Safety Guidelines

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

#10 of 40. ***Schedule regular departmental safety meetings for students and staff to discuss the results of inspections and aspects of laboratory safety***

Safety meetings are an integral part of a good safety program. You need to have a time when you and your colleagues can get together and focus on safety issues. Meetings that come as a follow-up on a regular safety inspection provide a good basis for discussion of problems and needs.

Both undergraduates and graduate students can benefit from participating in these discussions. They become more familiar with safety problems. They see that the faculty is concerned about these issues. They may even contribute some good ideas. Remember, no one's been telling them for years that "it can't be done, it’s never happened before, it won’t happen here, and it’s not in the budget."

Is a whole meeting too much for you to swallow! How about having safety as a regular agenda item on your normal department meeting? Set aside 10-15 minutes for a safety topic. Ask a member of the department to pick a safety topic related to his or her particular interests and present a 5-minute review for the benefit of the rest of the group.

Borrow one of the audio-visual programs from the Lab Safety Institute (LSI) and show it as part of your meeting. We have several that would be interesting and appropriate. LSI operates an audio-visual lending library with over 150 items. LSI members do not pay a rental fee; just the shipping and handling charges. Visit the LSI website (www.labsafety.org) to see the list of library holdings.

Further Useful Resources

ComPADRE (http://www.compadre.org/) The ComPADRE Digital Library is a network of free online resource collections supporting faculty, students, and teachers in physics and astronomy education.

Student Response Network (SRN) (http://studentresponsenetwork.com/) Audience response system software that allows students to respond using networked computers (wired or wireless) or an iPhone/iPod. The questions may be asked verbally or via a Word document, PowerPoint slide, or any other application. Includes free-text responses (i.e., a word, number, phrase, and/or sentence).

The Manga Guide to Physics (http://nostarch.com/mg_physics.htm) This book would be an interesting addition to any school science library, as well as the personal library of upper level elementary or high school students who are interested in science but who may not be ready to admit it to their peers. Any student who wants to see real-life examples illustrating physics concepts they study at school will find the book very useful. It is written in the form of translated manga (i.e., a comic book of Japanese origin) and describes a star tennis player, Megumi, who is excelling on the court yet very scared of physics in the classroom. Luckily for her, Megumi befriends Ryota, her male physics-geek classmate. Ryota uses real-world examples to help Megumi understand classical mechanics, and improve her tennis game along the way, while Megumi introduces him to sports!

Science teachers looking for innovative ways to present physics concepts to their students will enjoy reading the book and using it in the classroom. The dialog between Ryota and Megumi is well-written and it has a large number of thoughtful, yet informally stated, questions targeting major student physics misconceptions and difficulties. The inclusion of 10 laboratory activities and real-life problems that combine multiple representations--pictures, graphs, diagrams, and verbal descriptions--are a great asset to the story. For example, Newton’s third law (i.e., the action-reaction law) is clearly explained using the interaction between a tennis racket and a ball, making sure the reader understands that the forces are applied to two different objects. The problem of finding the distances traveled by objects while their velocities vary uses the concepts of calculus, yet they are introduced in such a skilful manner than the students do not need to have advanced mathematical background to understand them. The authors clearly discuss why the force is a measure of interaction between two objects and why we cannot think of an object “having its own force” (p.92). The discussions of the laws of conservation of energy and momentum are also very interesting and clearly relate to everyday life.

While at times science concepts are explained somewhat too informally (e.g., when acceleration is explained, negative acceleration is said to be equivalent to a decrease in an object’s speed, which is not always true, and the term force [$\boldsymbol{F}$] is used instead of the term net force [$\boldsymbol{F}_{\text{net}}$]), and one might argue that sometimes a more careful description is needed, the book will be a great start for curious students and will make them want to read more formal physics books. I would strongly recommend it to physics teachers and students.

Reference

Nitta, H., Takatsu, K., & Trend-Pro. (2009). *The manga guide to physics*. San Francisco: No Starch Press.

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Teachers' Instructional Decision-Making: Is it Gender-Biased?

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Abstract

This study examines teacher interactions with boys and girls in single-gender technology classes. We analyzed transcripts of videotapes of instruction, interviews with the teachers and students, student questionnaires, and final robot programs. Girls and boys differed in a number of ways, and teachers explained their differing interactions with boys and girls as responses purposely designed to address those differences. This finding is an important consideration as we strive to design instruction that promotes the learning of girls and boys equally, but we should not let it be an argument for the status quo. (This paper is a summary of Voyles, Fossum, & Haller, 2008)

Most teachers in today's schools are aware of the cultural gender roles that are taught to children well before they enter school and that can limit students' options as they become adults. The research from public school classrooms shows how teachers may unintentionally contribute to the perpetuation of gender stereotypes especially during instruction in STEM (Science, Technology, Engineering, and Math) areas.

As early as 1973, Good, Sikes, and Brophy (1973) reported that boys dominated their elementary classrooms in a number of ways, and subsequently similar findings have been reported for all grade levels. For example, teachers have been found to call on boys more often, accept more call outs from boys, give boys more praise and more criticism, ask boys more higher-level questions, and more often ask boys to expand on a response (Drudy & Chathain, 2002; Einarsson & Granstrom, 2002; Guzetti & Williams, 1996; Martin & Newcomer, 2002). Female and male teachers are equally likely to show gender bias (Martin & Newcomer, 2002; Sadker & Sadker, 1994). In 2000, despite a growing awareness of gender stereotyping, the American Association of University Women (AAUW) reported that classroom bias was a factor in girls' decisions to pursue STEM-related coursework and careers. What little is known about instruction with students working in small groups shows similar instructional bias (Forgaz & Leder, 1996).

Two computer scientists (Tim Fossum and Susan Haller), who were aware of gender bias and concerned about the large underrepresentation of girls in computer science, decided that they would offer a summer robotics course in single-gender sections so that girls would not be competing for attention with boys. They also wanted to compare the two sections. With an educational researcher (Martha Voyles), they developed two research questions:

1) In a single-gender robotics course, do boys and girls differ with respect to enrollment, interest, prior experience, achievement and self-confidence, cooperation, and requesting help?
2) Do teachers differ in the way they interact with boys and girls who are working in same-gender triads in a robotics course?

Method

Course description. During each of two summers we taught 2-week-long, single-gender sessions of a robotics course for rising fourth-, fifth-, and sixth-grade students. Students spent 3 hours each day working in assigned groups of 3 sharing a robotics kit and a computer. The instructional materials were adapted from the curriculum developed by the Center for Engineering Education Outreach at Tufts University and used a discovery approach. After building their Lego robots using typical Lego pictorial instructions and learning some basic commands used by the Robolab program, students were given challenges that required the group to engineer various moving features for their robots and then program their robot to use the features. For example, the group with a robotic house had to design a door that would play music and open automatically when the doorbell was pressed. Each challenge had many possible solutions. Four instructors provided assistance but did not provide solutions.

Data collection. In each of the four sessions, two student groups were randomly selected to be videotaped, and the videotapes were then transcribed. We interviewed individually the students in those two groups, plus an additional non-videotaped group, at the beginning, middle, and end of each session. We also interviewed the 4 teachers every day. All of the students completed a daily, three-item questionnaire about their interest, course difficulty, and group cooperation, and we selected the best final robot program from each group to use as a measure of achievement.

Data analysis. We coded all the student-teacher interactions using three codes: 1) initiated by student or teacher, 2) type of task students were working on (building, programming, or engineering), and 3) function of the talk (social, procedural, feedback, promoting cooperation, or instructional). The instructional category was then further subdivided into seven categories: 1) low level exchanges, 2) high level exchanges, 3) doing things for students, 4) thinking for students, 5) explanation, 6) summarizing, and 7) checking for understanding. Each interaction was coded with all the applicable codes. Using grounded theory, the student and teacher interviews were analyzed for common themes across interviews. A grading rubric was developed for the students' final programs.

Findings

Our first research question was whether there would be gender differences among the students. The most pronounced difference was in initial interest. In the first year only 3 girls enrolled for the class whereas 28 boys tried to enroll. We had to actively recruit 15 girls and turn away 10 boys. The same thing happened the second year. The authors chose to work with students entering fourth, fifth, and sixth grades because other researchers (AAUW, 2000) have reported that girls' interest in technology declines in middle school. Our study demonstrates that when it was a matter of selecting courses, gender preferences are obvious even with fourth- to sixth-grade girls. However, it was not difficult to recruit girls, and in their initial interviews before they knew much about what they would be doing, the girls claimed to be interested in computers and in construction activities and did not express a preference for art or craft activities. The boys did report much more experience with Legos, and this was evident in their initial building of robots from a set of directions. However, their greater experience with Legos did not make them any better than the girls when it came to designing moving parts. Even though the project compared recruited girls with volunteer boys, we found no differences in interest or enjoyment of the course in the interviews and no significant differences in daily ratings of interest or course difficulty, although the girls' ratings were slightly more favorable. There were also no differences in achievement in the final programs they wrote.

Girls did initiate more interactions with teachers than did boys, and this applied to most categories of talk. Because some of the questions girls asked were ones to which they already knew the answers, such as asking if they should clean up at the end of the day or use a slow motor speed as per instructions, many of the questions seemed designed to develop a relationship with the teachers and show themselves to be good students rather than to get information. Neither an examination of the transcripts nor the teacher interviews indicated that the girls actually needed more assistance except with the initial building task. In addition, girls were somewhat more cooperative with the instructors. Similar numbers of boys and girls expressed a preference for group or individual work, but the coding of the videotapes, students daily ratings of their group work, and teacher interviews indicated that the girls were somewhat more cooperative with their peers. Looking at the data by group shows that it is a subset of boys that are responsible for most of the difference.

Our second research question was whether teachers' interactions with students differed by gender. We did find significant differences, and those differences largely corresponded to gender differences. Table 1 shows the student gender differences and the corresponding teacher behaviors. Across all types of interaction, teachers initiated many more interactions with boys than with girls. In their interviews, the teachers spontaneously talked about this, saying they did it on purpose because in their opinion the boys were less likely to initiate interactions with teachers even when they were floundering. Because Fennema and Peterson (1985) have suggested that boys' greater achievement in STEM areas might be due to greater perseverance, we asked the teachers if they thought the girls were too dependent and quick to ask for help. The teachers responded with an emphatic "no." They explained that they could trust girls to ask for help when they needed it, but boys glossed over problems, ignored contradictory results, and even blamed faulty robot behavior on mechanical or computer error rather than programming mistakes. In terms of explicitly instructional talk including higher- and lower-level questions and the strategies teachers used to assist students, the only difference was that teachers were somewhat more likely to think for, or do things for, girls. Much of that teacher behavior, however, was provided during the initial robot building where girls were much less familiar with Lego directions and during the first girl session when teachers were unfamiliar with the curriculum and anxious that the recruited girls have a positive experience. Still, this is an area of concern.

Conclusion

One could interpret the results of our research to mean that teachers do not display gender bias, and that what appears to be bias in some prior research is simply teacher responsiveness to gendered behaviors that students have learned in the wider culture and bring to the classroom. We do think it is critical in doing workshops about gender bias with teachers to acknowledge that they do have instructional reasons for their behavior and that students come into their classes with gender differences that must be addressed. Nonetheless, we think that rather than reinforcing gender differences, schooling should help students identify and challenge behavioral mores that tell girls and boys what they should be interested in and how they should behave.

One could also interpret our results as providing a rationale for single-gender classes in STEM areas. From our data an argument could be made that since the literature generally reports that boys receive more of their teachers' attention than girls, and our research shows that when there is no competition with boys, girls engage in more teacher interactions than boys, coeducational classes may be doubly detrimental for girls. However, we would argue that a better approach would be to use this research to design better coeducation. One reason is that although we did find evidence for masculine and feminine learning styles, individuals displayed them to a greater or lesser extent, and they were not perfectly coincident with gender. For example, the highest achieving boy group had more interactions with teachers over programming than any other boy or girl group. Another reason is that we found no differences in the actual instructional questioning teachers used with boys and girls. Additional research may be able to tell us if, for example, there is an optimum amount of teacher-student interaction or an optimum amount of cooperative work. In the meantime, we think that both styles have limitations, sometimes where the other has strengths, and that with knowledge about gender differences, teachers could design instruction that would help students stretch themselves to develop the flexibility to learn and function in a variety of instructional environments.

Table 1
Characteristics of Feminine/Masculine Style and Corresponding Teacher Behaviors

Style	Teacher behavior
Feminine	
Less inclined to enroll in a technology course	More encouragement and assurance of correctness
Lack of experience in male domain activities	More inclined to do and think for girls
More likely to initiate interaction with teachers	Fewer teacher initiated interactions
Somewhat more cooperative with peers	Fewer interactions about cooperation
More attention to directions	Fewer corrective interactions
More social, more responsive to teachers, use talk to develop relationship with teacher	More social interactions with girls
Masculine	
More inclined to enroll in a technology course	Less encouragement and assurance of correctness
Experience with male domain activities	Fewer teacher-student interactions during building and technical tasks
Less likely to initiate interaction with teachers	More teacher-initiated interactions
Somewhat less cooperative with peers	More interactions about cooperation
Less attention to directions	More corrective interactions
Less social	Fewer social interactions

By far the largest student difference was in the enrollment pattern. Given this large difference, we expected to find accompanying differences in attitudes toward computers and toward building and engineering robots. However, that was not the case. It seems that girls behave in gender-stereotypic ways even before they have developed the attitudes that go with such behavior. Even though they were recruited for the course, they enjoyed it as much, if not more, than the boys, and they were equally good at it. The fact that fourth- through sixth-grade girls do not differ from boys in their attitudes toward technology argues strongly for providing them with experiences in these areas so that whatever attitudes they develop will be based on personal experience rather than on gender stereotypes. This might well result in more girls discovering technology interests and could eventually address the large gender imbalance in computer science and engineering, but even if that did not happen, girls would at least be making their own decisions about their interests rather than simply accepting society's ideas about what girls like or should do.

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Professional Development of Science Teachers: History of Reform and Contributions of the STS-Based Iowa Chautauqua Program

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Abstract

During the last quarter of a century, it became abundantly clear that the desired reforms in science teaching and learning could not be accomplished without significant professional development of in-service science teachers. Yet, there was a dearth of effective professional development models that could lead to the kind of instructional reforms desired. It was soon realized that professional development itself must undergo significant reform. New guidelines for professional development began to be developed in order to reform it. We trace the history of this reform and describe a model that emerged as an exemplar of the new guidelines. This model has been used extensively in the USA and in many other countries of the world. The characteristics of the model, research related to its effectiveness and impact, and its implementation around the world are presented.

Professional Development: Need and Role in Science Education Reform

> What lends urgency to professional development is its connection to reform and to the ambitious new goals for education that are to be extended to all students. Can professional development lead educational reform? (Sykes, 1996, p. 465)

This question, raised by Sykes, regarding the critical role of professional development in educational reform provides the foundation for this exploration of professional development as a reform mechanism and the contributions of an STS-based approach to the K-12 in-service science teachers professional development process. Given the increasing impact of science and technology in contemporary society, making science relevant to the lives of all students emerged as a key aspect of reform in science education during the final two decades of the 20th century (Hickman, 1982; Hurd, 1986, 1989, 1990, 1991, 1994, 1997; Kennedy, 1982; McCormack & Yager, 1989; Yager, 1984a, 1984b, 1998; Yager & Tweed, 1991). Several science education reform efforts around the world during that time, such as *Project 2061* in the USA (American Association for the Advancement of Science [AAAS], 1994) and *Science Education for the Future* in the UK (Millar & Osborne, 1998) reflected this common concern for science education that is relevant to the lives of all students. Achieving such reform that effectively addressed this common concern is a complicated task and cannot be accomplished simply by introducing new curricular materials or technological gadgetry into the classrooms. With the recommendations for reform grew a growing realization of the importance of ongoing professional development of in-service science teachers in order to achieve the vision of the desired reform. For example, the National Science Education Standards (NSES) developed in the USA (National Research Council, 1996) included a section devoted entirely to professional development standards. Long before the publication of NSES, Sparks (1983) noted: "Staff development offers one of the most promising roads to the improvement of instruction" (p. 65).

While the importance of professional development in bringing about science education reform became increasingly obvious, it also became evident that the traditional forms of professional development were severely limited in their capability to bring about the desired reform. Traditionally, professional development of teachers was packaged into an afternoon or a full day in-service session, which seemed to be designed as a quick-fix for teachers' inadequacies and incompetence (Guskey & Huberman, 1995; Huberman & Guskey, 1995; Kyle, 1995). This form of professional development came to be widely criticized as inadequate and inappropriate in the context of contemporary educational reform efforts, and as being out of step with current research about teacher learning (Darling-Hammond & McLaughlin, 1995; Fullan, 1995; Kyle, 1995; Lieberman, 1995; Lieberman & Miller, 1992; Little, 1993; Miles, 1995). The need for a new perspective on professional development of teachers emerged as a crucial first step in the reform process. For example, Fullan (1995) noted that "radical changes are required in how teachers learn and in their opportunities to learn" (p. 266) and Lieberman (1995) warned: "The conventional view of staff development as a transferable package of knowledge to be distributed to teachers in bite-sized pieces needs radical rethinking" (p. 592).

Making science relevant to the lives of students requires, among a variety of other factors, a classroom environment in which they can be actively involved in making meaning of the information within a relevant context. Teachers need to learn to create a suitable environment and employ strategies that encourage active questioning and identification of issues and answers by students. They need to be able to encourage students to challenge the information presented and discuss its personal relevance. These abilities cannot be developed through brief, “one-shot” in-service sessions traditionally regarded as professional development. They require carefully designed, sustained, professional development opportunities that actively involve teachers in the learning process. As Shanker (1996) noted, such professional development will be far more effective than the traditional practice:

> For professional development to be effective, it must offer serious intellectual content, take explicit account of the various contexts of teaching and experiences of teachers, offer support for informed dissent, be ongoing and embedded in the purposes and practices of schooling, help teachers to change within an environment that is often hostile to change, and involve teachers in defining the purposes and activities that take place in the name of professional development. (p. 223)

Therefore, reforming professional development from brief in-service sessions to comprehensive programs became essential to the broader science education reform efforts.

Effective Professional Development or Business as Usual?

The concern regarding teacher professional development worldwide was well expressed by an Australian teacher, as follows:

> Staff development days in education are still being called curriculum days—and they often just have a focus on the students and the curriculum in schools. ...They should focus on professional development for teachers because that’s going to benefit the kids as well. (Ball, Jones, Pomeranz, & Symington, 1995, p.21)

Until recently, staff development for teachers was dominated by a “training” paradigm (Grant, 1997). Within this paradigm, professional development of teachers is characterized by terms such as “teacher training” and “in-service education.” Staff development activities under this paradigm have traditionally been packaged into short-term, discrete, in-service sessions or workshops. Most of these workshops tend to follow a somewhat standard format whereby an outside expert (or consultant) “blows in, blows up, and blows out” while teachers are expected to passively receive whatever was “blown up” and try to make use of it in their instructional practice. They seldom ever see or hear from the expert again.

The training paradigm evolved concurrently with curriculum development projects of the 1960s and 1970s. The need to help schools and teachers adopt the new curricula legitimized the training format whereby "teachers were ‘trained’ to faithfully implement the various innovations" (Blunck, 1993, p. 23). Teachers were viewed as “vessels to be filled rather than lamps to be lit” (Blunck, 1993, p. 24). The major problem with the training paradigm was its view of teachers as passive recipients of knowledge and its prescription from the top down. The realization of the limitations of the “teacher training” model led to formal studies of in-service programs. For instance, Berman and McLaughlin (1978) studied federally-supported programs and found that the programs that made a lasting difference in schools were characterized by in-service activities that had a local focus, allowed teachers to experiment with and customize the innovation to suit the local context, had active support from the administrators, and involved extended opportunities and ongoing support for teachers to implement the innovations. Findings such as these stimulated new interest in the in-service education of teachers. New guidelines for effective in-service education were developed. For instance, exhaustive research undertaken by Evans (1986) led to a set of 22 guidelines.

In spite of the development of these guidelines, very few programs actually followed them in designing in-service activities (Liu, 1992). Even though staff development came to be viewed as a key aspect of school improvement efforts (Sparks & Loucks-Horsley, 1990), much of what was offered as professional development of teachers continued to follow the training paradigm and remained largely out of touch with the emerging guidelines. Miles (1995) paints a very sobering picture of a majority of professional development work that emanated from the training paradigm and dominated the educational arena:

> It’s everything that a learning environment shouldn’t be: radically under resourced, brief, not sustained, designed for “one size fits all,” imposed rather than owned, lacking any intellectual coherence, treated as a special add-on event rather than as part of a natural process, and trapped in the constraints of the bureaucratic system we have come to call “school.” In short, it’s pedagogically naive, a demeaning exercise that often leaves its participants more cynical and no more knowledgeable, skilled, or committed than before. (p. vii)

Training-based discrete workshops may be useful for delivering certain types of information such as methods for organizing portfolio assessment of students’ work (Little, 1993) or teaching specific skills such as the use of a particular computer software package (Grant, 1997). However, their usefulness as the dominant channel of professional development in diverse contexts has been widely criticized (Darling-Hammond & McLaughlin, 1995; Fullan, 1995; Kyle, 1995; Lieberman, 1995; Lieberman & Miller, 1992; Little, 1993; Miles, 1995; Sykes, 1996). Advances in research on adult learning (Wood & Thompson, 1980) and the change process (Fullan, 1993), coupled with identification of new needs for science education reform, stimulated new views about professional development of teachers and its role in improving education.

Professional development began to be recognized as an ongoing process of teacher growth rather than a series of discrete remedial events to fix their inadequacies (Kyle, 1995; Kyle & Sedotti, 1986), leading to the development of professional communities of learners (Little, 1993) and a pathway to producing new professional cultures in schools (Fullan, 1995). Within this new paradigm, teachers are regarded as sophisticated and responsible professionals rather than “mere functionaries handing out and collecting materials prepared by commercial or bureaucratic sources outside the classroom" (Renyi, 1996). Teachers are also being recognized as change agents whose equal partnership in defining and designing professional development activities is critical to the success of contemporary reform efforts. Based on the works of Sparks (1995), Little (1993), and Sykes (1996), the National Foundation for the Improvement of Education in the USA summarized the major aspects of shifting emphases in teacher professional development shown in Table 1 (from Renyi, 1996, p. xvi). The emphases in the right-hand column of Table 1 can also be regarded as a list of key elements that make professional development effective in the broader context of educational reform.

Table 1
Shifting Emphases in Teacher Professional Development

From	To
Isolated, individual learning	Learning both individually and in the context of groups, such as the whole school faculty and teacher networks interested in particular subjects
Fragmented, one-shot "training"	Coherent, long-range learning
District-level, one-size-fits-all programs	School-based learning tailored to the needs of all the students in the building
Bureaucratically convenient	Focused on student needs
Outside the workplace	Embedded in the job and closely related to both student and teacher needs
Experts telling teachers what to do	Teachers taking an active role in their own growth
Skills that can be used by everyone and therefore available in depth to no one	Involvement of all teachers and instructional leaders in developing new approaches to teaching based on their needs
Teachers as passive receivers	Teachers and administrators as active makers of their own learning
Adult learning as an add-on that is not essential to schooling	Adult learning as a fundamental way of teaching and a transformation of schooling
Measuring effectiveness by attendance at workshops	Measuring effectiveness by improvements in teaching and learning

Specific to science education, guidelines have emerged for the professional development of science teachers. Examples of these include Standards for Professional Development for Teachers of Science (National Research Council, 1996, Ch. 4, pp. 55-73) and the National Science Teachers Association's (NSTA) Position Statement on Professional Development in Science Education (NSTA, 1996). These guidelines embody a spirit of "change throughout the system" (National Research Council, 1996, p. 72). Accordingly, they encompass the shift in several areas of emphases in the professional development of science teachers shown in Table 2 (from National Research Council, 1996, p. 72). Collectively, the shift in emphases presented in Tables 1 and 2 reflects the changing conception of the role of professional development in educational reform as well as the role of teachers in the professional development and reform process.

Table 2
Shift in Emphases Encompassed by the Standards for Professional Development for Teachers of Science

Less emphasis on	More emphasis on
Transmission of teaching knowledge and skills by lectures	Inquiry into teaching and learning
Learning science by lecture and reading	Learning science through investigation and inquiry
Separation of science and teaching knowledge	Integration of science and teaching knowledge
Separation of theory and practice	Integration of theory and practice in school settings
Individual learning	Collegial and collaborative learning
Fragmented, one-shot sessions	Long-term coherent plans
Courses and workshops	A variety of professional development activities
Reliance on external expertise	Mix of internal and external expertise
Staff developers as educators	Staff developers as facilitators, consultants, and planners
Teacher as technician	Teacher as intellectual, reflective practitioner
Teacher as consumer of knowledge about teaching	Teacher as producer of knowledge about teaching
Teacher as follower	Teacher as leader
Teacher as an individual based in a classroom	Teacher as a member of a collegial professional community
Teacher as target of change	Teacher as source and facilitator of change

The Iowa Chautauqua Program: An STS-Based Model of Exemplary Professional Development

Endorsed by the NSTA (1990-91), the Science-Technology-Society (STS) approach to both science instruction and professional development of science teachers provided the basis for designing the Iowa Chautauqua[1] Program (ICP) at the University of Iowa, Iowa City, Iowa, USA during the early 1980s. It soon emerged as an exemplary model of professional development for K-12 in-service science teachers. Its success in improving the teaching and learning of science in Iowa schools led to its recognition and validation in 1993 by the U.S. Department of Education as a model professional development program, worthy of dissemination through the Department's National Diffusion Network. Consequently, the ICP model has been emulated in several states in the USA and in several countries worldwide during the last decade (Dass & Yager, 1999). Some of the key elements of the program, which make ICP an exemplary model of professional development reform, include learning experiences based on research-compatible ideas and that actively involve teachers, an expectation from teachers to practice what they learn, feedback and follow-up support, and an on-going approach involving collaborative efforts. Central to these key elements is the STS approach to the teaching and learning of science; using real-life situations, questions, concerns, and problems as the context and starting points for studying science (Figure 1) or setting the content of science in the context of human experiences (Blunck & Yager, 1996). The key elements of the ICP model are now described.

CHAUTAUQUA LEADERSHIP CONFERENCE

LEAD TEACHERS MEET TO:
Plan Summer and Academic Year Workshops
Enhance Instructional Strategies and Leadership Skills
Refine Assessment Strategies

THREE-WEEK SUMMER WORKSHOPS

3-4 LEAD TEACHERS + UNIVERSITY STAFF + SCIENTISTS WORK WITH TEACHERS IN LOCAL/REGIONAL WORKSHOP SETTINGS

Teachers are introduced to constructivist instruction in a Science-Technology-Society (STS) context. Teachers:

- Participate in activities and field experiences that integrate concepts and principles from all major disciplines of school science.
- Make connections between science, technology, and society in the context of real-life experiences.
- Use local questions, problems, and issues to provide an organizing context for science instruction.
- Create a 5-day teaching module.

5-DAY CLASSROOM TEACHING TRIAL

Teachers involved in summer workshops teach and assess a 5-day module using constructivist principles in an STS context

Academic Year Workshop Series

3-4 LEAD TEACHERS + UNIVERSITY STAFF + SCIENTISTS WORK WITH SUMMER TEACHERS + NEW TEACHERS

Fall Short Course: 20-Hour Instructional Block
Defining techniques for developing teaching modules and assessing their effectiveness; selecting a tentative topic; practicing specific assessment tools in multiple domains of science.

Interim Project: Three- to Six-Month Interim Project
Developing a constructivist instructional module for a minimum of 20 days of instruction; developing a variety of authentic assessment strategies; administering pre-tests in multiple domains of science; teaching the module; communicating with regional staff, lead teachers, and central program staff.

Spring Short Course: 20-Hour Instructional Block
Discussing assessment results; analyzing experiences related to teaching the module; planning next steps for expanding constructivist and STS approaches; planning for professional leadership in local reform efforts.

Figure 1. The Iowa Chautauqua Program (ICP) of professional development.

Learning experiences. During the 3-week summer workshops of the ICP, teachers are involved in learning experiences that help them identify or generate specific issues that they would expect to explore in their science classes. The learning experiences include field trips and introduction of audio-visuals or other media reports of some current events. Issues potentially relevant to students are gleaned out of these experiences. After identifying the issues, teachers study research and other information and gather materials needed for treating the issues in their science classes in a Science-Technology-Society (STS) context. The first product of this exploration is a small, issue-based teaching module designed by each participant. In developing these modules, teachers are designing instruction compatible with research on effective teaching, their own teaching goals, and the issues involved. Throughout the workshops, teachers are actively involved in their own learning as they identify issues, develop teaching modules based on the STS approach, develop assessment plans to match their modules, and assess their current teaching practices in light of these approaches. Appendix A shows elements of the STS pedagogy embedded in the modules, and sample modules may be accessed from Dass (n.d.).

Expectation to practice. Following the summer workshop, participants of the ICP try out their modules in their classes during the early part of fall semester. Since the STS approach to science teaching and learning is not presented in an abstract fashion during the workshop and teachers personally design each module within the context of the realities of their own teaching situations, the use of these modules does not appear to be an extra add-on activity. Rather, it fits within the context of what they would normally be doing. This increases the chance of their actually practicing what they learned during the workshop. The modules and the instructional strategies belong to the teachers, not a phantom consultant long gone. Practicing and applying in classrooms what is learned during professional development activities are key ingredients of quality professional development if the goal is to bring about a change in teacher behavior (Joyce & Showers, 1980; Sparks, 1983).

Feedback and follow-up support. The ICP teachers are not left on their own after the summer workshop. Mentored by lead teachers from local teams, teachers receive feedback, encouragement, constructive criticism, and support as they try their first modules. In addition to the on-going support provided by lead teachers, follow-up workshops during fall and spring both support teachers and push them a bit to take risks in their classrooms. These workshops are designed to provide an opportunity to share, assess, and reflect upon the results of trying the first module. Teachers learn from their peers and are encouraged to continue the effort by refining the first module and designing a second, relatively larger, module whose trial results are discussed during the spring follow-up workshop. Thus, the series of workshops not only provides feedback on the first teaching trial but helps participants continue to practice what they have learned by way of designing and teaching new modules. And, in the process, they see other teachers trying new things as well. Teachers learn from each other as they share experiences and results of their practice. This form of feedback and follow-up support contributes toward the development of a community of learners. Feedback and follow-up support have been found critical in ensuring behavior change and are, therefore, identified as key features of quality professional development (Guskey, 1995; Joyce & Showers, 1980; Sparks, 1983; Wood & Thompson, 1980).

On-going approach with emphasis on collaboration. In order to bring about real change, teachers must be involved in long-term learning activities and should have the support of professional learning communities that include their colleagues, administrators, parents, and other community members (Darling-Hammond & McLaughlin, 1995; Guskey, 1995; Lieberman, 1995). Recognizing the need for long-term learning and ongoing support to change teaching practices, the ICP offers a full academic year program (involving summer, fall, and spring workshops) and promotes regular communication among participants and central staff through telephone conferences, meetings, e-mail, and a newsletter. Participants are encouraged to contribute articles for the newsletter about their experiences and accomplishments in the classroom. Each issue of the newsletter has several first person stances of participants' successes and limitations.

The ICP exemplifies high quality professional development in its emphasis on collaboration between teachers, administrators, parents, scientists, business and industry leaders, and other community members in improving science education for all students. One of the key elements of the ICP is to develop a network of professional learning communities. This is achieved by involving scientists and other community resources in the workshops, inviting administrators and parents to participate in the workshops, and encouraging teachers to develop partnerships with other teachers and community members as they design and teach issue-oriented modules.

The emphasis on the STS approach is ideally suited for helping teachers develop skills necessary to be able to design learning experiences that will make science relevant to their students. While achieving this goal, the ICP also provides opportunity for teachers to develop leadership qualities. Activities such as developing their own teaching modules, organizing local area workshops during summer, fall, and spring, and writing articles for the newsletter and other outlets all contribute to the development of professionalism, teacher leadership, and competence, as well as foster a sense of ownership of the program on the part of teachers. This implies that within a few years time in any given area, a cadre of local lead teachers will develop who can successfully design and implement professional development activities based upon the ICP model but tailored to meet the specific needs of local teachers as they change through time. This is a critical point for those seeking to develop effective professional development programs. Just as effective science education, viewed through the lens of STS, means relevance in terms of real-life experiences of students, effective professional development also means relevance in terms of the local teaching situations and realities of the teachers involved. The ICP model offers that relevance by involving teachers actively in developing the leadership to influence how science will be taught in their classes and schools.

Effects of the STS-based ICP Model: Teacher Growth in Multiple Domains

While engaging teachers in the STS approach to the teaching and learning of science, the ICP model of professional development offers opportunities for teacher growth in several domains. These include: leadership qualities, use of instructional approaches that connect science to real life, attitudes toward teaching, confidence and competence regarding science subject matter, ability to collaborate with other teachers, and integration of modern communication and information technology in instruction. The studies described below point to the effectiveness of the ICP model in helping teachers grow in these domains.

Liu's (1992) comparison of new ICP participants with non-ICP teachers revealed that by the end of the program, ICP teachers had significantly higher confidence levels to teach science, better understanding of the basic features of science, and more positive perspectives on teaching science. He also conducted a comparison of teaching behaviors in classes using the STS approach versus those using the “traditional” textbook approach. This comparison indicated that in the STS classes, teachers employed more elements of the student-oriented, constructivist teaching and learning principles as compared to what was going on in traditional classrooms.

Blunck (1993) studied the impact of ICP on “reculturing behaviors” of teachers that lead to a positive change in the culture of the school. The reculturing behaviors considered in this study relate particularly to change in teacher confidence so that they view their roles inside and outside the classrooms differently. These behaviors relate to teacher interaction with their peers, interaction with school administrators, interaction with parents, and interaction with field experts in the community. Blunck discovered that after participating in the ICP, teachers' confidence increased significantly to involve other teachers, school administrators, parents, and experts in the community as they implemented the STS approach in their classes. They also showed increased confidence with respect to dealing with differing opinions from those inside and outside the school and with respect to working with others on projects to improve their science programs. This increased confidence to effect change, both within one's own classroom and in the school as a whole, positioned ICP teachers to influence real educational reform and enhance the quality of science education in their schools.

Using a combination of quantitative and qualitative methods, Dass (2005) studied professional growth of a group of teachers participating in an ICP-based program in Florida, USA. This study led to the following conclusions:

1. The Chautauqua program helped teachers develop leadership skills in the areas of mentoring, coordinating teamwork, sharing their work at professional meetings, and taking roles of responsibility within the program.
2. Chautauqua teachers learned to focus more on student questions and concerns. They learned to value prior conceptions and knowledge levels of students and developed instructional activities, which took into account students’ prior knowledge levels. In general, Chautauqua teachers grew in their understanding and use of constructivist pedagogy.
3. Chautauqua teachers developed a markedly positive attitude toward teaching in general and toward teaching science in particular. They demonstrated a new excitement and enthusiasm toward their profession.
4. Chautauqua teachers became more confident about teaching science. Elementary teachers in particular reported spending more time on science activities and integrating science topics more with other areas of the curriculum.
5. Chautauqua teachers collaborated more with their peers and administrators in improving instructional practices. They also utilized resources available in the local community more than they did formerly. These collaborations enhanced the quality of their instructional activities and made learning experiences more meaningful for their students.
6. Chautauqua teachers integrated more of the available technological resources than they did formerly in their instruction. This also enhanced the quality of activities and helped students explore avenues of learning otherwise inaccessible to them.

As evident from these results, the STS-based ICP model has contributed significantly to the reform of professional development and, in turn, to the reform of the teaching and learning of science in K-12 classrooms. However, it must also be noted that in order to be successful, a comprehensive program of professional development must provide for ownership of the reform by teachers and the school community at large. Also, other demands on teacher time, such as various administrative duties, must be taken into consideration. These issues of ownership and other time demands may make it difficult for professional development to be effective. Applying the Concerns Based Adoption Model (Hall, 1979; Hall, Wallace, & Dossett, 1973), Dass (2001) investigated what made the adoption and implementation of ICP successful in Collier County, Florida. The findings indicated that several of the features of ICP, described in the previous section, enable teachers to develop the ownership of reform and make it part of their normal instructional practice (rather than implement it as something extra) so that it does not make additional demands on their time.

Professional Development Using STS and ICP: Efforts Around the World

Based upon its success with teachers and students in Iowa, and validation as an exemplary model of professional development from the U.S. Department of Education, the STS-based ICP model has been widely disseminated throughout the USA and in several other parts of the world. In some cases, such as Collier County, Florida, comprehensive programs have been developed emulating the ICP model while in other cases a Chautauqua-style series of workshops have been conducted.

Within the USA, almost 5,000 K-12 teachers have experienced professional development based on the STS-ICP model over the last 10 years, which in turn has impacted the science education of nearly 200,000 students. Some of the prominent programs that have used elements of the STS-ICP approach within the USA include the Vermont Chautauqua Program, South Dakota STS Project, Collier Chautauqua Program (Collier County, Florida), Tennessee Valley STS Project, North Carolina SCI-LINK/GlobeNet Project, and Oklahoma TEEMS Project. On the international landscape, the STS-ICP model has influenced professional development programs across several countries including Australia, China, Estonia, Germany, Indonesia, Israel, Japan, South Korea, Malaysia, Singapore, Spain, Taiwan, and Thailand. Internationally, nearly 500 teachers have been involved in these programs, impacting the science education of almost 15,000 students. It can demonstrably be argued that the STS-ICP model has been instrumental in helping realize the visions of contemporary science education reform worldwide by significantly improving professional development practices and programs for K-12 in-service science teachers.

Conclusion

On one hand, the notion of in-service education in the form of discrete workshops to “fix” teachers' inadequacies has been replaced by a notion of professional development for continuous enhancement and the ongoing learning of teachers. On the other hand, the notion of desirable education in the sciences has shifted from an emphasis on mastery of the so called “content” of science to an emphasis on the real-life relevance of science to students. The very nature of science has undergone drastic changes within the last 50 years and demands a new perspective on school science education. School education in the sciences must change to reflect this changing nature of science, as well as the changing notion of what is desirable science education. The two developments--the changing notion of in-service education and the changing notion of the desirable features of science education--have led to an urgent need for effective professional development programs that address both. However, such programs with proven track records are not easy to find.

The ICP model is based upon the idea that "in-service education is both a strategy for specific instructional change as well as a strategy for basic organizational change in the way teachers work and learn together" (Blunck, 1993, p. 132). This basis of the ICP model is congruent with the current notion of professional development for the continuous enhancement and ongoing learning of teachers. The STS approach, focusing on the teaching and learning of science in the context of human experience, is poised to provide real-life relevance to school science education. Thus, an engagement with the STS approach through the ICP model addresses both of the developments mentioned above. Further, the ICP model and the STS approach embedded within it have a track record (indicated by the studies described above) that demonstrates their effectiveness in bringing about the desired reform both in the general professional growth of teachers and in specific science instruction in their classes. The fact that this professional development package (i.e., STS plus ICP) model has been emulated successfully in several different settings worldwide attests to its adaptability to local educational realities and priorities. Thus, the STS approach presented through the ICP model of professional development offers undeniable promise in contributing to the educational reform much desired around the world as we progress through the 21st century.

Note

[1] The name *Chautauqua* in Iowa Chautauqua Program (ICP) reflects the ongoing, recurring nature of the professional development process, in contrast to professional development consisting of isolated, sporadic events that characterize the traditional notion of in-service education. The word Chautauqua is borrowed from the name of the recurring educational summer camp assemblies that began in 1874 on the shores of Chautauqua Lake, New York, and later spread to various locations across North America as recurring educational, cultural, and entertainment camps. Thus Chautauqua is meant to imply the recurring, ongoing, long-term characteristic of the ICP model of professional development.

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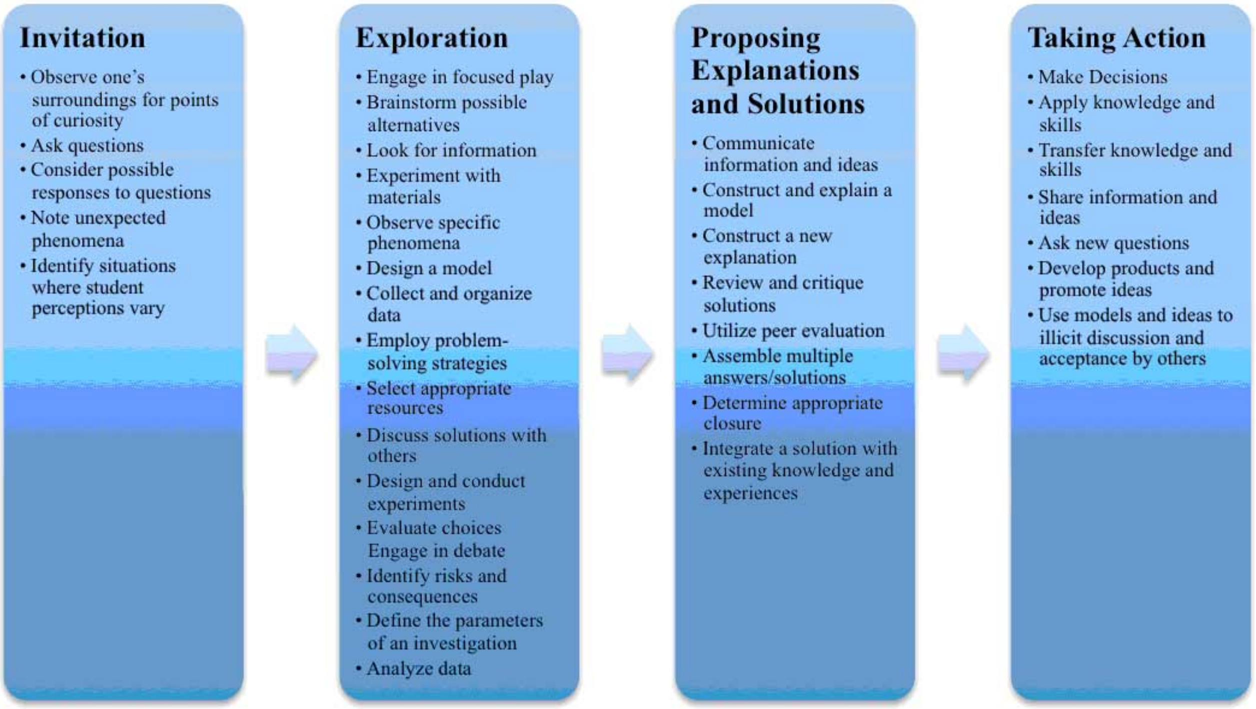
Appendix A: Elements of the Science-Technology-Society (STS) Pedagogy



Invitation

- Observe one's surroundings for points of curiosity
- Ask questions
- Consider possible responses to questions
- Note unexpected phenomena
- Identify situations where student perceptions vary

Exploration

- Engage in focused play
- Brainstorm possible alternatives
- Look for information
- Experiment with materials
- Observe specific phenomena
- Design a model
- Collect and organize data
- Employ problem-solving strategies
- Select appropriate resources
- Discuss solutions with others
- Design and conduct experiments
- Evaluate choices Engage in debate
- Identify risks and consequences
- Define the parameters of an investigation
- Analyze data

Proposing Explanations and Solutions

- Communicate information and ideas
- Construct and explain a model
- Construct a new explanation
- Review and critique solutions
- Utilize peer evaluation
- Assemble multiple answers/solutions
- Determine appropriate closure
- Integrate a solution with existing knowledge and experiences

Taking Action

- Make Decisions
- Apply knowledge and skills
- Transfer knowledge and skills
- Share information and ideas
- Ask new questions
- Develop products and promote ideas
- Use models and ideas to illicit discussion and acceptance by others

Exploring Scaling: From Concept to Applications

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Abstract

This paper discusses the concept of scaling and its biological and engineering applications. Scaling, in a scientific context, means proportional adjustment of the dimensions of an object so that the adjusted and original objects have similar shapes yet different dimensions. The paper provides an example of a hands-on, minds-on activity on scaling that can be adapted to a middle school, high school, or even undergraduate science curriculum. The student activity is preceded by an introduction and followed by a summary discussion with possible suggestions on how a teacher might guide student exploration.

A number of fundamental concepts in science fascinate students and teachers, yet the students require only basic algebra and very general science knowledge to understand them. As a result, these concepts can be studied at different levels and are well suited for middle or high school students, as well as college undergraduates. Moreover, the concepts often have fascinating applications connecting science to students' everyday lives. Biological scaling is a good example of such a concept as it provides a great opportunity to teach interesting physics and to see how it applies to biological systems. Scaling, in this context, means the proportional adjustment of the dimensions of an object such that the adjusted and original objects have similar shapes, yet different dimensions. In other words, an object is scaled when each one of its dimensions is changed (increased or decreased) by the same factor, referred to as a scaling factor (S.F.). The concept of scaling can be also successfully applied to engineering, architecture, the film industry, and other fields.

This paper presents a brief discussion of scaling and suggests a hands-on, minds-on activity that explores some of its interesting applications. A more in-depth discussion of scaling and its applications can be found elsewhere (Barnes, 1989; Fowlers, 1996; Goth, 2009; Haldane, 1970; Peterson, 2002; Thompson, 1992; Tretter, 2005; West & Brown, 2004). Having taught the topic of scaling to thousands of students over the years (from middle school to undergraduate non-science and science majors in college), I find it to be a topic that generates hot debates and raises students' interest and excitement about science.

Activity: Discovering Scaling

Materials

For each group: set of 27 or more small wooden or plastic cubes such as the ones used in elementary school mathematics classes, two or three metallic spheres of different sizes (wooden spheres do not sink in water and it is difficult to measure their volumes), a graduated cylinder large enough to fit the spheres and used to measure their volume, play dough, and a ruler.

Student Independent Investigation

Imagine a small cube with side 1 cm (Figure 1). The volume of such a cube is 1 cubic cm (1 cm^3), while its surface area is 6 square cm (6 cm^2) (a cube has six faces and each has an area of 1cm^2). Notice that, if you double every edge of the cube (i.e., enlarge it by a factor of 2), the volume of the cube increases by a factor of 8, while the surface area only increases by a factor of 4:

$V_{\text{small}} = 1\ \text{cm}^3$; $V_{\text{large}} = (1\ \text{cm} \times 2)^3 = (2\ \text{cm})^3 = 8\ \text{cm}^3$

$A_{\text{small}} = 1\ \text{cm}^2 \times 6 = 6\ \text{cm}^2$; $A_{\text{large}} = (1\ \text{cm} \times 2)^2 \times 6 = 4\ \text{cm}^2 \times 6 = 24\ \text{cm}^2$

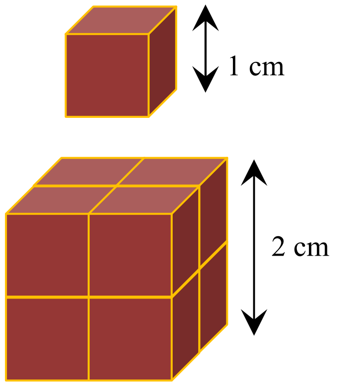

Figure 1. Two scaled cubes with a scaling factor of 2.

Stop and Think

Q1: What will happen to the surface area and the volume of the original cube if every edge of the original cube triples?

Definition of Scaling

Two objects are said to be *scaled* if one object can be obtained from the other by increasing its every dimension by the same factor, called the scaling factor (S.F.). In other words, two objects are scaled if one can be obtained from the other by proportional adjustment of all its dimensions. Notice that the scaling factor is a pure number (i.e., it has no unit). In the example above, the scaling factor is 2 (i.e., S.F. = 2).

Use the cubes provided to you to explore different scaling factors. Fill in your results in Table 1 below.

Table 1

Exploration of Scaling With Different Scaling Factors: Finding the Pattern in the Data

Length/m	Surface area/m^2	Volume/m^3	Ratio of Surface Area to Volume/m^{-1}	Scaling factor (compared with the smallest cube)
1				
2				
3				
10				
100				
1000				

Stop and Think

Examine Table 1 carefully and answer the following questions:

Q2: What interesting/surprising patterns have you observed in Table 1? Describe them.

Q3: When the scaling factor increases, the surface area and the volume of the object also increase. Do they increase at the same rate? Explain.

Q4: Any two cubes are always scaled. The same applies to any two spheres. Is it going to be true for any two rectangular prisms? Explain. (*Hint*: a cube is a rectangular prism, but is any rectangular prism a cube?)

Q5: In the SI system of measurement, 1 m = 10 dm = 100 cm = 1000 mm. What is the relationship between:

a) 1 m^2 and each of 1 dm^2, 1 cm^2, and 1 mm^2?
b) 1 m^3 and each of 1 dm^3, 1 cm^3, and 1 mm^3?
c) How are these relationships related to the concept of scaling?

Q6: For biological systems, surface area and volume play distinctively different roles: surface area (skin for example) is responsible for energy dissipation (or heat loss) while the volume is responsible for energy generation. How do you think the pattern you discovered in this activity might be relevant to biological systems?

Q7: A cross-sectional area of an object represents its strength (object's ability to withstand a load). For example, the larger the cross-sectional area of a bone is, the stronger is the bone. If the mass of an object is proportional to its volume, what can you say about the relative strengths of two scaled objects?

Q8: You are asked to help resolve an argument between three of your friends. David claims that when you enlarge every side of a cube n times, its volume also increases n times, Jane says that the volume of a cube increases 3n times, and Anne is convinced that the volume increases n^3 times. Who do you agree with and why?

Q9: Scaling is widely used in map-making. A map of a certain town is produced to a scale of 1:10 000. The town has a circular shape, and the map is 0.5 m across. What are the town's dimensions? What is the town's area? What is the town's area as represented on the map?

Q10: Rachel and Daniel have been assigned the task of peeling potatoes for the entire summer camp. Rachel is given 60 kg of potatoes that average 1 kg in mass, while Daniel is given 30 kg of potatoes that average 0.5 kg in mass (so Rachel's potatoes are on average twice heavier than Daniel's). Assuming that Rachel's and Daniel's peeling skills are equal, and if Rachel finishes her task in two hours, how long will it take Daniel to accomplish his task?

Q11: How do you think the scaling phenomenon might be relevant to other aspects of everyday life?

Activity Summary: Comments for the Teacher and Ideas for Class Discussion

At first glance, Table 2 does not hold any particular significance. But let us take a closer look at the ratio of the surface area of an object to its volume: the larger the scaling factor, the smaller is the ratio of the surface area to volume. For very large objects, the amount of surface area (or for that matter, cross-sectional area) compared to their volume becomes relatively small.

Galileo Galilei (1564-1642) noticed the phenomenon of scaling almost 400 years ago. In 1635, Galileo wrote in his *Dialogs Concerning Two New Sciences*:

> I am certain you both know that an oak two hundred cubits high would not be able to sustain its own branches if they were distributed as in a tree of ordinary size; and that nature cannot produce a horse as large as twenty ordinary horses or a giant ten times taller than an ordinary man unless by miracle or by greatly altering the proportions of his limbs and especially his bones, which would have to be considerably enlarged over the ordinary. (Galileo, 1635/2002, p. 402)

Table 2

Exploration of Scaling With Different Scaling Factors: Finding the Pattern in the Data. (The table shows that the ratio of the surface area to volume of scaled cubes decreases as the scaling factor increases.)

Length/m	Surface area/m^2	Volume/m^3	Ratio of Surface Area to Volume/m^{-1}	Scaling factor (compared with the smallest cube)
1	6	1	6	1
2	24	8	3	2
3	54	27	2	3
10	600	1000	0.6	10
100	60 000	1 000 000	0.06	100
1000	6 000 000	10 000 000 000	0.0006	1000

The reason for this trend in surface area to volume ratio is that the mass of an object is proportional to its volume (considering that the scaled objects have similar densities), while the cross-sectional area of a bone or a tree branch, which is responsible for an object's strength, is proportional to the square of the scaling factor. As a result, when one scales the object up, its mass increases more than does its surface and cross-sectional area (see solution to Q10 earlier). A cross-sectional area influences the strength of an animal's bones (large animals have disproportionally large legs to support their weight, unless they live in water!). On the other hand, the surface area for many animals (their skin) has many important bodily functions: one of them is to help warm-blooded animals keep their temperature via heat exchange with the environment. When it is too hot, the animals sweat or pant to lose heat. And what happens if a large animal does not have enough surface area?

Nature came up with many interesting solutions. For example, elephants have very large ears that provide additional surface area and help them to cool down by losing heat (the size of elephants' ears depends on the climate they live in). More interesting is that the laws of scaling tell us that one cannot scale up living organisms (humans, plants, and animals), without modifying their shape. There is no way of making a chicken 1 meter tall without changing its shape! Unfortunately it also applies to Hollywood famous giants, such as Mighty-Joe-Young or King-Kong. A 15-foot-tall gorilla cannot have the same shape as a 6-foot-tall gorilla.

Scaling down has similar limitations, as exemplified by bonsai trees. Although they look very much like a reduced replica of the larger trees, the looks can be deceiving. If one makes a careful comparison, the differences between the trees' structure will be apparent (Barnes, 1989):

> The physics of things that we can only imagine is often more interesting and exciting than the physics of things that are real. However, when entering the world of imagination one must be careful. Although physics is an experimental science, in the imaginary world, it is impossible to verify ones' theories. So we must not let our imaginations carry us too far. (p. 234.)

Following Barnes' observation, it is pedagogically valuable to remind the students about the value of experiment in testing scientific theories. A valid scientific theory must be able to generate predictions that can be verified (Etkina & Van Heuvelen, 2001; Etkina, Van Heuvelen, Brookes, & Mills, 2002; Kalman, 2008). The following two testing experiments can serve this purpose.

Testing Experiment 1

Measure the diameters of your spheres. Calculate the scaling factor. Predict the volume of the larger sphere based on the diameter of the smaller sphere and the scaling factor. Conduct an experiment to test your prediction. (The volume of the metal sphere can be measured by submerging it in water and measuring the volume of the displaced liquid.) Do your experimental results confirm your prediction?

Testing Experiment 2

Use play dough to build three scaled rectangular prisms (Figure 2): a small prism, a medium prism (S.F. = 2) and a large prism (S.F. = 3). Before building the larger prisms, hold the smallest prism by its base and make sure you can hold it horizontally (as a cantilever). If you cannot hold it (i.e., the unsupported end of the prism falls), make it a little shorter. Now build the other two prisms. Predict if it is going to be easier to hold the other two prisms horizontally by their bases and use them as cantilevers compared to the smallest prism. Test your predictions. How might what you found be relevant to architectural designs?

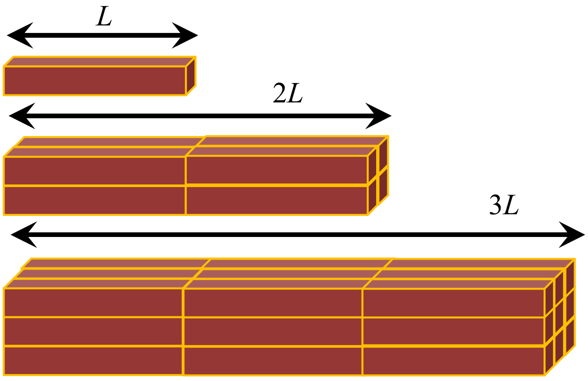

Figure 2. Three scaled rectangular prisms.

In addition to Barnes (1989), a very interesting explanation of scaling laws and their applications can be found in the following references: Fowlers (1996), Haldane (1970), Peterson (2002), and West and Brown (2004). Scaling plays a central role in our lives; in its biological applications (Ahlborn, 2004), as well as in engineering, architecture, geography (Wiegand, 2006), art, and design.

Answers to Some of the Stop and Think Questions From the Student Activity

Q3: When the scaling factor increases, the surface area and the volume of the object also increase. Do they increase at the same rate? Explain.

Answer. The volume increases faster than the surface area. This can be illustrated using small cubes to build bigger ones. While stacking small cubes together, some of the faces of the smaller cubes will become internal, decreasing the surface area. For example, if you stack 27 small black cubes together to create a larger cube and paint the surface area of the larger cube in red and then take the 27 small cubes apart, you will see that 1 of the 27 cubes will be completely black, 6 cubes will have one red face and five black faces, 12 cubes will have two red faces and four black faces, and 8 of the cubes will have three red faces and three black faces. Since the red faces represent the surface area of the larger cube, one can see that smaller cubes, when considered separately, have more surface area compared to when they are stacked together.

Q4: Any two cubes are always scaled. The same applies to any two spheres. Is it going to be true for any two rectangular prisms? Explain. (*Hint*: a cube is a rectangular prism, but is any rectangular prism a cube?)

Answer. By definition, all the dimensions of a cube (width, length, and height) must be equal. Therefore, if the ratio of two sides of any two cubes is found, the ratio between any two other sides of the two cubes must be the same. The same applies to any two spheres. However, when considering two arbitrary rectangular prisms, the ratios of their corresponding edges might be different, as shown in Figure 3. The ratio of the heights of these prisms is 3:2, yet the ratios of their lengths and widths are 2:1 and 1:1 respectively. So, when you enlarge or reduce different dimensions of an object by different factors, the original and enlarged/reduced objects are not scaled.

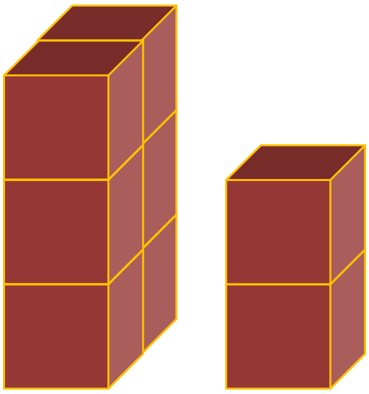

Figure 3. Two prisms that are not scaled.

Q5: In the SI system of measurement, 1 m = 10 dm = 100 cm = 1000 mm. What is the relationship between:

a) 1 m^2 and each of 1 dm^2, 1 cm^2, and 1 mm^2?
b) 1 m^3 and each of 1 dm^3, 1 cm^3, and 1 mm^3?
c) How are these relationships related to the concept of scaling?

Answer. a) $1\ m^2 = (10\ dm)^2 = 100\ dm^2 = 10^2\ dm^2$ (S.F. = 10)
$1\ m^2 = (100\ cm)^2 = 10\ 000\ cm^2 = 10^4\ cm^2$ (S.F. = 100 or 10^2)
$1\ m^2 = (1000\ mm)^2 = 1\ 000\ 000\ mm^2 = 10^6\ mm^2$ (S.F. = 1000 or 10^3)

b) $1\ m^3 = (10\ dm)^3 = 1000\ dm^3 = 10^3\ dm^3$ (S.F. = 10)
$1\ m^3 = (100\ cm)^3 = 1\ 000\ 000\ cm^3 = 10^6\ cm^2$ (S.F. = 100 or 10^2)
$1\ m^3 = (1000\ mm)^3 = 1\ 000\ 000\ 000\ mm^3 = 10^9\ mm^3$ (S.F. = 1000 or 10^3)

Q6: Answered in the text of the paper.

Q7: A cross-sectional area of an object represents its strength (object's ability to withstand a load). For example, the larger the cross-sectional area of a bone is, the stronger is the bone. If the mass of an object is proportional to its volume, what can you say about the relative strengths of two scaled objects?

Answer. If two objects are entirely scaled, a larger object is going to be weaker and will have less surface area per unit of mass than a smaller object. This is especially important in architecture and engineering science, while building models and testing the effects of wind, air ventilation, and load. If an engineer tested a small model of a bridge and found that the model of the bridge can support its weight, it does not mean that a real bridge will be able to support its weight!

Q8: You are asked to help resolve an argument between three of your friends. David claims that when you enlarge every side of a cube n times, its volume also increases n times, Jane says that the volume of a cube increases 3n times, and Anne is convinced that the volume increases n^3 times. Who do you agree with and why?

Answer. Anne is right. The reasoning is described earlier in the paper.

Q9: Scaling is widely used in map-making. A map of a certain town is produced to a scale of 1:10 000. The town has a circular shape, and the map is 0.5 m across. What is the town's real dimension? What is the town's area? What is the town's area as represented on the map?

Answer. The real dimension of the town is 0.5 m x 10 000 = 5000 m, or 5 km across. Therefore, the area of the town is $\pi D^2/4 = 3.14 \times 25\ \text{km}^2/4 \approx 20\ \text{km}^2$. The area of the town, as represented on the map, is $\pi D^2/4 = 3.14 \times 0.25\ \text{m}^2/4 \approx 0.2\ \text{m}^2$, which is also $20\ \text{km}^2/100\ 000\ 000$ or $20\ \text{km}^2/(\text{S.F.})^2$.

Q10: Rachel and Daniel have been assigned the task of peeling potatoes for the entire summer camp. Rachel is given 60 kg of potatoes that average 1 kg in mass, while Daniel is given 30 kg of potatoes that average 0.5 kg in mass (so Rachel's potatoes are on average twice heavier than Daniel's). Assuming that Rachel's and Daniel's peeling skills are equal, and if Rachel finishes her task in 2 hours, how long will it take Daniel to accomplish his task?

Answer. Although Rachel and Daniel have, on average, the same number of potatoes (60) to peel, the surface areas of these potatoes (the area of potato skin) are not equal. Let us compare the surface areas (the area of the potato skin) of Rachel's and Daniel's potatoes. Since an average Rachel's potato has a mass of 1 kg and an average Daniel's potato has a mass of 0.5 kg, the volume of an average Rachel's potato must be twice the volume of an average Daniel's potato (assuming the potatoes have the same densities, ρ).

From the earlier discussion on scaling, we saw that if we assume that Rachel's (R) potatoes are a scaled version of Daniel's (D) potatoes, then the ratio of their volumes (V) is equal to the cube of the scaling factor (see Table 2). Therefore, the scaling factor can be found as follows:

$$V_{\text{R\_potato}}/V_{\text{D\_potato}} = 2 = (\text{S.F.})^3 \qquad \text{Hence, S.F.} = \sqrt[3]{2}$$

On the other hand, we saw (see Table 2) that the ratio of the surface areas (A) of two scaled objects equals the square of the scaling factor. Therefore, the ratio of the area of the skin (surface areas) of Rachel's potato to the area of the skin of Daniel's potato can be calculated as the square of the scaling factor:

$$A_{\text{R\_potato}}/A_{\text{D\_potato}} = (\text{S.F.})^2 = (\sqrt[3]{2})^2 \approx 1.59$$

Finally, since peeling time (t) will be proportional to surface area, and Rachel's peeling time is 2 hours, Daniel's peeling time can be calculated as follows:

$$t_R/t_D = 1.59 \qquad \text{So, if } t_R = 2 \text{ hours, } t_D = 2 \text{ hours}/1.59 = 1.26 \text{ hours}$$

Notice that, even though the mass of each of Rachel's potatoes is twice as much as the mass of each of Daniel's potatoes, it will take Rachel only 1.59 times longer than Daniel to peel her potatoes!

Q11: How do you think the scaling phenomenon might be relevant to other aspects of everyday life?

Answer. See earlier discussion and the references at the end of this paragraph. In addition, the topic of sound generation by musical instruments is another great application of the law of scaling. Larger instruments produce lowers sounds, but how is the ratio of produced tones related to the ratio of the sizes of these instruments? And what about the sounds produced by human vocal cords; how are they scaled? Think of the voices of kids versus the voices of adults, or males compared with females. These and many other interesting questions can be discussed qualitatively and quantitatively with more advanced students. A good start for the discussion of the applications of scaling to music can be found in Hoon and Tanner (1981) and Jeans (1968).

Conclusion

We hope that this paper will whet the appetite of readers for considering scaling phenomena in science classrooms. We have shown how the concept of scaling can be illustrated visually, as well as mathematically, and offered relevant hands-on and minds-on activities, as well as additional questions to think about. We have also shown that, when an object is scaled, its surface and cross-sectional areas change more slowly than its volume. Despite its straightforward formulation, scaling has profound effects on many aspects of our lives. The sources mentioned earlier, as well as Hewitt (1997), Levy and Salvadori (1994), and Salvadori (1980) will provide curious and creative science teachers and students with many additional scaling examples from the arts, science, engineering, and architecture. We hope that the discussion in this paper will help science teachers come up with exciting and unexpected activities for students of different ages and interests.

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