ASEJ
alberta science education journal

Vol. 38, No. 1, November 2006

Contents

ASEJ is a publication of the Science Council of the ATA. Editor: Wytze Brouwer, Department of Secondary Education, University of Alberta, 57 University Campus NW, Edmonton T6G 2G5. Editorial and production services: Document Production staff, ATA. Opinions of writers are not necessarily those of the Council or the ATA. Address all correspondence to the editor. ISSN 0701-1024

Individual copies of this journal can be ordered at the following prices: 1 to 4 copies, $7.50 each; 5 to 10 copies, $5.00 each; over 10 copies, $3.50 each. Please add 5 per cent shipping and handling and 6 per cent GST. Please contact Distribution at Barnett House to place your order. In Edmonton, dial (780) 447-9400, ext 321; toll free in Alberta, dial 1-800-232-7208, ext 321.

ASEJ publishes scholarly work and strictly follows the "blind review" procedures and many other editorial policies described in the *Publication Manual of the American Psychological Association* (Washington, DC: American Psychological Association, 1983). Thus *ASEJ* is a refereed journal similar to most other scholarly periodicals published in Canada and the United States.

From the Editor

Susan Barker shows how creative lesson starters and lesson closures can help promote deeper learning in science, and presumably in other subjects also.

Deborah Hanson and Valerie Akerson discuss an inservice program for elementary school teachers that alleviates the lack of self-confidence these teachers have in teaching science. Besides recommending a greater emphasis on hands-on activity-based college science courses, the authors also recommend a greater emphasis on nature of science (NOS) understanding, and call for further research in this area.

Dougal MacDonald and Brenda Gustafson describe three strategies for doing what Hanson and Akerson suggest; that is, three strategies for teaching the nature of science, with specific suggestions of student activities and discussions on NOS.

Guoqiang Zhou, Zhijin Xu and Xiaoming Wu discuss the nature of conceptual change and suggest that a major factor in promoting greater conceptual understanding involves extensive student–teacher and student–student discussion and argumentation. A number of examples are given to illustrate the point.

Bonnie Shapiro discusses a number of new approaches to professional development. Of special interest is Shapiro's discussion of the Japanese *kenkyuu jugyou* method, in which teachers collaboratively develop research lessons to teach and to analyze. The method is based on the Japanese belief that intensive lesson study "develops the eyes/vision to see children."

Aditya Saha reviews two issues that question the scientific ethics some scientists and scientific bodies have practised in the 20th century, especially with respect to women in scientific research.

Bert Millsap is back. He is upset about the demotion of Pluto from the rank of planets and puts forward some good arguments for restoring Pluto and adding Xena, so that our solar system now has 10 planets.

The next two issues of the *Alberta Science Education Journal* will be devoted to science education research that makes a difference in the classroom. These issues will be fully refereed, and Dr Bonnie Shapiro will be coeditor for these issues. The deadline for submission for the next issue will be January 31, 2007.

—Wytze Brouwer

Interactive Starters and Closures for Deep Learning

Susan Barker, ***Department of Secondary Education, University of Alberta***

The start of a lesson is prime learning time when students are often at their most receptive and concentration levels are high, so let's exploit it to its maximum. Effective teachers who make good use of starters and closures in the context of interactive whole-class teaching engage students in constructive deep learning rather than surface learning. This article will present some key ideas and examples of successful interactive starters and closures to enhance science teaching by providing activities for deep learning. It draws heavily on a strategy developed in the United Kingdom to increase motivation and performance of students aged 11–15 years studying science (DfES 2004).

Surface and Deep Learning—What Are We Trying to Achieve?

Surface learning is characterized by students reproducing or memorizing facts and information or simply accepting ideas and information passively.

When engaged in deep learning, students

- try to understand and make sense of material,
- relate ideas and information to previous knowledge and experience,
- critically evaluate material,
- use organizing principles to integrate ideas,
- relate evidence to conclusions and
- examine the logic of arguments.

Deep learning leads to better understanding, so developing activities with these characteristics defines good practice in successful interactive starters and closures.

Why Have an Active Starter Activity?

Effective starters are also about purposeful, whole-class, interactive teaching involving all students. They have a significant and direct impact on the quality of the learning and play an important role in "connecting the learning," which, from a constructivist perspective, is vital in assisting students to build on what they already know. Some teachers rely on a relatively narrow range of teaching techniques and are sometimes reluctant to use approaches that promote whole-class interactive involvement because of the risk of its leading to misbehaviour. However, starters can actually assist with classroom management. For example, Muijs and Reynolds (2001, 76) comment that

> research suggests that teachers can keep disruption to a minimum by instituting a number of set procedures for dealing with lesson starts. For example, write instructions on the board before the pupils come in so they can get started with the lesson immediately, train pupils to record attendance and read instructions, have certain activities that students can start doing as soon as they come into the classroom.

Fundamental to managing student behaviour during starters and closures are rigorous planning, the appropriate use of a range of interactive teaching strategies and embedding the starter in the routine of the lesson. Lesson objectives written on the board help students recognize what is expected from them, but they can also be linked to the starter activity and usefully used by the teacher to review the lesson in the closure. Planned effective starters, as part of a series of episodes of learning, allow pupils to engage immediately with the learning objectives, and in 10 minutes students will already have achieved something. Wow!

Suggested Strategies for Effective Starters

A well-balanced starter allows students to work independently for some of the time, but we should not see it as free time for the teacher. The teacher must have some direct and specific input, such as directing the learning and moving it on, differentiating the level of challenge and ensuring that the main teaching points are conveyed clearly.

The key challenge is to get all students on-task quickly. Engagement is more likely to happen if the task

- does not outlast the concentration span of pupils;
- is immediately accessible to all or most students; thus, complex instructions and extended reading or writing activities are best avoided;
- hooks pupils' interest by incorporating an element of mystery, curiosity, novelty or particular relevance; and
- includes clear expectations; for example, "Each group should come up with at least five suggestions in the next three minutes."

Students' ability to engage in learning is also influenced by their emotional state and is maximized in high-challenge, low-stress situations. Handing in homework is thus better deferred to later in the lesson.

The relationship between challenge and engagement is also important. If the learning activity is too easy, students will become bored. If it is too hard, their frustration will reduce their motivation. More challenging starter activities will require students to apply, analyze, synthesize or evaluate information or ideas; these activities are all characteristics of deep learning.

Starters are important because they

- influence early levels of engagement and motivation when interest levels are high,
- allow students to gain an understanding of the objectives and purposes of the lesson,
- provide a sense of pace and challenge,
- are an alternative to whole-class question-and-answer reviews,
- create an expectation that students will think and participate in the lesson,
- involve students in deep learning and
- help teachers find out what students already know and understand, can do (skills) or are aware of (values and attitudes).

Closures and Plenaries

Closures and plenaries allow teachers to draw together, summarize and direct learning, so that students focus on what is important, what they have learned, the progress they have made and their next steps. Closures allow teachers to recognize what has been achieved in the lesson. Plenaries can occur partway through a lesson but should always be a feature at the end of a lesson. An important aspect of the closure is bridging, whereby the teacher helps connect the learning in one lesson to learning in another or to the everyday world. Linking science in the classroom with science in everyday life is vital for effective scientific literacy and helps students address that ever-present question, "So what?" Muijs and Reynolds (2001, 76) also identify the link between planning of closures and classroom management: "Effective teachers experience fewer problems with ending the lesson than less effective teachers through methods such as planning and pacing the lesson to leave sufficient time for activities at the end."

What Makes an Effective Closure?

Closures should link carefully to the objectives, outcomes and success criteria of the lesson as a whole. Active, engaging, challenging and well-paced learning can be achieved in closures as well as in starters through carefully planned tasks, planned management and organization of the classroom, and use of appropriate interactive teaching skills.

Why Have Active Closures?

Active closures increase the effectiveness of teaching and help the teacher to

- review the lesson's objectives while taking stock of what the class has covered in a task or a sequence;
- be diagnostic, assessing both individual and collective learning as well as progress in order to plan accordingly;
- recognize and value the achievements of individual students and the class; and

- stimulate interest, curiosity and anticipation about the next phase of learning.

They also enable students to

- remember what has been learned,
- crystallize their thoughts about what has been learned,
- deepen and extend their learning,
- see the big picture and
- create a sense of achievement.

Where Do I Start?

A huge range of starters and closure activities are now well documented for science lessons and are available on the Web. Searching for the key words *science starters* and *plenaries* will bring up a wealth of sites that you can adapt to your own needs. Two examples are provided below to get you started.

Stop Lights

This activity can be used as a starter or closure. In a closure, the teacher refers back to the lesson objectives and asks students

- what they understand or can do well (pupils hold up green cards),
- what they are not 100 per cent sure of (amber cards) and
- what needs further explanation or attention (red cards).

In this activity, students review the lesson's objectives and take stock of what the class has achieved within a task or a sequence. It can be used during a lesson or at the end and is a good way to inform planning. It is suitable for knowledge-based and skills-based objectives but is less useful for objectives that relate to more complex understanding or to values and attitudes. For this type of objective, more detailed success criteria are needed to enable pupils to evaluate their level of success. To use stop lights as a starter activity, use objectives from the previous lesson for review.

Sequencing Strips

The overall aim is for students to work in groups and put a number of pieces of information (pictures, text or both) into a logical sequence. The activity strengthens group work; no one is left out and they must all listen to each other. The activity requires a range of thinking skills, and the teacher can carry out informal assessments by listening to the group discussions as they take place. Description-groups form a circle and explain the task. The task can be a problem to be shared, a sequence to be decided, a solution to be found and so on. Students are responsible for their own piece of information; they can only exchange their information by speaking, and only one person in the group can write. The teacher puts a time limit on the activity and reminds the groups how much time is left. At the end of the time limit, each group reveals their answers, and the teacher assesses the starting point/misconceptions for the lesson. The information can be written or drawn. Pupils will have to explain what pictures they have; for example, sequencing an experiment. Pieces of the sequence could be a mixture of text and pictures. For the more able, the text could be lengthy, and the pupils may require some individual working time before they come together as a group.

In conclusion, lessons are like stories: they need to have an engaging beginning and a memorable ending. By planning interactive activities for the whole class at these key points, lessons become complete entities, students engage in deep, effective learning for better understanding, and teachers have more fun.

References

DfES. 2004. *Key Stage 3 National Strategy, Pedagogy and Practice Unit 5: Starters and Plenaries.* London, UK: HMSO.

Muijs, D, and D Reynolds. 2001. *Effective Teaching: Evidence and Practice.* London: Paul Chapman.

Will an Improved Understanding of Nature of Science (NOS) Improve Elementary Teachers' Self-Efficacy for Science Teaching? A Call for Research

Deborah L Hanson, ***Hanover College, Hanover, Indiana***
Valerie L Akerson, ***Indiana University, Bloomington, Indiana***

We were starting a new professional development inservice for elementary teachers and requested the assistance of a graduate student from the physics department. During the interview process, the interviewees made many interesting comments. I vividly remember one statement in particular. We were interviewing a graduate student from Taiwan who was not familiar with the American educational system. She said that in her country teachers had a specialized content area that they taught even at the elementary level. The idea that we expected elementary teachers to teach all subject areas was simply mind-boggling for her. She stated, "What? Are they super people?" We all laughed, but her comment holds much truth. We do expect elementary teachers to be prepared and do an excellent job teaching all subject areas—from correct sentence structure to the basics of genetic inheritance. This is a daunting task. And unfortunately, the area that is overlooked and not well taught is science. Seventy-seven per cent of elementary teachers feel prepared to teach language arts/reading, while 66 per cent are confident with mathematics instruction and 52 per cent feel prepared to teach social studies. Only 30 per cent of teachers feel confident about teaching science at the elementary level (2000 National Survey of Science and Mathematics Education 2002). Many elementary teachers simply lack confidence in their own science teaching abilities. One reason for this low level of science teaching self-efficacy is the lack of content knowledge. To help prepare elementary teachers for the challenges they face, science teacher educators need to emphasize the overarching concepts that provide a basis for understanding other concepts. One of those basic underlying principles is nature of science (NOS). By treating NOS as a content area, elementary teachers can understand the basic underlying principles of science and gain the content knowledge needed to increase their science teaching self-efficacy and, hopefully, improve their classroom teaching practices.

Despite various attempts and movements to reform elementary science teaching, practices remain relatively unchanged (DeBoer 1991). Science is often presented as a body of knowledge to be learned with an emphasis on memorizing facts. The curriculum is driven by the textbook, and science is often more of an exercise in reading rather than active hands-on learning. The reasons are varied. Many teachers feel constraints of time and materials, and diverse student learners make it difficult to teach science. Recent demands of standardized assessments in language arts and mathematics have placed additional curricular and accountability demands on teachers, forcing science to a back-burner role.

Self-Efficacy

For some elementary teachers, the issue is deeper and more personal. Even with supplies and science labs available, science is still taught on a limited basis. Something else is present that keeps the teacher from being fully engaged in doing science. Many elementary teachers question their abilities to teach science. This directly relates to Bandura's theory of self-efficacy or the "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura 1977, 3). In general, people avoid engaging in activities that they think they will not accomplish successfully. This internal feeling in one's abilities dictates how much effort or perseverance will be devoted to a particular task or to overcoming certain obstacles. Self-efficacy is content specific. Teachers can feel very comfortable and positive in their abilities to teach one part of their curriculum, but not another. Many times it is science that teachers are not comfortable teaching. And, as we know, most elementary teachers do not adequately understand NOS content. According to Bandura, many factors contribute to one's self-efficacy. If a person has a positive experience in doing a particular task (enactive mastery experiences) or receives positive feedback (verbal and social persuasion) that relates to the situation, then one's self-efficacy may increase. Also if a peer or another person in a similar circumstance succeeds in a particular task (vicarious experiences), then one's own confidence in his or her abilities to master the task may increase.

Research in science teaching self-efficacy confirms Bandura's theory. Studies have found that poor experiences in science coursework at any level—elementary, high school or college—may lower science teaching self-efficacy. Poor experiences cause teachers to question their ability to lead students in an area they personally struggled with and translate into a poor attitude about science, reluctance in teaching science and a high level of anxiety (Koballa and Crawley 1985; Ramey-Gassert, Shroyer and Staver 1996). When teachers are asked to describe their science experiences, many, at inservice and preservice levels and having various levels of academic success, recall science as boring and remember being embarrassed or uncomfortable during the science course (Ramey-Gassert, Shroyer, and Staver 1996; Tosun 2000). Some teachers use these incidents to motivate themselves to be better teachers; others simply withdraw from science and teaching science in their classrooms.

Another major contributor to low science teaching self-efficacy that is closely associated with the poor experiences in science content classes is the lack of content knowledge. Simply stated, teachers cannot teach what they do not know or what may be intimidating. Numerous studies have confirmed that elementary teachers who question their science content knowledge or have numerous misconceptions about science also have low confidence in their abilities to teach science (Bencze and Hodson 1999; Harlen and Holyrod 1997; Schoon and Boone 1998). Elementary teachers often report taking the minimum number of science courses possible, thus limiting their exposure to science content (Tosun 2000).

To compensate for their low content knowledge and the low science teaching self-efficacy that may result, teachers develop special coping mechanisms to help them present science in their classroom; some simply avoid science as much as possible. As one elementary teacher who felt unprepared to teach science said, "When I started teaching, science was the last subject I did. And I did not prepare for it much; I just went off the cuff." This is typical of science instruction at the elementary level. Teachers who have low levels of science teaching self-efficacy are more likely to use teacher-directed authoritarian practices and spend less time teaching science in the classroom (Enochs and Riggs 1990; Finson 2001). Low self-efficacy teachers fear the unknown and seek to avoid situations such as a student's question that the teacher cannot explain, or a student doing a science activity beyond the scope or comfort level of the teacher. The result is that many scientific concepts receive only surface treatment. Other science-avoidance strategies include relying on the textbook and lectures as a dominant teaching strategy, step-by-step directions in an activity or kit-based activities, restricting the number of student questions and teaching science as little as possible (Harlen and Holyrod 1997). Needless to say, these coping strategies greatly affect the amount and quality of science instruction that occurs.

Nevertheless, a direct correlation cannot be made between the number of science courses or a teacher's academic success in science and that teacher's level of science teaching self-efficacy. Enochs, Scharmann and Riggs (1995) reported an inverse relationship between the number of science content courses and science teaching self-efficacy level, and concluded that it was not the number of science courses that is important, but the format of the classes. Traditional lecture and textbook-based content courses may contribute to the feelings of low science teaching self-efficacy. The researchers conclude that activity-based hands-on instruction at the college level may increase teachers' self-efficacy, particularly of preservice teachers. Those working with preservice teachers should ask: How can science content become meaningful and positive for an audience that may be already disengaged in science?

The structure of many college-level science courses has changed in the past few years—an emphasis has been placed on tailoring the content-level courses to the needs and learning styles of preservice teachers. Science courses have started incorporating new strategies to assist teachers to acquire the pedagogical content knowledge (PCK) needed to transform their content knowledge into successful teaching practices for elementary students. More elementary preservice teachers are learning content by inquiry techniques; they are active participants, doing science instead of passively observing or memorizing facts. Professional development programs are being developed to strengthen inservice teachers' content knowledge.

What Is Science Anyway?

While these are steps in the right direction, these changes may not be enough. One key aspect is still missing. While we speak highly of the body of knowledge and give some insight into the process of obtaining that information by learning science through inquiry, we often omit the personal or background framework in which that information was generated and processed. This part of science, referred to as nature of science (NOS), gives insight to the scientific process and the true work of a scientist. NOS refers to the epistemological foundation or framework of the activities of science; it answers the questions "How do we know?" and "How did this new conclusion come to be?" Understanding NOS content empowers teachers to develop a deeper understanding of what science truly is.

So many times a simplistic surface overview of scientific facts and vocabulary is presented in the science classroom. The emphasis is on how much information can be covered in a semester-long class. Topics are covered quickly, often without instilling true understanding of the concepts involved. When teachers base their ideas about science on these types of experiences, it is not surprising that they fail to acquire confidence and do not wish to even try to improve their understanding. The teachers do not feel comfortable participating in this arena and many wish to prevent their students from inflicting this discomfort on their own students. Investigating the processes of science provides some insight into the process. But the foundation and the inherent guiding ideas for how that information was developed is missing; without this strong foundation, many students simply cannot fully understand what science is all about and develop misconceptions about science. By studying NOS as a content area, the learner, regardless of level, is given the tools to fully understand and debunk their misconceptions, and begin to understand and envision science differently.

Treating NOS as a content area is not a new idea. Lederman (1998) recommended that NOS content be treated as a cognitive objective of equal importance to other content material presented. What is new is the idea of linking NOS to the content areas and looking at it as a vehicle to increase science teaching self-efficacy. By emphasizing the basics and the foundation of science, students at all levels can gain a new insight to science, correct existing misconceptions about science and possibly prevent some of the poor science experiences that many elementary teachers have experienced.

What should be taught as NOS content? This question has been argued thoroughly, and many theoretical perspectives have been put forward. Philosophers, scientists and science educators do not agree—and may never agree—exactly what should constitute NOS. But before such philosophical debate can occur, one must be familiar with the basic ideas of science because they are the foundation for effective K–12 instruction. It is to be noted that, at this level, major philosophical differences and the philosophies of Karl Popper and Paul Feyerabend do not apply and are not developmentally appropriate. By looking through the reform documents at an international scale, certain basic ideas serve as the appropriate starting point for NOS instruction. These ideas can be condensed into seven basic NOS aspects and can provide a working guideline for both the core concepts in the K–12 classroom and all teachers' NOS content focus. Table 1 shows the NOS aspects deemed accessible by K–12 learners

If teachers recognize these NOS aspects as science and incorporate them into their personal definitions of science, they may feel better about what they are teaching and have more confidence in their science teaching abilities.

Improving NOS Views: Will Self-Efficacy Improve Too?

By ignoring this central NOS foundation and focusing on science only as a distinct body of knowledge, many elementary teachers simply do not understand what science is or how it operates. Their lack of content knowledge creates

Table 1
Recommended NOS Aspects for K–12 Learners

Empirical	Science is a way of knowing that is based on evidence. It explains natural phenomena based on evidence that is gathered through many methods.
Observation and Inference	Observations and inferences need to be distinguished from each other. Observations are a key tool that scientists use; observations form the foundation of scientific work and are detailed and descriptive statements involving information gained directly from the senses. Observational studies are a valid method of collecting data. Inferences are assumptions or predictions based on observed evidence.
Theory and Law Distinction	Laws are statements or descriptions of relationships between observable phenomena and are often written as formulas or equations. Theories are inferred explanations of laws.
Creativity and Imagination	Creativity and imagination are used when interpreting data and fitting the various pieces of data together to form a new scenario or to fill-in gaps resulting from missing data.
Subjective or Theory-Laden	Scientists are human and have personal mind-sets based on the influence of beliefs, knowledge, training, experiences and expectations that form a filter through which the scientist operates and interprets his or her work. These mindsets allow scientists to look at the same data set yet interpret it differently.
Cultural Influences	Science is embedded in a specific context, and scientists are a product of the culture. Culture influences how that data is interpreted.
Tentativeness	Scientific knowledge, theory or laws are never absolute or certain. They may change when new evidence is discovered or when old evidence is reinterpreted.

misconceptions that impede future science engagement and also affects students. Without the insight gained from learning NOS content, the misconceptions perpetuate and continue to grow in a vicious cyclic manner. McComas (1998) identified the following common misconceptions about NOS: (a) hypotheses become more accepted and develop into theories that in turn evolve into laws; (b) one general and universal scientific method exists for all scientific endeavours; (c) if careful techniques are used, the resulting knowledge will be sure and definite; (d) established knowledge is steadfast and will never change; (e) science is objective; and (f) experiments are the principle route to scientific knowledge and (g) science is more of a step-by-step procedure rather than a creative process.

These misconceptions are roadblocks to fully understanding the fundamental ideas of science and how scientific knowledge is gained. When looking at most science content courses, it is easy to see how these misconceptions come about. Science content is often delivered to students as though it were incontrovertible. Laboratory activities are very procedure oriented and focused on obtaining and verifying one correct answer. In textbooks the scientific method is illustrated by examples of how various scientists have used the scientific method in their work. It is hard to see science as a changing body of knowledge when one sees information presented in an absolute fashion. It is also hard to see science as creative when following the step-by-step procedures of the scientific method. Information presented in a textbook is accepted as an unchanging fact, often without the proper or full explanation of how this information was gathered and formed. The tentativeness of science is hard to see when only a factual body of knowledge is presented in the classroom. The creativity of science is hard to appreciate when one sees only the scientific method and experimental procedures.

Even when looking beyond the science classroom, misconceptions are perpetuated; Reiff (2005) refers to as the "hidden" world of science, by which he means that scientific findings are presented in their final form—very polished and neatly done. The information gained from an investigation is presented matter-of-factly; scientific journals request the work be published in a format that closely emphasizes the scientific method. Those serendipitous moments or creative insights are often never revealed. At the same time, sometimes out-of-a-box thinking is emphasized to the point that it seems that only creative thinkers can participate in science.

Effective NOS instruction simply does not happen by doing science. It is not enough to pattern the work of a scientist; being effective in teaching about NOS requires an explicit-reflective approach, which calls attention to the various NOS aspects. After each activity, participants should discuss the various NOS aspects present and explain how those aspects were used in the exercise. This reflection allows students to purposely reflect on the activity just completed and make explicit connections with the targeted NOS aspects. The explicit-reflective approach has been successful in helping preservice and inservice teachers learn NOS (Akerson, Abd-El Khalick and Lederman 2000; Akerson, Hanson and Cullen, in press).

As students participate in these situations, they start to form a personal definition of science. Elementary teachers have formed personal definitions of science based on their previous experiences in preservice college-level science coursework and in all the preceding years as a science student (Thomas and Pederson 2003). When science is presented as a body of knowledge, people develop many distorted ideas and misconceptions. As a consequence, many elementary teachers feel alienated from science and begin to think that they cannot teach it; this contributes to feelings of low science teaching self-efficacy (Ramey-Gassert, Shroyer and Staver 1996). Teachers' personal definition of science prevents them from fully engaging in it. Science, as they have learned and know it, is foreign domain that they cannot enter. Teachers start to identify with other curricular areas that they are more comfortable with, such as language arts, social studies and science. Improving NOS conceptions to change personal definitions could affect teachers' science teaching self-efficacy and increase teachers' comfort level. This could then lead to their truly doing science and making science a part of the elementary classroom.

Call for Future Research

The argument for incorporating explicit-reflective NOS pedagogy and content into science coursework is strong. We advocate further research to see if elementary teachers will improve their science teaching self-efficacy if they incorporate the various NOS aspects into their personal definitions of science. Will teachers, especially at the elementary level, improve their self-efficacy in science if they understand that science is a creative and imaginative endeavour based on evidence that uses observations and inferences to come to conclusions and theories? Will teachers seek to improve their science teaching if they know what science really means and come to see science as more interesting than rote memorization? Will elementary teachers spend more time on science instruction if they develop more informed definitions of science? We call for research in this area.

References

Akerson, V L, F Abd-El Khalick and N G Lederman. 2000. "Influence of a Reflective-Explicit Activity-Based Approach on Elementary Teachers' Conceptions of Nature of Science." *Journal of Research in Science Teaching* 37, 295–317.

Akerson, V L, D L Hanson and T A Cullen. In press. "The Influence of Guided Inquiry and Explicit Instruction on K–6 Teachers' Nature of Science Views." *Journal of Science Teacher Education*.

Bandura, A. 1977. "Self-Efficacy: Toward a Unifying Theory of Behavioral Change." *Psychology Review* 84, 191–215.

Bencze, L, and D Hodson. 1999. "Changing Practice by Changing Practice: Toward More Authentic Science and Science Curriculum Development." *Journal of Research in Science Teaching* 36, no 5: 521–39.

DeBoer, G. 1991. *A History of Ideas in Science Education: Implications for Practice*. New York: Teachers College Press.

Enochs, L G, and I M Riggs. 1990. "Further Development of an Elementary Science Teaching Efficacy Belief Instrument: A Preservice Scale." *School Science and Mathematics* 90, 694–704.

Enochs, L G, L C Scharmann and I M Riggs. 1995. "The Relationship of Pupil Control to Preservice Elementary Science Teacher Self-Efficacy and Outcome Expectancy." *Science Education* 79, 63–75.

Finson, K D. 2001. "Investigating Preservice Elementary Teachers' Self-Efficacy Relative to Self-Image as a Science Teacher." *Journal of Elementary Science Education* 13, 31–42.

Harlen, W, and C Holyrod. 1997. "Primary Teachers' Understanding of Concepts of Science Impact on Confidence and Teaching." *International Journal of Science Education* 19, 93–105.

Horizon Research. 2002. *2000 National Survey of Science and Mathematics Education: Status of Elementary School Teaching*. http://2000survey.horizon-research.com (accessed September 14, 2006).

Koballa, T R, and F E Crawley. 1985. "The Influence of Attitude on Science Teaching and Learning." *School Science and Mathematics* 85, 222–32.

Lederman, N G. 1998. "The State of Science Education: Subject Matter Without Context." Electronic Journal of Science Education 3, no 2: 1–13. http://unr.edu/homepage/jcannon/ejse/Lederman.html (accessed September 14, 2006).

McComas, W F. 1998. "The Principal Elements of the Nature of Science: Dispelling the Myths." In *The Nature of Science in Science Education: Rationales and Strategies*, ed W F McComas, 53–72. Dordrecht, the Netherlands: Kluwer.

Ramey-Gassert, L, M G Shroyer and J R Staver. 1996. "A Qualitative Study of Factors Influencing Science Reaching Self-Efficacy of Elementary Level Teachers." *Science Education* 80, no 3, 283–315.

Reiff, R. 2005. "Scientists' Conceptions of Scientific Processes: Is the Scientific Method a One-Size-Fits-All Model?" Paper presented at the annual meeting of the Association for the Education of Science Teachers, Colorado Springs, Colo, January.

Schoon, K J, and W Boone. 1998. "Self-Efficacy and Alternative Conceptions of Science of Preservice Elementary Teachers." *Science Education* 82, 553–68.

Thomas, J A, and J E Pederson. 2003. "Reforming Elementary Science Teacher Preparation: What About Extant Teaching Beliefs?" *School Science and Mathematics* 103, no 7: 319–30.

Tosun, T. 2000. "The Beliefs of Preservice Elementary Teachers Toward Science and Science Teaching." *School Science and Mathematics* 100, no 7: 374–79.

Three Classroom Strategies for Teaching About the Nature of Science

Dougal MacDonald and Brenda Gustafson, ***University of Alberta***

The main goals of science teaching are generally stated as content knowledge (concepts), cognitive skills (for example, designing experiments) and attitudes (for example, respect for evidence). Another historically important goal has been to teach students about the nature of science (NOS). NOS is not about specific science content but about matters applicable to science as a whole; for example, how scientific investigations are carried out, standards defining acceptable scientific explanation and the reliability of scientific knowledge.

Why teach children about the nature of science? Overall, it contributes to students' scientific literacy. Specifically, many good reasons can be given (Collins et al 2001). Teaching about the nature of science helps achieve the following:

- Helps science education offer value to all students, not just those pursuing a science career.
- Clarifies how classroom scientific inquiry is based on the work of scientists.
- Enlightens students about the inner workings of science (for example, how hypotheses are tested).
- Helps create citizens who can think critically about science-related discoveries (for example, critically evaluating the results of the tests of a new drug).
- Helps create citizens who can contribute intelligently to decisions about science-related issues (for example, genetically modified foods).
- Gives students insight into the difficulty of constructing reliable knowledge about the world.
- Helps students understand not only *what* we know but also *how* we know (for example, how the theory of plate tectonics became accepted in geology).
- Helps to explain and justify why science is considered a rational enterprise (for example, why we should give credence to a theory, such as natural selection).

Science teachers convey an image of the nature of science to students even if they do not do so explicitly. For example, teachers who have students carry out and write up all classroom experiments in the same way may erroneously convey to students that there is such a thing as the scientific method. This suggests that science teachers should (1) consciously teach about the nature of science and (2) convey an authentic notion of the nature of science when doing so.

Further, students will not necessarily develop an authentic notion of the nature of science simply by doing authentic science. For example, students will not necessarily better understand the role of evidence in scientific inquiry just by finding evidence to support their explanations. More realistically, the teacher needs to (Gustafson and MacDonald 2005)

- decide on appropriate nature of science goals,
- meaningfully intertwine NOS goals with other lesson goals (for example, knowledge and skills) and
- make the NOS goals explicit to students during the lesson.

A Consensus on the Nature of Science

What is an authentic notion of the nature of science? Disagreement among science educators, scientists and others on this question will likely persist, but teachers need some basis to work from, so a consensus among most critics would be useful. One such consensus is presented in the documents of Project 2061, a long-term initiative by the American Association for the Advancement of Science (AAAS) to promote scientific, technological and mathematical literacy.

The Project 2061 consensus on NOS is validated by the lengthy collaboration of over 400 scientists, engineers, science educators, philosophers of science and others who developed it. The result is found in *Science for All Americans* (AAAS 1989). The article's internal headings are useful for teacher knowledge and for teaching about NOS because they are framed as statements about NOS. The headings or statements are grouped under three categories:

Scientific Worldview

- The world is understandable.
- Scientific ideas are subject to change.
- Scientific knowledge is durable.
- Science cannot provide complete answers to all questions.

Scientific Inquiry

- Science demands evidence.
- Science is a blend of logic and imagination.
- Science explains and predicts.
- Scientists try to identify and avoid bias.
- Science is not authoritarian.

Scientific Enterprise

- Science is a complex social activity.
- Science is organized into content disciplines and is conducted in various institutions.
- There are generally accepted ethical principles in the conduct of science.
- Scientists participate in public affairs both as specialists and as citizens (AAAS 1989).

Focusing on the Nature of Scientific Inquiry

Because the recommended approach to teaching classroom science is scientific inquiry, it is useful to pay special attention to ideas about the nature of science relevant to scientific inquiry. The second section of the Project 2061 article on NOS specifically addresses scientific inquiry, and a close reading suggests a number of teachable ideas about NOS that expand on the more general statements made in the article headings. These ideas may need to be rephrased and/or simplified, depending on students' ages, abilities and backgrounds:

Scientific Methods

- Scientists agree generally on what is a valid investigation but there is no fixed set of steps that scientists always follow.
- Scientists resolve the validity of scientific claims by referring to observations of phenomena.
- Scientists use their senses and instruments to gather accurate data through observations and measurements.
- Scientists gather data in both natural settings (eg, forests) and under controlled conditions (eg, in laboratory experiments).
- Scientific arguments follow the principles of logical reasoning (eg, in how conclusions are inferred from evidence) (AAAS 1989).

Role and Nature of Hypotheses

- Formulating and testing hypotheses are fundamental scientific activities.
- Scientists use tentative hypotheses to seek, choose and interpret scientific data.
- To be useful, a hypothesis should be testable and should suggest what evidence would support it and what evidence would refute it (AAAS 1989).

Invention and Discovery

- Inventing hypotheses and theories requires logic, close examination of evidence and creativity.
- Scientific discoveries require a combination of knowledge and creative insight (AAAS 1989).

Theoretical Explanations

- Scientists produce knowledge by making observations of phenomena and inventing theoretical explanations to make sense of them.
- Theoretical explanations should use or be consistent with currently accepted scientific principles.
- Theoretical explanations must be logically sound and incorporate a substantial body of valid observations.
- Theoretical explanations often gain acceptance by showing relationships among phenomena that previously seemed unrelated.
- Theoretical explanations should have predictive power and should fit both known observations and additional observations not used in formulating the theories (AAAS 1989).

Bias and Authority

- Biases may influence the choices, recording, reporting and interpreting of scientific data.
- Scientists are alert to bias in their own work but objectivity may not always be achieved.
- It is appropriate in science to turn to knowledgeable people as sources of information and opinion, however, no scientists are believed to have special access to the truth and there are no pre-established conclusions that must be reached (AAAS 1989).

Theory Change

- New scientific theories may encounter opposition from the scientific community in the short run; however, in the long run, theories are judged by their results.
- When a scientist proposes a new theory that explains more phenomena or answers more questions than a previous theory, the new theory eventually becomes established in its place (AAAS 1989).

Strategy One: Scientific Inquiry

Many important ideas about the nature of science can be explicitly taught within the context of scientific inquiry (Gustafson and MacDonald 2005):

- *While scientists agree generally on what constitutes a valid investigation, there is no fixed method or set of steps that they always follow*. Student groups compare and find differences in how they conducted an investigation into light and shadows, but also note similarities; for example, each group tried to control the same variables.
- *Scientists use their senses and instruments to gather accurate data through observations and measurements*. Students provide examples of observations and measurements they made during their investigation, and the role played by instruments (for example, using a thermometer to track the temperature of melting ice cubes).
- *Scientists gather data in both natural settings and under controlled (laboratory) conditions*. Students describe how an uncontrolled investigation (for example, observing different shapes of leaves on trees) differs from a controlled investigation that they engaged in (for example, testing leaves for chlorophyll).
- *Biases may influence the recording, interpreting and reporting of scientific data.* Students give examples of where they tried to explain results that contradicted their existing ideas (for example, insisting that an ammeter registered different amounts of current in a circuit before and after a bulb when all other groups found the amount of current to be the same).

- *Scientific arguments must adhere to the principles of logical reasoning.* Students outline how their conclusions about the connection between bird beak shape and type of food were inferred from the evidence that they gathered during a simulation activity.
- *The validity of scientific claims is eventually resolved by referring to observations of phenomena*. Students resolve a debate over the result of a test by repeating it (for example, using iodine to determine if cornstarch is part of a mystery mixture of three white powders).
- *To be useful, a hypothesis should be testable and should suggest what evidence would support it and what evidence would refute it.* Students frame a hypothesis using an If … then … format so they can test it (for example, "If the mineral fizzes when acid is dripped on it, then it is a carbonate").
- *Scientific theories should be logically sound, incorporate a substantial body of valid observations, and use or be consistent with currently accepted scientific principles.* Students explain how their theory (for example, their explanation for why a hot air balloon ascends to the ceiling of the room) meets the above three criteria.

Strategy Two: History of Science

Teachers can also address NOS goals through familiarizing students with the history of science. Current science textbooks generally present summaries of up-to-date scientific ideas, often without reference to their historical development. Students may be left with the erroneous impression that scientific knowledge is a collection of unchanging facts requiring little or no justification. Because the history of science shows how scientific ideas change over time, studying it can help students better understand how we know as well as what we know. Studying the history of science is particularly useful in helping students understand the nature of scientific theories, because many historical accounts focus on the creation and testing of new theories (Gustafson and MacDonald 2005):

- *Scientific knowledge is generated by making observations and inventing theoretical explanations to make sense of them.* Students are familiarized with the story of how Fleming realized penicillin's antibiotic properties when he observed that colonies of bacteria in a Petri dish stopped growing where mould existed.
- *Theoretical explanations often gain acceptance by showing relationships among phenomena that previously seemed unrelated*. Students are familiarized with the story of how the theory of plate tectonics came to be accepted as an explanation for such diverse phenomena as earthquakes, volcanoes, fold mountains, seafloor spreading and oceanic trenches.
- *Theories are validated by their predictive power*. Students are familiarized with the story of how the astronomer Leverrier used anomalies in Uranus's orbit to predict where to find the then unknown planet Neptune in the night sky.
- *New scientific theories may encounter strong opposition in the short run, but in the long run they are judged by their results*. Students are familiarized with the story of how Wegener's idea of continental drift was rejected then later accepted.
- *New theories arise when they explain more or answer more questions than previous theories*. Students are familiarized with the story of how Darwin's theory of natural selection replaced Lamarck's theory of inheritance of acquired characteristics as the explanation for adaptation (for example, the long neck of the giraffe).

Strategy Three: Current Science-Related Events and Issues

A third strategy for teaching about the nature of science concerns science in the news. Almost daily, the media contain stories of science-related events and issues that include references to the nature of science, though those references are often only implicit. For example, Norris and Phillips (2003, 234) state that "Texts contain expression of the wide range of degrees of doubt and certainty applied to statements in science" and discuss whether it is a factual assertion or a tentative hypothesis that there is an ocean beneath the frozen crust of Europa, one of Jupiter's moons.

The January 20, 2006, issue of the *Edmonton Journal* includes the following three headlines and accompanying news stories:

- "United States the Next Front in City Company's Cold War" (This article was about marketing Alberta-developed COLD-fX in the United States.)
- "Wandering Whales Worry Scientists" (This article was about the possible connection between disruption to right whale migration patterns by shipping routes and military sonar testing.)
- "Winds Delay Pluto Mission Launch" (This article was about the unmanned US spacecraft soon to be sent on a nine-year voyage to Pluto.)

Below are some examples of how each could be used to teach about the nature of science.

- *Scientists gather data under controlled conditions*. Claims about the effectiveness of COLD-fX are based on controlled clinical trials in Canada and the US. In the Canadian trials, COLD-fX dramatically reduced the incidence and frequency of recurrent colds. The American results showed that COLD-fX dramatically reduced respiratory infections in elderly patients.
- *Scientists generally agree on what is a valid investigation, but there is no fixed set of steps that scientists always follow*. Scientists agree that testing new drugs such as COLD-fX should involve double-blind testing, where neither the subject nor the experimenter knows which substance is the drug and which is the placebo. Students could be asked to design and participate in a double-blind study themselves (for example, which of three unknown cleaning products works the best).
- *Science produces knowledge by making observations of phenomena and inventing theoretical explanations to make sense of them*. Right whale migration patterns have been disrupted and scientists are trying to explain why.
- *Theoretical explanations should use or be consistent with currently accepted scientific principles*. Current scientific knowledge about the effects of sonar transmissions and ship movements on aquatic life will inform an explanation incorporating these two factors.
- *Theoretical explanations should have predictive power and should fit both known observations and additional observations not used in formulating the theories*. One test for a sonar/shipping explanation for disruption to whale migration could be to stop the sonar transmissions and change the shipping lanes and monitor the effects. The related prediction would be that, once the effects of these two factors are eliminated, the whales will gradually return to their traditional patterns.
- *Scientists resolve the validity of scientific claims by referring to observations of phenomena.* Pluto raises many questions among space scientists because of its distance and anomalous characteristics; for example, Pluto resembles neither the rocky inner planets nor the outer gas giants. The Pluto space probe has the potential to make observations that may help answer many questions.

A Final Word: Science, Technology and Society

When teaching about the nature of science, it is important to keep in mind that science, technology and society are interconnected. For example:

- Social factors influence which scientific research projects get government funding.
- Decisions about science-related social issues are partially informed by scientific knowledge.
- Technological successes, such as more powerful telescopes, advance scientific knowledge.
- Science helps to explain technological failures such as the crash of the Columbia space shuttle.
- Technological innovations, such as the automobile, influence social change (for example, an automobile culture gives rise to freeways, service stations and suburban shopping malls and fast food outlets).
- A technological link to the testing of three white mystery powders relates to the importance, synthesis and use of indicators in chemistry in general (students can actually make and use their own red cabbage solution indicator to distinguish acids from bases).

- A social link to the story of Fleming and penicillin relates to how, for centuries prior to Fleming's "discovery," indigenous people in North America made and applied a paste of mouldy corn to prevent the infection of wounds. Students could discuss the role of social factors in the recognition of what constitutes a scientific discovery.

Often, then, an authentic portrayal of NOS can be extended to include investigation and discussion of technological and societal links. Important for teachers is that students understand what is called science, how science happens and the degree of trust we should place in scientific knowledge. This understanding will assist students to know the world and their place within it, to ask important questions about the world and to think critically about how the world should be.

References

American Association for the Advancement of Science (AAAS). 1989. *Science for All Americans*. Project 2061. New York: Oxford University Press. Also available at www.project2061.org/publications/sfaa/online/chap1.htm (accessed September 15, 2006).

Collins, S, J Osborne, M Ratcliffe, R Millar and R Duschl. 2001. "What 'Ideas-About Science' Should Be Taught in School Science? A Delphi Study of the Expert Community." Paper presented at the annual conference of the National Association for Research in Science Teaching, St Louis, Mo.

Gustafson, B, and D MacDonald. 2005. *A Conceptual Approach to Teaching Children About Science, Technology, and Society*. Edmonton, Alta: Ripon Press.

Norris, S, and L Phillips. 2003. "How Literacy in its Fundamental Sense Is Central to Scientific Literacy." *Science Education* 87, no 2: 224–40.

Argument and Conceptual Change

Guoqiang Zhou, ***City University of New York***
Zhijin Xu, ***University of Alberta***
Xiaoming Wu, ***Shandong Jiaotong University, China***

Since the late 1970s, scholars have become increasingly aware that students come to school with their own understanding of the world (Driver, Guesne and Tiberghien 1985). Students' conceptions are often called preconceptions in the literature because they exist before students receive formal instruction on the relevant topics. Student preconceptions have been identified in the various areas of science and in most cases differ from scientific notions (Bar, Zinn and Rubin 1997; Berg and Brouwer 1991; Clement 1982; Erickson 1979, 1980; McCloskey 1983; Zhou et al 2000). Because science education is structured around scientific notions, conceptual change has been a nonquestionable goal of science education for the last three decades. Scholars have proposed instructional strategies to help students change their conceptions (Posner et al 1982; Scott, Asoko and Driver 1992). Among these efforts, Posner et al (1982) presented the most famous model about conceptual change.

Posner's Model for Conceptual Change

Posner et al (1982) were inspired by Kuhn's (1970) theory of scientific revolution when they developed their model of conceptual change. As stated in their paper, they believed that "a major source of hypotheses concerning this issue [conceptual change] is the contemporary philosophy of science" (p 211). In Kuhn's picture of science progress, some necessary preconditions can be detected for scientific revolutions. They include the appearance of anomalies that eventually lead to scientists' dissatisfaction with the old paradigm; the appearance of a new paradigm that provides scientists with a choice; and the merits of the new paradigm, such as enhanced problem solving, more accurate predictions, closer matches with subjective matter and more compatibility with other specialties. Paralleling these conditions for scientific revolution, Posner et al (1982) claim that several important conditions must be fulfilled before conceptual changes can occur:

1. There must be dissatisfaction with existing conceptions. Scientists and students are unlikely to make changes in their conceptions until they believe that their current conception will not work. It is reasonable to suppose that people must have collected a store of unsolved puzzles and lost faith in the capacity of their current conceptions to solve these problems before they are willing to give up their current conceptions.
2. A new conception must be intelligible. The person must be able to grasp how experience can be structured by a new conception sufficiently to explore the possibilities inherent in it. To put this simply, a person must be able to understand the new concept.
3. A new conception must appear initially plausible. Any new conception adopted must at least appear to have the capacity to solve

the problems generated by its predecessors. Otherwise, it will not appear a plausible choice. Plausibility is also a result of the consistency of the conception with other knowledge. A new idea is less likely to be accepted if it is inconsistent with current agreed-upon knowledge.

4. A new conception should suggest the possibility of a fruitful research program. It should have the potential to be extended and open up new areas of inquiry.

In short, conditions of conceptual change can be described in terms of the dissatisfaction with the old conception and the intelligibility, plausibility and fruitfulness of the new conception.

Posner's model attracted much attention from science education researchers, especially scholars in the camp of constructivism. Most strategies for conceptual change conducted in the 1970s and 1980s were based on, or related to, this model.

Criticisms of Posner's Model

Empirical studies, which attempt to bridge the gap between a personally held concept and the scientific view, generally have revealed that preconceptions are hard to change. Preconceptions are apparently changed in school settings but may quickly reassert themselves in the broader context of daily life. Clement (1982) gave one example of the Aristotelian versus the Newtonian view of motion. In his study, 88 per cent of pre-university physics students thought a coin experienced an upward force on the way up after it was thrown up. After the university mechanics course, 75 per cent of students still held this concept; namely, that "motion implies force." Redish and Steinberg (1999) described a case in which a student struggled with Newton's third law. The student knew what Newton's third law was, but she changed her answer numerous times between the physics class model and her common sense for one particular test question that asked whether a truck or a car exerted a bigger force during a mutual collision between the two. The common-speech wording of the question brought up her common sense: "Larger objects exert a larger force." In the study of Erickson (1979, 1980), students' viewpoints on the nature of heat were found to drift between the idea of heat as a flowing substance and heat as molecular motion. The failure of practical efforts to change student preconceptions forces scholars to question Posner's model, on which practical work was built. Is something wrong with Posner's model?

Learning and Nonrational Factors

As Pintrich, Marx and Boyle (1993) point out, one major criticism of Posner's model focuses on the nonrational characteristics of learning. "Our central commitment in this study is that learning is a rational activity" (Posner et al 1982, 212). This model implies that when students meet new experiences in the classroom that do not match their existing mental structure, they will feel dissatisfied and willingly accept new concepts to overcome this conflict; in other words, academic understanding is seen as the goal of student learning. However, the assumption that students approach their classroom learning with a rational goal of making sense of the information and coordinating it with their prior conceptions may not be accurate. There is both theoretical and empirical evidence to believe that learning is not purely rational. Piaget reminded us that affectivity plays an essential role in human beings' behaviour. Affectivity, including interests, feelings, values and so on "constitutes the energetics of behavior patterns whose cognitive aspect refers to the structures alone. There is no behavior pattern, however intellectual, which does not involve affective patterns as motives" (Piaget and Inhelder 1969, 158). Affectivity influences our selection of experiences. We pay attention to events we like or that interest us but ignore others. There is no wonder that in some cases, cognitive conflict is clearly there from an instructor's perspective, but students may not buy it. These kinds of events fail to occasion cognitive equilibration in students and thus will not result in cognitive development. Therefore, affectivity is a doorkeeper; it controls whether or not the mechanisms of assimilation, accommodation and equilibration happen during certain experiences.

Students come to class with different motivational levels, which can influence their cognitive engagement in academic task. Wentzel (1991) stated that students may have many social goals in the schooling context besides academic understanding, such as making friends, impressing peers or pleasing instructors. These goals may shorten the circuit of any indepth intellectual engagement. Students may passively face the conceptual discrepancy by simply memorizing the scientific concepts without understanding them. If we roughly sort students' learning goals into two groups—mastery learning and performance learning—the normative goal theory tells us that students with the goal of mastery learning are more engaged in deeper cognitive processing and use more sophisticated cognitive strategies, whereas students with performance-orientated goals more often use surface processing and have less cognitive engagement (Ames 1992; Dweck and Leggett 1988; Nolen 1988, 1996; Pintrich and De Groot 1990). Recent studies reveal a more complex picture of students' learning goals (Harackiewicz, Barron and Elliot 1998; Wolters, Yu and Pintrich 1996); nevertheless, some students may have both learning goals, although mastery learning is still essential for students' adaptive outcomes because it involves higher levels of efficacy, interest, positive effect, effort and persistence, the use of more cognitive and metacognitive strategies, as well better performance (Harackiewicz et al 2002; Pintrich 2000). It is not difficult to understand that students may get good marks on traditional exams, but still have difficulty understanding the concepts, because traditional exams leave room for students to learn with high performance-orientated goal orientation and low mastery goal orientation. The conceptual change does not really happen to them.

Learning Has a Dimension of Social Construction

Other main criticisms of Posner's model focus on the lack of social dimension in learning. The model suggests that when students become dissatisfied with their original beliefs, they will try to find an alternative that is intelligible, plausible and fruitful. These adjectives focus on personal cognition and imply that all reasoning happens in the mind of an individual. However, a great number of theoretical and experimental studies suggest that an individual's learning in the classroom is not isolated, but rather is greatly influenced by interactions with others. For Piaget, social interaction is seen as a requirement for children to construct social knowledge and as a resource of occasions for cognitive disequilibration that leads to the reconstruction of knowledge. In Vygotsky's account, all higher mental functions originate from social relationships:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological), and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals (Vygotsky 1978, 57).

> All higher mental functions are internalized social relationships; . . . their composition, genetic structure, and means of action—in a word, their whole nature—is social. Even when we turn to mental processes, their nature remains quasi-social. In their own private sphere, human beings retain the functions of social interaction (Vygotsky 1981, 164).

Many experimental studies conducted in the school setting have documented the merits of cooperative learning. While a large portion of the literature on cooperative learning focuses on its function of improving students' tolerance, mutual respect, collaboration and debate in science-related social issues, which are claimed to be important components of citizenship education (Rotblat 2002; Campbell 2002), many studies suggest that cooperative learning can improve students' interest in science, self-esteem, learning autonomy, decision-making ability and academic achievement. For example, Barbosa, Jofili and Watts (2004) claim that cooperative learning experiences increase students' self-esteem, interest in the subject, learning autonomy, and indepth comprehension of learning tasks. Driver et al (1994) report that in a group setting students can successfully bring their knowledge and experiences together to advance their thinking. Johnson and Johnson (1985, 2000) demonstrate that cooperative learning promotes higher achievement than do competitive and individual learning experiences. Chang and Mao (1999) and Sadler (2002) report that while there is no difference in student achievement in knowledge and comprehension parts of a test that incorporated Bloom's taxonomy, the students who worked cooperatively performed better on the application part of the test. For too long, we have assumed that the individual mind functions well independently for learning and have ignored the social dimension of knowing. When students fail a course, we claim that they did not work hard enough or that they were not smart enough, while part of the reason may come from a poor learning environment.

Learning is both an individual cognitive activity and a social construction. When Piaget and his followers insisted that children individually invent knowledge, they did not forget the function of social interaction in knowledge acquisition. Although Vygotsky and his students stated that knowledge is people's internalization of a sociocultural relationship, they did not mean transmission. Internalization is an active process. In the words of Leont'ev (1981), a student of Vygotsky, "the process of internalization is not the transferal of an external activity to a pre-existing, internal plane of consciousness. It is the process in which this plane is formed" (p 57). Some experimental studies have supported this convention. In the study of O'Donnell and Dansereau (1993), college students listened to a prerecorded lecture in one of four experimental conditions: (a) individual note takers who reviewed their notes individually after the lecture, (b) dyads (two students) who took notes during the lecture with the expectation of cooperatively reviewing the material after the lecture, (c) dyads in which one partner listened to the lecture without taking notes and subsequently summarized the information to a partner who took notes during the lecture, and (d) dyads whose members took notes individually without expecting to review cooperatively, but who did in fact review cooperatively after the lecture. A free-recall test on lecture contents was administered to students. The study result showed that students who reviewed the lecture cooperatively outperformed, in a test situation, the students who reviewed the lecture individually. Among the three different ways of cooperative reviews, the unexpected cooperative condition (d) is most effective. Each individual contribution is therefore critical for group learning. In the study designed to investigate whether and how collaborative learning at the computer fosters conceptual changes, Tao and Gunstone (1999) found that computer-supported collaborative learning provided students with experiences of coconstruction of shared understanding and peer conflicts that lead to conceptual change. They also found that when coconstruction of knowledge was accompanied by personal construction, conceptual change became stable over time. When students did not personally make sense of the new understanding, their change was short-lived.

Argument, Science and Science Education

Argument is one primary component of scientists' work. In the discourse of constructing scientific knowledge that has consistence between pieces and is widely accepted by the scientific community, scientists argue with themselves through frequent idea changes and, more important, argue with each other through publication, conferences and informal occasions to build knowledge that has minimum bias. The role argument plays in science is more obvious and important during scientific revolutions or paradigm changes. As Kuhn (1993) and Thagard (1992) state, in the history of science a new framework takes the place of its previous one through scientific argument. The dialogues between the caloric and kinetic views of heat, the particle and the weave views of light, and the debate between Bohr and Einstein on quantum mechanics are typical examples in which argument plays a major role.

Experiment has been widely viewed as a fundamental characteristic of science, particularly with the success of so-called experiment-based modern science that began with the work of Galileo. However, if we look at science as a process of argument, experiment becomes one measure that provides scientists with insights and justification for their arguments, but it is not the only one. Intuition, guesswork and imagination can also play important functions in scientists' work. As Einstein states, a scientific hypothesis does not come directly from experiment; it comes out of imagination and guesswork. This statement describes his creative work on relativity. A more convincing example is the famous Franck-Hertz experiment in atomic physics. Franck and Hertz started to conduct studies on the ionization of atoms by electron impact in 1911, which eventually led them to their being awarded the 1925 Nobel Prize in physics. In 1914 when Franck and Hertz first published their report, they interpreted their typical experimental value of 4.9ev as the ionization voltage of mercury atoms. Bohr, however, believed that this value represents the excitation voltage of an atom from one energy state to another; in other words, Bohr took this experiment as a direct verification of his hypothesis about the stationary state of atoms and published a paper in 1915 criticizing Franck's and Hertz's interpretation.

In 1916, Franck and Hertz published a paper to announce their refutal of Bohr's explanation. It wasn't until 1919, five years after their first publication and eight years after their first attempt on their experiment, that Franck and Hertz accepted Bohr's interpretation. They won the 1925 Nobel Prize because their experiment directly verified Bohr's hypothesis, which turned out to be Bohr's interpretation of their experiment. Franck mentioned this five-year-long argument in his Nobel Prize lecture (Franck 1926). The case of the Franck and Hertz experiment clearly demonstrates that it is the argument not the experiment itself that defines the meaning and function of experiments in the discourse of science.

Science should be taught in a way that reflects the nature of science (AAAS 1990; NRC 1996). The central position of argument in science development has caused science education scholars to show interest in the function of argumentation in the classroom. Based on their understanding of the history and philosophy of science, Driver, Newton and Osborne (2000) considered the importance of the contribution of discursive practice in the construction of scientific knowledge. Osborne (2000) provides insights into the aims and purpose of science teaching and recommends the use of argument in science teaching. He stated that:

> A rhetorical characterization of the practice of science itself shows that argument is a central feature of the practice of science and that if developing epistemic goals and understandings about science within science education is important, the consideration of argument and reasoning should be a core feature of the practice of science education. (p 1)

The use of argument in science education can well address the criticisms that the Posner's model received. Effective learning is a self-regulated activity and a process of social construction. Like scientists, students need to expose their ideas to evidence and common regulations for judgment and be convinced before accepting any new idea. As the word *argument* itself implies, the argument approach puts the teacher and students at the same power level. The aim of this new science-teaching approach is to persuade rather than force students to accept scientific views. This agrees with the goal of constructivist science teaching; namely, the reconstruction of knowledge by students. As the result of argument, students may prefer scientific views over their own concepts, or at least step closer to scientific views. In the course of arguments, students are allowed to present and defend their ideas. Whatever ideas they bring up are significant to the classroom community. This process will result in students feeling respected; consequently, they will be motivated to get involved.

Argument is a social process because it involves the dialogues between at least two sides. When argument is implemented in the classroom, it can happen between individuals or groups, depending on the nature of learning tasks. For the simple topics, the inclass dialogue may work well enough; for more complex topics, students can be divided into groups to build arguments collaboratively, and then the groups can share their ideas and discussions in the class conference. In either case, the teacher is a facilitator as well as an arguer who presents scientific notions.

Argument can address the importance of motivation and collaboration in learning and effectively incorporate metacognition, which is an important issue in the literature. As Paris and Winograd (1990, 19) say, "Any cognition that one might have relevant to knowledge and thinking might be classified as metacognition." We can generally understand metacognition as cognition of cognition. According to Paris and Winograd, metacognition has two essential features for learning in a classroom setting: self-appraisal and self-management. Self-appraisal includes personal reflections about one's knowledge of states and abilities. Metacognitions of this sort are associated with answering such questions relating to what one knows and needs to know; how one learns; when, where, why and how to apply knowledge of strategies; and whether one can do a task. In contrast, self-metacognition refers to how metacognition helps to orchestrate cognitive aspects of learning. It is reflected in the ways that learners plan and perform learning tasks. It controls their learning behaviours, and evaluates their learning processes and achievements.

The virtues of metacognition have been well documented. As Paris and Winograd (1990) concluded after reviewing many studies, students can enhance their academic learning and cognitive development "by becoming aware of their own thinking as they read, write, and solve problems in school" (p 15). They also claimed that "a teacher can promote this awareness directly by informing students about effective problem-solving strategies and discussing cognitive and motivational characteristics of thinking" (p 15). This statement raises another question: Can metacognitive skills be taught? The answer to this question is yes. Because metacognition involves attitude, perspective and habit, which are beyond knowledge and skills, metacognition cannot be taught in the traditional ways in which we teach knowledge such as 1 + 1 = 2. Students' attitudes and habits can, however, be greatly influenced by what and how students are taught in the classroom. "Since reflective things and metacognitive strategies do not automatically develop in learners, learning activities need to be structured so that they teach and support the use of metacognitive skills" (von Wright 1992, 60). Teaching should be designed with an explicit purpose of metacognition acquisition. Students obtain metacognition implicitly. Little by little, student attitudes and perspectives are developed through metacognition-associated contents and activities. For example, more and more textbook writers and physics instructors agree that we should teach the topic of the atomic model in a storyline format, rather than by simply telling students what the commonly accepted model is. The teaching sequence starts with the finding of electrons, through Thomson's model, the Nagaoka's model, Rutherford's model, Bohr's model, to the Quantum model. This sequence facilitates students' understanding of the nature, development, methodology and criteria of science, which will all influence their perspectives on knowing. With a perspective of social construction of knowledge, Driver (1989, 482) suggests that metacognition must be taught:

> Learning science . . . is seen to involve more than the individual making sense of his or her personal experiences but also being initiated into the "ways of seeing" which have been established and found to be fruitful by the scientific community. Such "ways of seeing" cannot be "discovered" by the learner—and if a learner happens upon the consensual viewpoint of the scientific community, he or she would be unaware of the status of the idea.

Arguments cannot be fruitful without a given set of conventions or criteria that are accepted by all arguers. In science, criteria implemented by scientists, such as logic consistence, testability, prediction power, explanatory coherence and so on, should be explicitly addressed to students. Argument ensures that these common criteria for evaluating hypotheses are applied, discussed and reinforced. These kinds of meta-knowledge are necessary for students to learn science, understand issues about science and benefit their own learning.

Argument Approach for Conceptual Change

An argument starts with a gap. Students' preconceptions are in most cases different from scientific notions, and disagreements among students often exist as well. These differences provide an opportunity for arguments to occur in the classroom. An argument is a cursive journey. It takes time for arguers to understand each other's point and justification. Arguers explain, testify, defend and convince opponents to accept their ideas; at the same time, they should remain open-minded, try to understand the viewpoint of their opponents and always be ready to modify their own stand. Taking the norm of argument into science teaching for conceptual change, we propose the following instructional process (Figure 1).

Present problem context: Our instruction model starts with problems. We assume that the problem-oriented instruction design attracts students' attention, promotes thinking and motivates participation. Question formats can be diverse—the teacher can ask students to interpret phenomena or to watch a demonstration with their predictions in mind.

Elicit student ideas: Students are asked to predict the result of experiments or interpret phenomena. Students can work individually first, then are encouraged to share their thinking with partners. It is expected that this discussion can help students clearly recognize their preconceptions and their partner's preconceptions. Through joining in student discussion and listening to groups reporting their discussion, the teacher gets to know students' preconceptions.

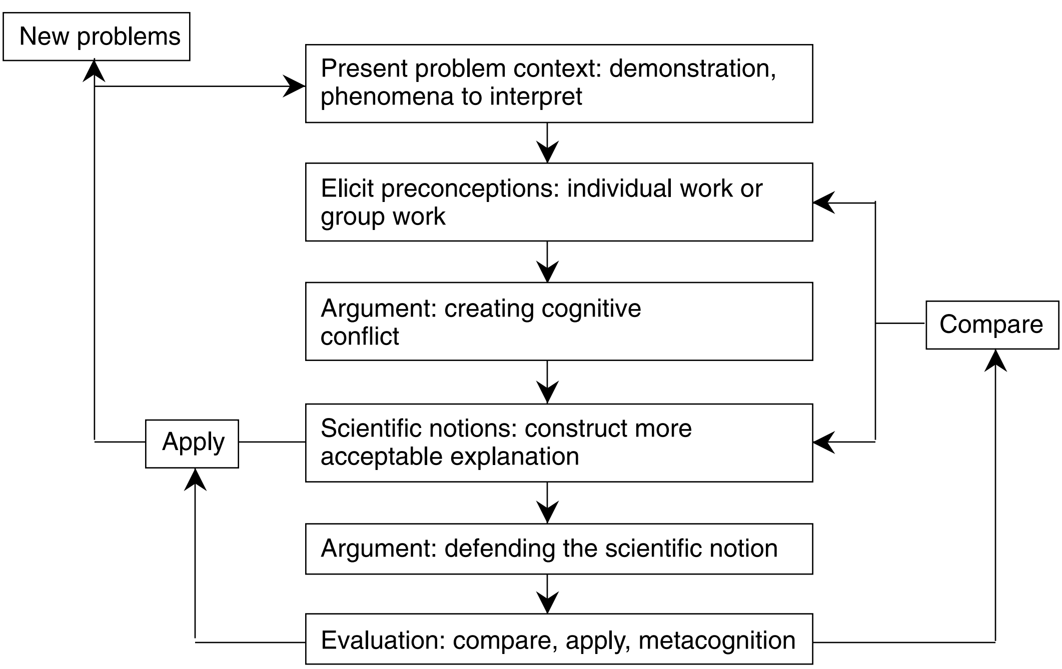
Argument—creating cognitive conflict: After the previous step, students become clear about their own ideas and begin to wonder about the different ideas that their classmates have. Experiments are performed at this step, the results of which are quite often different from students' predictions. At this moment, if the instructor is eager to offer students scientific concepts, hoping to use them to replace students' concepts, he or she will fail to convince students. Students will not easily give up their concepts, and they may think that something might be wrong with the demonstrations. The instructor should be responsive to students' wondering, and design new experiments and demonstrate them. In the case of interpreting phenomena, students' interpretations often have inconsistencies. Their ideas work well for one phenomenon, but not for others. Pointing out these inconsistencies is a useful way to create dissatisfaction with their own interpretations. Showing that their ideas lead to obvious wrong deductions is a common strategy to deal with unscientific opinions.

Scientific notion: In this step, evidence that leads to scientific notions is supplied and scientific explanations are constructed. Quite often, the same events used to create cognitive conflicts provide evidence for scientific concepts as well.

Argument—defending the scientific notion: When students challenge scientific notions, the instructor needs further evidence to convince them. The focus of this step is to defend the scientific concept.

Evaluation: This step is a further effort to encourage students to accept scientific ideas by comparing scientific notions with students' ideas and applying scientific notions to new problems. Clear identification can help students to discover where they were wrong and to better understand scientific ideas. More applications can demonstrate the validity of science. Furthermore, evaluating the ways of personal and scientific knowing may help students with metacognition. Generalizing the scientific method reflected in a special case is recommended for constructivist instruction.

Figure 1
The argument approach to science teaching



As you may realize, in this argument approach the teacher is doing two kinds of things: one is to break down students' less acceptable ideas; the other is to engender scientific notions in students. At first sight, the breaking down appears to happen in the third step—argument, or creating cognitive conflict. In fact, the breaking down continues through the whole process. The argument approach is a dynamic and dialectical process that breaks down students' less acceptable ideas and establishes acceptable scientific ideas. Just as breaking down an old theory and building a new one often occurred at the same time in the history of science, we cannot definitely say that one happens ahead of the other. Breaking down students' concepts helps students establish new visions; the validity and fruitfulness of new ideas helps students reject unacceptable ideas. The teacher designs and organizes this dynamic process at the macro-pedagogical level, but the process is driven by the argument between the teacher and students.

An Example of the New Approach

In this session, we will use an example to illustrate our argument approach of science teaching. The topic is Newtonian third law in a simple magnetic phenomenon: a magnet attracting a paper clip. We use this topic because most students have preconceptions about it, and these preconceptions turn out to be very resistant to change (Redish and Steinberg 1999; Zhou et al 2000). When the first author (Zhou) of this article wrote physics textbooks for Chinese school students before he moved to Canada, he started the text of this topic with the description of a demonstration: one bar magnet and one metal bar, sitting on two small wooden pieces floating on water, move toward each other. Then the text gave the scientific conclusion inferred during this demonstration, followed by an application of the law to more situations. This kind of scientific explanation-centred curriculum sequence places students in a passive position. In contrast to this way of presenting materials, the argument approach starts the instruction from the students' point of view.

Students often have difficulty understanding the third law in a nonequilibrium situation (Redish and Steinberg 1999; Zhou et al 2000). They think a large truck exerts a bigger force on a small car in a collision, and the magnet exerts force on the paper clip but not vice versa. Therefore, we start the instruction with a demonstration.

> Demonstration: When a paper clip is placed near the south or north pole of the magnet, it jumps onto the magnet.

The teacher can do this demonstration on the overhead projector so that everyone can see it, or students can do it on their own. The latter practice has merit because students can feel the force the magnet applies on the clip. Following the demonstration, the teacher asks students the following questions in order:

> Questions:
> 1. Does the clip exert any force on the magnet?
> 2. How does this force compare with the force the magnet exerts on the clip?

Students can respond to these questions based on their viewing of the demonstration or construct their ideas by performing the hands-on experiments in a group. Responses to the first question can be grouped into three categories: no, yes and do not know. A high percentage of students will likely respond to the second question by saying, "smaller," and the rest will say, "equal" or "do not know."

The next two hands-on experiments will serve the functions of creating cognitive conflict and constructing scientific concepts.

> Experiment 1: Hang one metal piece and one button magnet with a similar mass from a level stick. Move one of them close to the other. The metal block and button magnet attract and move toward each other.
>
> Experiment 2: Hook up two spring force scales. One student holds one spring scale and another holds the other one. Ask one student to pull his or her spring scale or both students to pull their scales at the same time. Students will see that the readings of two scales change simultaneously and always keep the same magnitude.

Based on the first experiment, students can construct the scientific concept that when an object experiences a force, it also exerts a force on the object acting upon it. Through the second experiment, students can induce that the action force is always equal to the reaction force. Once again, these two experiments can be demonstrated by the instructor or performed by students themselves.

Some students may argue that they did not see the magnet move toward the clip; they saw the clip move toward the magnet. Therefore, action and reaction cannot coexist and have the same magnitude. To solve this puzzle, the instructor can organize a class discussion that leads students to realize the different frictional forces the clip and magnet experience on the table. This step is important because the instructor in this step can guide students to apply the newly constructed concept to the phenomena from which they drew their preconceptions. The success of scientific concepts in explaining the in-class–designed experiments and the real-life phenomena familiar to students will demonstrate the explanation power of scientific concepts.

The teacher can then move on to the last step: evaluation. He or she can explicitly discuss with students the notion that the explanatory consistency is an important requirement in judging ideas or theories. The teacher can remind students that real-life phenomena are normally complicated and involve many variables. Solely visible and touchable variables, on which students quite often construct ideas, are not enough to scientifically understand the phenomena. People are often fooled by what they see and feel in daily life. For example, people think the sun moves around the earth, because they notice that the sun rises in the east and sets in the west. The way to correct these mistakes is to use scientific reflection and scientific experiments.

Acknowledgement: The authors owe great thanks to Wytze Brouwer for his comments and suggestions when we prepared this manuscript.

References

American Association for the Advancement of Science (AAAS). 1990. *Science for All Americans*. Project 2061. New York: Oxford University Press. Also available at www.project2061.org/publications/sfaa/online/chap1.htm (accessed September 15, 2006).

Ames, C. 1992. "Classrooms: Goals, Structures, and Student Motivation." *Journal of Education Psychology* 84: 261–71.

Bar, V, B Zinn and E Rubin. 1997. "Children's Ideas About Action at a Distance." *International Journal of Science Education* 19, no 10: 1,137–157.

Barbosa, R, Z Jofili, Z and M Watts. 2004. "Cooperating in Constructing Knowledge: Case Studies from Chemistry and Citizenship." *International Journal of Science Education* 26, no 8: 935–49.

Berg, T, and W Brouwer. 1991. "Teacher Awareness of Student Alternate Conceptions About Rotational Motion and Gravity." *Journal of Research in Science Teaching* 28, no 1: 3–18.

Campbell, P. 2002. "A Citizenship Dimension to Physics Education." *Physics Education* 37, no 3: 191–96.

Chang, C-Y, and S-L Mao. 1999. "The Effects on Students' Cognitive Achievement When Using the Cooperative Learning Method in Earth Science Classrooms." *School Science and Mathematics* 99, no 7: 374–79.

Clement, J. 1982. "Students' Preconceptions in Introductory Mechanics." *American Journal of Physics* 50, no 1: 66–71.

Driver, R. 1989. "Students' Conceptions and Learning of Science." *International Journal of Science Education* 11: 481–90.

Driver, R, E Guesne and A Tiberghien, eds. 1985. *Children's Ideas in Science.* Milton Keynes, UK: Open University Press.

Driver, R, P Newton and J Osborne. 2000. "Establishing the Norms of Scientific Argumentation in Classrooms." *Science Education* 84: 287–312.

Driver, R, A Squires, P Rushworth and V Wood-Robinson. 1994. *Making Sense of Secondary Science*. London: Routledge.

Dweck, C S, and E L Leggett. 1988. "A Social Cognitive Approach to Motivation and Personality." *Psychological Review* 95, no 2: 256–73.

Erickson, G L. 1979. "Children's Conceptions of Heat and Temperature." *Science Education* 63, no 2: 221–30.

——. 1980. "Children's Viewpoints of Heat: A Second Look." *Science Education* 64, no 3: 323–36.

Franck, J. 1925. *Transformations of Kinetic Energy of Free Electrons into Excitation Energy of Atoms by Impacts*. Nobel Lecture, December 11, 1926. http://nobelprize.org/physics/laureates/1925/franck-lecture.pdf (accessed September 18, 2006).

Harackiewicz, J M, K E Barron and A J Elliot. 1998. "Rethinking Achievement Goals: When Are They Adaptive for College Students and Why?" *Educational Psychologist* 33, 1–21.

Harackiewicz, J M, K E Barron, P R Pintrich, A J Elliot and T M Thrash. 2002. "Revision of Achievement Goal Theory: Necessary and Illuminating." *Journal of Educational Psychology* 94, no 3: 638–45.

Johnson, D W, and R T Johnson. 1985. "Classroom Conflict: Controversy Versus Debate in Learning Groups." *American Educational Research* 22, no 2: 237–56.

——. 2000. "The Eight Steps of Ensuring Diversity Is a Resource." *The Newsletter of the Cooperative Learning Institute* 15, no 1. www.co-peration.org/pages/newsletter2000.html (accessed September 19, 2006).

Kuhn, D. 1993. "Science as Argument: Implications for Teaching and Learning Scientific Thinking." *Science Education* 77, no 3: 319–37.

Kuhn, T. 1970. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Leont'ev, A N. 1981. "The Problem of Activity in Psychology." In *The Concept of Activity in Soviet Psychology*, ed J V Wertsch, 37–71. Armonk, NY: Sharpe.

McCloskey, M. 1983. "Intuitive Physics." *Scientific American* 248, 114–22.

National Research Council (NRC). 1996. *National Science Education Standards*. Washington, DC: National Academy Press.

Nolen, S B. 1988. "Reasons for Studying: Motivational Orientations and Study Strategies." *Cognition and Instruction* 5, 269–87.

——. 1996. "Why Study? How Reasons for Learning Influence Strategy Selection." *Educational Psychology Review* 8, no 4: 335–55.

O'Donnell A, and D Dansereau. 1993. "Learning from Lectures: Effects of Cooperative Review." *Journal of Experimental Education* 61, no 2: 116–25.

Osborne, J. 2000. "Promoting Argument in Science Classroom: A Rhetorical Perspective." Lecture, Faculty of Education, University of Alberta, Edmonton, February.

Paris, S G, and P Winograd. 1990. "How Metacognition Can Promote Academic Learning and Instruction." In *Dimensions of Thinking and Cognitive Instruction*, ed B F Jones and L Idol, 11–52. Hillsdale, NJ: Lawrence Erlbaum Associates.

Piaget, J, and B Inhelder. 1969. *The Psychology of the Child*. Trans H Weaver. New York: Basic Books.

Pintrich, P R. 2000. "Multiple Goals, Multiple Pathways: The Role of Goal Orientation in Learning and Achievement." *Journal of Educational Psychology* 92, no 3: 544–55.

Pintrich, P R, and E De Groot. 1990. "Motivational and Self-Regulated Learning Components of Classroom Academic Performance." *Journal of Educational Psychology* 82, 33–40.

Pintrich, P R, R W Marx and R A Boyle. 1993. "Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change." *Review of Educational Research* 63, no 2: 167–99.

Posner, G J, K A Strike, P W Hewson and W A Gertzog. 1982. "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change." *Science Education* 66, no 2: 211–27.

Redish, E F, and R N Steinberg. 1999. "Teaching Physics: Figuring Out What Works." *Physics Today* 52, 24–30.

Rotblat, J. 2002. "Citizenship and Science." *Physics Education* 37, no 3: 186–90.

Sadler, K C. 2002. "The Effectiveness of Cooperative Learning as an Instructional Strategy to Increase Biological Literacy and Academic Achievement in a Large, Non-Majors College Biology Class." Paper presented at the annual meeting of the Mid-South Educational Research Association, Chattanooga, Tenn, November 6–8.

Scott, P H, H M Asoko and R H Driver. 1992. "Teaching for Conceptual Change: A Review of Strategies." In *Research in Physics Learning: Theoretical Issues and Empirical Studies*, ed R Duit, F Goldberg and H Niedderer, 310–29. Kiel, Germany: IPN.

Tao, P-K, and R F Gunstone. 1999. "Conceptual Change in Science Through Collaborative Learning at the Computer." *International Journal of Science Education* 21, no 1: 39–57.

Thagard, P. 1992. *Conceptual Revolutions*. Princeton, NJ: Princeton University Press.

Vygotsky, L S. 1978. *Mind in Society: The Development of Higher Psychological Processes.* Ed M Cole, V John-Steiner, S Scribner and E Souberman. Cambridge, Mass: Harvard University Press.

——. 1981. "The Genesis of Higher Mental Functions." In *The Concept of Activity in Soviet Psychology*, ed J V Wertsch, 144–88. Armonk, NY: Sharpe.

von Wright, J. 1992. "Reflections on Reflection." *Learning and Instruction* 2, 59–68.

Wentzel, K R. 1991. "Social and Academic Goals at School: Motivation and Achievement in Context." In *Advances in Motivation and Achievement*, ed M L Maehr and P R Pintrich, 7, 185–212. Greenwich, Conn: JAI Press.

Wolters, C, S Yu and P R Pintrich. 1996. "The Relation Between Goal Orientation and Students' Motivational Beliefs and Self-Regulated Learning." *Learning and Individual Difference* 8, 211–38.

Zhou, G, B Martin, W Brouwer, and D Austen. 2000. "Computer-Based Physics and Student Preconceptions." *Alberta Science Education Journal* 32, no 2: 23–35.

Professional Development in Elementary Science: New Conversations Guiding New Approaches in Teachers' Work and Learning

Bonnie Shapiro, ***University of Calgary***

Valuable opportunities arise for building professional knowledge and competencies when new elementary science curriculum materials are adopted in a school jurisdiction. Periods of curriculum renewal in science education have been sparked by revitalizing new discussions about what is most worthwhile and effective in elementary science teaching. In recent years new conversations and fresh approaches to teacher development in elementary science challenged the traditional ways that the professional development work unfolds (Bilbao et al 2002).

Since the 1980s, there has been a widely recognized need for changes in how professional development is conceptualized and carried out. As cited by Supovitz and Turner (2000), in Smylie's (1989) study, teachers ranked inservice training as the least effective way to learn to teach. Guskey (1986) suggested that the reasons for this are poor understanding of teachers' motivations and a lack of insight into the individual and environmental factors involved in the process of change. Marx et al (1998) described the generative and constructive nature of professional development and called for greater acknowledgement of the ways teachers integrate innovation into classroom practice with their own theoretical views, in a process referred to as *enactment*.

In enactment, teachers accept and enact new practices that they consider warranted. If teacher development is to have a lasting effect, then staff development must be connected to the changes and reforms that are occurring in schools as a whole, and there must be personal ownership and encouragement (Dillon 2000). This view states that if we plan to improve schools, we must help educators within the schools improve their skills and abilities. Real change, therefore, must be seen as personal and institutional.

Recently, science educators and professional development leaders have strongly agreed on what should change. This article briefly outlines some of these consensus views, including insights, principles and exemplary features of professional development that have become part of this conversation. There are many useful summaries of ideas in a wide range of international literature on best practices in approaches to professional development (Darling-Hammond and Bransford 2005; Fraser-Abder 2002; Shapiro and Last 2002). The second part of the article presents examples of these ideas applied to teacher development in science education. The first example focuses on a description of ideas about the importance of practice-based or action research. The second is a specific example of a collaborative form of this kind of approach that has gained considerable interest among North American science and mathematics educators. This approach is Japan's long tradition of *kenkyuu jugyou,* which means research lessons or the lesson/instruction study approach to teacher development.

New Emphases and Ideas About the Important Features of Successful Professional Development in Elementary Science

Several thinkers present ideas that represent a broad consensus of views in the field and call for more intensive, more collegial and longer approaches to professional development. Bell (2005) asserts that teacher development must be successful before any difference in how students are taught the curriculum is possible. She views teacher development as having two elements or aspects: (1) the input of theoretical ideas, new approaches and teaching suggestions, and (2) the processes involved in trying out, evaluating and practising these ideas and approaches. In most professional development programs, while the first aspect of professional development receives formal attention, teachers' efforts to try, evaluate and practise new thinking and approaches occur informally, often with little support (p 190). Tobin, Tippins and Gallard (1994) describe two factors essential for successful professional development: (1) the importance of connecting professional development efforts to teachers' previous knowledge base, and (2) the need to provide a supportive, long-term environment for change.

In, *Science for All Children: A Guide to Improving Elementary Science Education in Your School District*, the National Science Resources Center (1997, 78–81) presents the following strategies to create successful professional development programs that address the personal, social and political features that affect the learning of science:

1. Provide continuous and sustained support for professional development—support from school administration must go beyond rhetoric and take the form of stressing science as a basic in the school curriculum.
2. Provide teachers with time to engage in professional development activities—time during the school day should be given to participate in professional learning work.
3. Create an environment of collegiality and collaboration—strong professional relationships help teachers feel comfortable sharing ideas, acknowledging difficulties and solving problems that they encounter in the classroom.
4. Incorporate the change process into the professional development design—allow for the growing pains of new ways of teaching, learning and curriculum design.

Supovitz and Turner (2000, 964–65) suggest that high-quality professional development strategies in science must

- immerse participants in inquiry, question and experimentation, and must, therefore, model inquiry forms of teaching;
- be intensive and sustained over a long period of time;
- engage teachers in concrete teaching tasks based on teachers' experiences with students;
- focus on subject-matter knowledge and deepen teachers' content skills;
- be grounded in a common set of professional development standards and show teachers how to connect their work to specific standards for student performance; and
- be connected to other aspects of school change.

One rationale for the importance of this type of development work is recognition that teachers in the 21st century are dealing with new and dramatically more complex issues and changes in school curriculum and schooling reforms. Science educators need time to enhance their content and teaching skills and to be involved in professional interactions with colleagues and other associates that help them test and reflect on new ways of teaching science, and to reconsider what it means to be a science teacher. Research by Supovitz and Turner (2000) provides evidence to support this view and shows that, in fact, the amount of time spent in professional development work is statistically linked to an increase in two reform indicators, use of inquiry-based teaching practices and the observation of high levels of investigative classroom culture. They found that the most powerful individual influences on teaching practices and development of investigative culture were teachers' attitudes to school reform (p 973).

New Approaches to Professional Development

Practice-Based Inquiry: Teacher Engagement as Students/ Researchers of Their Own Teaching

In the last decade, professional development embraced teacher engagement through a practice-based inquiry or action-research approach that involves educators systematically reflecting on their practices. Through its focus on experience and direct interaction with students in classrooms, action research has become a valuable professional development strategy that allows teachers to define areas of importance in their questioning of practice. Practice-based research uses the natural language of practitioners to describe and discuss ideas about teaching and learning. Action research has become a major tool in the restructuring of schools. Through this work, teachers have a say in the process of defining problems to pursue and the ways outcomes will be used to promote changes based on their findings. In many cases, teachers who are engaged in projects not only contribute to their professional development but also add to the literature and research knowledge in the field of science education.

Darling-Hammond and Bransford (2005) give high status to learning about teaching from examples that have been created by teachers. They recommend the preparation and use of carefully constructed case studies that present situations that student teachers may encounter in their careers. They describe how teachers develop written and video-recorded cases that raise issues of culture and learning for teachers, and allow them to become not only more conscious of their own beliefs and perspectives but also more aware of strategies for reaching their students. Ideally, in practice, teachers discuss these pedagogy-based investigations. When teachers gather for such discussions, they learn from each other. As Loucks-Horsley et al (1998, 96–97) note, there are some important underlying assumptions about teachers, learners and professional development in action-based research:

- Teachers are intelligent, inquiring people with important expertise and experiences that are central to the improvement of educational practice.
- By contributing to or forming their own questions, and by collecting the data to answer these questions, teachers grow professionally.
- Teachers are motivated to use more effective practices when they are continuously investigating the results of their actions in the classroom.

Lesson Study: Japan's *kenkyuu jugyou*

A more specific example of professional development through which teachers engage in practice-based inquiry is Japan's lesson study model. For at least a century, Japanese teachers have used a collaborative process of professional development called lesson study. Using a framework with specific structural elements, teachers work collaboratively to plan, implement, observe, discuss, analyze and refine lessons called *kenkyuu jugyou*, meaning research lessons or lesson research. The approach has created great interest in the United States, and many lesson study sites have emerged that focus on this form of collaboration and research. Lesson research offers an effective opportunity to build and critique the goals of science teaching and learning. In practice, school sites focus on meaningful research themes that may be connected to state, provincial or national research and policy themes as well.

To begin, a group of teachers collaboratively develop a theme for the research. For example, they may want to implement a new topic in the curriculum or may be concerned about some aspect of their work, such as building student interest in science. Typically, the following steps represent the sequence of activities that occur over a significant span of time. First, the teachers develop a lesson plan. Then, one or two teachers teach the lesson while others in the study group observe. Lewis (2000), who studied the model in Japan, noted that individual lessons have a structure that is followed by all who participate. They usually consist of four parts:

1. *Hatsumon* (asking a question to stimulate children's thinking)
2. *Shu hatsumon* (the key question for the day)
3. *Neriage* (polishing up, a whole-class discussion)
4. *Matome* (summing up)

A community discussion follows the lesson observation during which recommendations are made for revision, and the lesson is taught again with the suggestions and changes in mind. All aspects of the procedure are carefully documented for study and review, and data is collected to assure that the changes have truly affected the children and their learning. The core piece of the process that is designed to bring about instructional improvement is the lesson. Lewis (2000) identifies five characteristics that research lessons share:

1. Research lessons are observed by other teachers.
2. Research lessons are planned for a long time, usually collaboratively.
3. Research lessons are designed to bring to life in a lesson a particular goal or vision of education.
4. Research lessons are recorded.
5. Research lessons are discussed.

But at the heart of this structure Lewis (2000, 14) writes, "The Japanese say that lesson study develops the eyes/vision to see children." Focusing on the development of the whole child is one of the most important goals of education. This involves attention to children's social, ethical, emotional, aesthetic, physical and intellectual development, or as summed up by one Japanese teacher, the "most important job is to create happy memories" of schooling (p 29).

Fernandez (2002) notes that Japanese culture further aids the lesson study process in many other ways. Large bookstores in Japan carry published collections of study lessons that include teachers' reflections about what does and does not work in classrooms. Superintendents also circulate these documents. Schools have open houses to demonstrate study lessons for teachers from other schools. At some national schools in Japan these forums draw up to 5,000 teachers. Japanese teaching staffs are also rotated in and out of a school about every eight years, thus continually bringing their lesson study expertise and knowledge to new levels.

Lewis summarizes several other supporting conditions of this approach to professional development:

- A shared, frugal curriculum
- Established practices of collaboration
- The belief that teaching can be improved through collective effort
- Self-critical reflection
- Stability of educational policy
- Instructional improvement time focused on instruction
- Focus on the whole child

Conclusion

This article reviewed some recent and widely agreed on foundational ideas that support new approaches to professional development. These views consider teachers' classroom experiences and understandings; current knowledge base; personal and social needs; and features of the larger school culture that enhance teacher development. Two highly successful forms of professional development were also presented that are bringing about change in the culture of science teaching and learning.

These professional development approaches help to change the culture of science teaching and learning in ways that address teachers' real concerns about what helps their professional growth and development and, ultimately, what is most effective in helping children learn. There is a shift away from short-term, one-shot teacher workshops, and greater movement toward approaches that acknowledge and value teachers' experiences, background and competencies. Such approaches support a shift toward helping teachers to see themselves as agents in their own development. This approach also helps educators gain new experiences in and deeper respect for collaborative efforts that address the context and culture of unique school settings and greater enjoyment in the outcomes. Taylor (1991) and Tobin (1993) refer to the importance of time needed to renegotiate changes in the culture of teaching. Bell (2005) notes that such activity occurs best in collaborative settings where teachers are given inspiration, support and feedback, and the opportunity to critically think about what it means to teach science. When given such opportunities in an atmosphere of curriculum reform, these approaches to professional development help teachers see themselves as real partners in the implementation of curriculum policies that have a meaningful effect on children's learning in science.

References

Bell, B. 2005. *Learning in Science: The Waikato Research*. New York: RoutledgeFalmer.

Bilbao, P, L Morano, T Barcenal, M Castellano, S Nichols and D Tippins. 2002. "Changing Traditions of Science Teacher Development in the Philippines." In *Professional Development in Science Teachers: Local Insights with Lessons for the Global Community*, ed P Fraser-Abder, 70–87. New York: RoutledgeFalmer.

Darling-Hammond, L, and J Bransford. 2005. *Preparing Teachers for a Changing World: What Teachers Should Learn and Be Able to Do*. San Francisco, Calif: Jossey-Bass.

Dillon, J. 2000. "Managing Science Teachers' Development." In *Improving Science Education: The Contribution of Research*, ed R Millar, J Leach and J Osborne, 94–109. Philadelphia, Penn: Open University Press.

Fernandez, C. 2002. "Learning from Japanese Approaches to Professional Development: The Case of Lesson Study." *Journal of Teacher Education* 53, no 5: 393–405.

Fraser-Abder, P. 2002. *Professional Development in Science Teachers: Local Insights with Lessons for the Global Community.* New York: RoutledgeFalmer.

Guskey, T R. 1986. "Staff Development and the Process of Teacher Change." *Educational Researcher* 15, no 5: 5–12.

Lewis, C. 2000. "Lesson Study: The Core of Japanese Professional Development." Invited address to the special interest group on mathematics education. American Educational Research Association Meetings, New Orleans, April 28.

Loucks-Horsley, S, P W Hewson, N Love and K E Stiles. 1998. *Designing Professional Development for Teachers of Science and Mathematics Education.* Thousand Oaks, Calif: Corwin.

Marx, R W, G Freeman, J S Krajcik and P Glumenfeld. 1998. "Professional Development of Science Teachers." In *International Handbook of Science Education,* Part 2, ed G J Fraser and K G Tobin, 667–80. Boston: Kluwer Academic.

National Science Resources Center. 1997. *Science for All Children: A Guide to Improving Elementary Science Education in Your School District*. Washington, DC: National Academy Press.

Shapiro, B, and S Last. 2002. "Starting Points for Transformation: Resources to Craft a Philosophy to Guide Professional Development in Elementary Science." In *Professional Development of Science Teachers: Local Insights and Lessons for the Global Community,* ed P Fraser-Abder, 1–20. New York: RoutledgeFalmer.

Smylie, M A. 1989. "Teachers' Views of the Effectiveness of Sources of Learning to Teach." *The Elementary School Journal* 89, no 5: 543–58.

Supovitz, J, and H Turner. 2000. "The Effects of Professional Development on Science Teaching Practices and Classroom Culture." *Journal of Research in Science Teaching* 37, no 9: 963–80.

Taylor, P. 1991. "Collaborating to Reconstruct Teaching: The Influence of Researcher Beliefs." Paper presented to the annual meeting of the American Educational Research Association, Chicago, April 3–7.

Tobin, K. 1993. "Referents for Making Sense of Science Teaching." *International Journal of Science Education* 15, no 3: 241–54.

Tobin, K, D J Tippins and A J Gallard. 1994. "Research on Instructional Strategies for Teaching Science." In *Handbook of Research on Science Teaching and Learning*, ed D L Gabel, 45–93. New York: MacMillan.

Predatory Academics

Aditya Saha, ***Department of Physics, University of Alberta***

1. Introduction

Predatory academics occur when established, even celebrated, members of academia encroach upon, and in some cases usurp, the research of their less-well-known peers or junior associates. Evidence suggests this tactic is not limited to any particular discipline; that is, it exists among the sciences, humanities and arts, and is a continuing phenomenon. This article is organized as follows: sections 2 and 3 outline two well-documented cases of predatory academics, which are the controversies surrounding (1) Lise Meitner and Otto Hahn, regarding the discovery of nuclear fission; and (2) Rosalind Franklin on the one hand, and the duo of James Watson and Francis Crick on the other, regarding the discovery of DNA structure. Section 4 outlines commonalities in both cases and suggests means to redress the controversy.

2. The Meitner–Hahn Controversy

Lise Meitner was born on November 7, 1878, into a prominent Viennese Jewish family. As a child she was shy and retiring, personality traits which would become more pronounced later in life. She was tutored predominantly at home, where she developed an interest in mathematics and physics. Given the prevailing Austrian restrictions on female education, she was only able to enter the University of Vienna in 1901. However, at university, under the tutelage of her teacher Ludwig Boltzmann, she developed an abiding interest in physics, which became to her "an ultimate truth, a vision she never lost" (Frisch 1991). On completing her PhD in 1907, with her thesis on the conduction of heat in inhomogeneous solids, she travelled to Berlin to study with Max Planck, the father of quantum mechanics. In Berlin she began her long and productive association with Otto Hahn, who was an organic chemist by training. Together they studied radioactive substances, focusing on the physical and chemical aspects. In 1912, they both moved to the Kaiser Wilhelm Institute of Chemistry. They made important advances in this nascent field of the time, both independently and together, competing with Irène Curie, Frédéric Joliot and numerous others. Their successes include the identification of at least nine different radioactive elements; the radiationless transition now called the Auger effect and many others. In 1926, Meitner became Germany's first female full professor at the University of Berlin.

Like many early female scientists, she faced adversity even in her early life. Her parents were opposed to her entering university, though, they later hired a tutor to help her prepare for the university entrance exams and even supported her with a stipend from 1907–12, when she was an unpaid researcher at the Chemical Institute in Berlin. During the first two few years at this institute, she was forbidden from entering it by the then director Dr Emil Fischer, so she had to conduct her experiments in the institute's basement. It was only later that she was allowed to enter Dr Fischer's institute. In 1912, even after she was admitted into the

Kaiser Wilhem Institute for Chemistry at Berlin-Dahlem, she was classified as a guest and hence was unpaid. In 1913, when she was offered a post in Prague University, she was finally given a paid position.

Nuclear Fission Controversy

I will now describe the events that led to Hahn and Meitner's discovery of nuclear fission and that conspired to exclude Meitner from the Nobel Prize awarded for it. The discovery of the neutron by James Chadwick in 1932 gave new impetus to radioactivity studies, because this uncharged atomic particle could probe the atomic nucleus more successfully. As early as 1934, Enrico Fermi's team in Rome had been able to produce radioactive isotopes by neutron bombardment. The bombardment of uranium (then the heaviest element known) had produced several products. The question that faced scientists was, Were there any transuranic elements or did uranium break up into smaller nuclei? Meitner, Hahn and Fritz Strassmann, an analytical chemist who worked under Hahn's supervision, soon became involved in identifying the products of neutron bombardment of uranium and their decay patterns. It was generally expected that elements close in atomic number, quite possibly elements with higher atomic numbers than uranium, would be produced. After the *Anschluss* in March 1938, when Germany annexed Austria, Lise Meitner who was of Jewish descent but of Protestant faith by conversion, became classified as a German Jew citizen. Because the Nazis had begun their systematic exclusion of people of Jewish ancestry from German universities, Lise Meitner, at the age of 59, fled to Denmark, where she stayed briefly at Copenhagen, at the Institute for Theoretical Physics, founded by Niels Bohr. After Denmark was overrun by the German army, she fled to Sweden in the summer of 1938, where she continued her work at Manne Siegbahn's Nobel institute, in Stockholm, despite Siegbahn's considerable antipathy toward her. As Sime (1996) writes, "Neither asked to join Siegbahn's group nor given the resources to form her own, she had laboratory space but no collaborators, equipment, or technical support, not even her own set of keys." Meanwhile, her nephew, the physicist Otto Frisch, was at the Niels Bohrs Institute in Copenhagen.

On November 13, 1938, Hahn met secretly with Meitner in Copenhagen. At her suggestion, Hahn and Strassmann performed further tests on a uranium product that they thought was radium. The three subsequently exchanged a series of letters about their activities. The experiments that provided the evidence for nuclear fission were done at Meitner's suggestion but in Hahn's laboratory in Berlin. Meanwhile Hahn and Strassmann found that they had unexpectedly produced barium, a much lighter element than uranium, and they reported this news to Meitner. She and her nephew worked out the physics calculations of the phenomenon based on the "droplet" model of the nucleus and clearly stated that nuclear fission of uranium had occurred. It was quickly recognized that barium was among the stable isotopes produced by radioactive decay of transuranic elements that must have been initially formed after neutron bombardment of uranium. The surviving correspondence demonstrates that Hahn believed nuclear fission was impossible until Meitner demonstrated to him that it had happened. She was the first person to realize that the nucleus of an atom could be split into smaller parts. Uranium had split to form barium and krypton accompanied by the ejection of several neutrons and a large amount of energy (the latter two products accounting for the loss in mass). A letter from Niels Bohr, saying that much larger amounts of energy were released when he bombarded the nucleus of an atom than expected from calculations based on a non-fissile core, sparked the inspiration of December 1938. Meitner's supporters (Sime 1996; Frisch 1991) claim that Meitner was the first to do the prediction calculations for a fissile (or fissionable) nucleus, yet they were unable to provide evidence to support her. Hahn and Strassman published the chemical findings in January 1939, and Meitner published the physical explanation the following month with her nephew, Otto Robert Frisch; they named the process *nuclear fission*. Given the exiled Meitner's precarious situation, it was impossible for her to publish jointly with Hahn in 1939. The separation of the former collaborators and Meitner's scientific and actual exile led to the Nobel committee's failure to understand her part in the work. Speculation also persists that the personal prejudice of Sigebahn, a member of the Nobel Committee, played a role (Sime 1996). Later Hahn rationalized the exclusion of Meitner, claiming that his chemistry had been solely responsible for the discovery. Subsequently

Hahn and others buried Meitner's role even deeper. News of the splitting of the atom and its awesome possibilities were brought by Bohr to scientists in the United States and, ultimately, resulted in the Manhattan Project.

3. The Franklin–Watson and Crick Controversy

The story of the discovery of DNA structure is a tale of relentless competition and intrigue. James Watson, Francis Crick and Maurice Wilkins received a Nobel Prize for the double-helix model of DNA in 1962. Rosalind Franklin, who was responsible for much of the research and discovery work that led to the understanding of the structure of DNA, had by then died prematurely at the age of 37. As the Nobel Prize is not awarded posthumously, she could not have been the recipient of that award.

Rosalind Franklin was born in London on July 25, 1920, into an affluent and influential British Jewish family. As with Lise Meitner, Rosalind Franklin's parents were decidedly against her higher education in science. Ultimately they relented, and in 1938 she enrolled at Newnham College, Cambridge, graduating in 1941. She earned her doctorate in physical chemistry from Cambridge University in 1945, on the basis of her fundamental studies of carbon and graphite microstructures. After Cambridge, she spent three productive years (1947–50) in Paris at the Laboratoire central des services chimiques de l'etat, where she learned X-ray diffraction techniques. In 1951, she returned to England as a research associate in John Randall's laboratory at King's College in London. Randall had assigned Franklin the task of elucidating DNA's structure. Franklin assumed that it was her own project. The laboratory's second-in-command, Maurice Wilkins, who had also worked on DNA structure, assumed that Franklin was to assist him. There were striking personality differences as well: Franklin came across as direct, quick, even pushy, and Wilkins as shy and mild-mannered. Though the mistake was acknowledged, it was never quite corrected. The strained relationship between the two had crucial bearing in the events that followed.

In February 1953, Francis Crick and James Watson, of the Cavendish Laboratory in Cambridge University, had also started to build a model of DNA using similar data.

The basic technique that Rosalind Franklin applied to her problem, and where she differed from Watson and Crick, was X-ray crystallography. Franklin made marked advances in X-ray diffraction techniques with DNA. She adjusted her equipment to produce an extremely fine beam of X-rays. She extracted finer DNA fibres than had ever been extracted before and arranged them in parallel bundles, and she studied the fibres' reactions to humid conditions.

After some complicated analysis, she discovered (and was the first to state) that the sugar-phosphate backbone of DNA lies on the outside of the molecule. She also elucidated the basic helical structure of the molecule. After Randall presented Franklin's data and her unpublished conclusions at a routine seminar, Wilkins provided Franklin's crystallographic photographs, without either her or Randall's knowledge, to her competitors at Cambridge University, Watson and Crick. By this time Franklin had decided to leave King's to work at Birkbeck College, in a move she had planned for some time. At a closer glance, these mundane events seem unprofessional if not unethical: (1) Franklin was leaving King's due to the strained relationship with Wilkins; thus, Wilkins was sharing the data of a colleague with whom some animosity existed; (2) Randall had permitted Franklin to transfer her fellowship to Birkbeck on the condition that she not work on DNA, an unjust demand, considering her contributions to the field. Moreover, Franklin was forced to leave her diffraction photographs behind at King's and to leave the work of confirming DNA's structure to Wilkins; and (3) the bitter animosity between Watson, the recipient of Franklin's data, and Franklin was common knowledge in biophysics circles of the time.

Franklin's photographs were central to the double helix model for DNA proposed by Watson and Crick. In their seminal 1953 paper, Watson and Crick made but an oblique acknowledgement to Franklin and misrepresented her role, leaving most people with the impression that her work mainly confirmed the results of Watson and Crick. It has been called one of the greatest understatements in the history of scientific writing.

Another lost opportunity for acknowledging Franklin occurred during the 1962 Nobel Prize ceremony. Neither Watson nor Crick thanked Franklin for making their discovery possible. Indeed, neither mentioned her name, although, according to Wilkins, Crick did ask him to mention Franklin. That request was a dubious shifting of responsibility, given Wilkins's antipathy toward Franklin, and Wilkins made only minor mention of her. The public spat between Watson and Franklin endures beyond her death. In Watson's book, *The Double Helix: A Personal Account of the Discovery of the Structure of DNA* (2001/1968), written after Franklin's premature death, he casts her in a most unflattering light. The caricature called Rosy (a name Rosalind Franklin despised) is an inferior, bad-tempered person, who selfishly hoarded her information. She was portrayed inaccurately as Wilkins's assistant, when in actual fact she was his colleague. To this day, James Watson insists that Rosalind Franklin was incompetent and incapable of interpreting her own data.

4. Discussion

The case studies above have an obvious commonality: they involve Jewish women, at a time when both being Jewish and female led to discrimination in academia. This obvious prejudice illustrates the tendency for marginalized communities in society to be the targets of predatory behaviour. Such communities lack of access to higher courts of appeal (or their academic equivalent) may encourage such predatory behaviour. One possible means of redressal for such a situation suggests itself: to identify marginalized academics and encourage them to voice their grievances, anonymously if necessary, at certain forums (for example, at seminars, records and, increasingly, on weblogs). The condition of anonymity tends to polarize opinion. It has been rightly argued that grievances aired anonymously can be dismissed as mere gossip and can function as channels for malice. However, it is this author's firm belief that such grievances repeated over time about behaviour that tends to be repetitive in nature can establish a pattern of abuse. A system of anonymous grievances has, in fact, proven to be effective in other contexts, for example, medical malpractices in American hospitals, police abuses in apartheid-era South Africa. The case studies above also bear a not-so-obvious commonality. During the key events of their respective controversies, both Lise Meitner and Rosalind Franklin were in unstable academic positions. Meitner was in exile, uncertain about the prospects of her career and life at large; Franklin was in an embittered transition from one workplace to another. Such transitions, in academia and otherwise, tend to highlight long-standing differences and provide opportunities for would-be academic predators to misrepresent themselves and to indulge in even worse activities, such as blackmail. Since transitions are inevitable, the recourse would be to keep accurate and timely records of research milestones by all academics. Such documentation, extant but little known in most universities (such as the University of Alberta), can deter predatory academics.

Bibliography

Frisch, O R. 1991. *What Little I Remember.* New York: Cambridge University Press.

Hahn, O, and F Strassman. 1939. "Proof of the Formation of Active Isotopes of Barium from Uranium and Thorium Irradiated with Neutrons." *Die Naturwissenschaften* (January 6).

Maddox, B. 2003. *Rosalind Franklin: The Dark Lady of DNA*. London: Harper Perennial.

Meitner, L, and O Frisch. 1939. "Disintegration of Uranium by Neutrons: A New Type of Nuclear Radiation," *Nature* 143, (February 11): 239.

Sayre, A. 2000. *Rosalind Franklin and DNA*. New York: W W Norton.

Sime, R L. 1996. *Lise Meitner: A Life in Physics*. Berkeley, Calif: University of California Press.

Watson, J D. 2001. *The Double Helix: A Personal Account of the Discovery of the Structure of DNA.* New York: Touchstone. (Orig pub 1968.)

Millsap and the "Ninth" Planet

Wytze Brouwer, *University of Alberta*

It was a sunny Wednesday in August. I was having a barbecue lunch at the Faculty Club with a couple of colleagues when suddenly a booming voice behind me stopped all conversation in a radius of 20 metres.

"Brouwer, what the hell are you guys up to? What have you done to the solar system?"

Needless to say, it was my old nemesis, Bert Millsap, professor of psychology and intellectual meddler in other people's sciences.

"Sit down and relax, Bert. What are you so excited about?"

"Excited? Upset is more like it. What right do you physicists have to decide whether or not Pluto is a planet?"

"Pick up some lunch and a drink, Bert, and we'll discuss the issue calmly."

Well, Bert did pick up some lunch, ordered his lethal rosemary sunset and sat down beside us. My colleagues, newly hired professors, had not yet met Professor Millsap, were unfamiliar with his somewhat argumentative style and appeared to be waiting with bated breath for the discussion to continue.

"Well, Bert, you've got your lunch. Now tell us why you are so angry with the whole physics community even though we three have had nothing to do with the decision to demote Pluto to a dwarf planet."

"OK, Brouwer, my main question is, Who has the right to change the status of Pluto when everyone in the world has accepted Pluto as the ninth planet for over 70 years?"

"The answer to that is quite easy. All astronomers belong to an organization called the International Astronomical Union that decides questions of this sort."

"But experts should not have the right to make such decisions. The public should have a voice in deciding major questions like this."

One of my young colleagues jumped in. "But that's nonsense. If the public should have a voice in deciding whether Pluto is a planet, then the public would also demand a voice in deciding whether evolution or creation is correct or not."

"That's a totally different issue," was Millsap's immediate retort, without explaining why. "There never was any controversy about Pluto's status. There are no religious anti-Plutonists and pro-Plutonists, so don't confuse the issue."

"Well, what about the way you psychologists value Freud's theories? Hasn't there been a major change in psychology since those days?" That was my intelligent contribution to the conversation.

"Yes, theories do change, but facts don't. When a fact is established, it remains a fact even though theories change."

Here I sensed a danger of a major shift in the discussion and the possibility of spending a whole afternoon on the question of whether facts always remained facts, so I jumped in. "Let's get back to the question, Bert, of whether or not Pluto should be considered a planet."

"Well, as far as I am concerned, the public is not going to accept this decision by a bunch of eggheads, and Pluto will stay as the ninth planet." No one ever accused Bert of being open-minded on scientific, political or social issues, as past stories in the archive have shown.

"I wonder how people in 1781 felt when the first 'new' planet, the seventh, was discovered to enlarge the solar system of six planets, which had been known for thousands of years. It even took quite a few years before the name Uranus caught on. Professor Herschel actually named it the Georgian Planet, after one of the Georges on the throne of England."

"And later the discovery of Neptune, and in 1930 the discovery of Pluto. People didn't get too upset about the new discoveries." This from one of the bystanders who had begun to gather around.

"Yes, Brouwer, but they've never taken away a planet. Once a planet, always a planet. Don't you remember the saying, My very educated mother just served us nine pizzas? What do you propose the students should learn now? Do you want them to memorize, My very educated mother just served us nothing?"

My colleagues and the others who had gathered around to enjoy the discussion burst into laughter. I suppose Millsap's new mnemonic would actually serve the purpose and expressed his disgust quite nicely.

I decided to try again. "Listen, Millsap, I have some sympathy for your view, but astronomers did have to make a choice. They did, after all, discover a new object out there, which just might be called Xena. It is larger than Pluto and also has a moon, which might be called Gabrielle. And Xena is similar to Pluto in that it takes hundreds of years to revolve around the Sun and actually will come inside the orbit of Pluto at some time in the future. It just doesn't behave like a regular planet."

"Regular planet, regular planet. What right do you have to decide what is a regular planet?

"Well, somebody had to define what we consider a planet. The International Astronomical Union has defined a planet as an object that orbits a star, and is large enough so that its gravitational field gives it a more or less round shape, and has cleared most of the debris out of its orbit. Pluto and Xena satisfy the first two requirements, but not the third."

"That third requirement sounds a bit fishy to me, Brouwer. I haven't heard of it before. Did they invent it to justify their decision? I think it would be better to make the third requirement one of size, say, 'A round object orbiting the sun, with a size at least that of Pluto is considered a planet.' Why wouldn't that satisfy everybody?"

A lot of listeners nodded their heads in agreement with Millsap. It would be a popular choice and quite unambiguous.

"But do you guys realize that Pluto is smaller than many of the satellites of Jupiter and Saturn, and even smaller than our own moon?"

"What does that matter? These satellites orbit a planet, not the Sun."

Consensus seemed to be settling in, but I was not yet ready to give up.

"But listen! Ceres, one of the asteroids in the asteroid belt between Mars and Jupiter, is about half the size of Pluto. Why not consider it a planet? Why should the size of Pluto be the minimum size?"

One of my young colleagues attempted a compromise: "You make a good point, Brouwer, there will always be an arbitrary element in the definition of a planet. But if we set Pluto's size as the minimum, we'll offend the fewest people."

"I don't mind that, but then you have to realize that there will now be 10 planets. Xena should definitely be added to the solar system, since it is close to twice the size of Pluto and there may be more large bodies in the Kuyper Belt."

"I think that's a better solution," agreed Millsap. "We don't mind adding a planet or two if that is necessary. After all, that's happened before and we can cope with that. But don't take Pluto away from us."

"But we'll have to invent a new saying to help students remember the order of the planets."

Millsap thought deeply. "How about this: 'My very educated mother just served us X pizzas.' That works especially well when this new planet Xena is inside the orbit of Pluto for a hundred years or so, and after all, the Roman numeral for 10 is X."

Strange to say, I actually agreed with Millsap. I would be happier with 10 or more planets than with the demotion of Pluto, because I suspected that the real reason for demoting Pluto had never been mentioned by the astronomers in the International Astronomical Union. From my own reading, I have concluded that models of the formation of solar systems all predict planetary systems with inner planets that are relatively small and rocky, and outer planets that are gas giants. Small, icy and rocky Pluto was an embarrassment to these theories, and the discovery of Xena and other Kuyper Belt icy and rocky bodies provided a good excuse for getting rid of this embarrassment. But, as Millsap said, the final verdict is not yet in.