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The Bertram Millsap Series

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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*, 5th edition (Washington, DC: American Psychological Association, 2001). Thus *ASEJ* is a refereed journal similar to most other scholarly periodicals published in Canada and the United States.

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From the Editor

Wytze Brouwer

Bob Ritter reviews the topic of problem-based learning, a cooperative, active learning approach, which may be more motivating for students than many traditional approaches to learning.

Dougal MacDonald focuses on the elementary science curriculum emphasis on problem-solving through technology and gives several examples of how teachers can convey a more authentic image of the relationships between science and technology.

Frank Weichman and Wytze Brouwer have a discussion on common ethical problems in scientific research. The topic of the month is "Authorship: What Rights and Responsibilities Does Authorship Confer upon a Scientist?"

A N Kamal's insightful article, "From Physics to the Bomb," outlines how scientists moved from pure research into the structure and decay of nuclei to the production of atomic weapons under the Manhattan Project.

Bert Millsap returns to offer his views on some impending research in physics to find the God Particle, which should be discovered within 18 months. This particle is supposed to explain why electrons, protons and other particles have mass, but Millsap isn't done yet. There are some energetic particles in cosmic rays that have befuddled physicists. Millsap always likes it when physicists are befuddled. It keeps them humble.

Millsap is busy these days attacking physicists. He actually ran into a rare occurrence. He, or rather his wife, Helen, has met a grumpy physicist who is too busy, or too self-important, to help a member of the public who wants to know something about physics. Naturally, Millsap is aroused.

Problem-Based Learning

Bob Ritter

In March 2007, I began doing some work with the assistant dean of undergraduate programs in the faculty of medicine. Like many faculties on campus, the faculty of medicine began reviewing how undergraduate programs were being taught. In reviewing and revising course syllabi, different departments began listing essential learnings. Not surprisingly, the list had grown exponentially. With an ever-expanding knowledge base, some faculty members raised the concern that traditional teaching approaches could not ensure that all learner outcomes could be covered. Science educators at many different levels have been raising this same concern for some time. An ever-expanding body of scientific knowledge has had its effects upon curriculum, no matter the discipline or academic level. In K–12 schools, science educators have reworked lessons to try to more efficiently accommodate a ballooning knowledge base—in some cases, to the detriment of their students. The goals of science programs must be re-examined and new models for program delivery must be explored to ensure that educators recognize the importance of lifelong learning and the necessity for the development of strong problem-solving skills within a collaborative environment.

Problem-based learning (PBL), pioneered and used extensively in the medical faculty at McMaster University in Hamilton for 25 years, has received great attention from professional faculties across North America (Savery and Duffy 1996). The model has been adopted in an increasing number of other areas, including business schools (Milter and Stinson 1995), schools of education (Bridges and Hallinger 1992; Duffy 1997), architecture, law, engineering and social work (Boud and Feletti 1991); and high schools (Lockhart and Le Doux 2005; Jerome School District 2000).

PBL is a form of active learning that places students in collaborative groups that are charged with solving a problem. It is rooted in cooperative and inquiry learning, approaches more familiar to K–12 teachers. However, unlike many approaches to cooperative learning, problem-based learning is driven by a challenge or open-ended problem. The problem is presented first, to focus and direct what needs to be learned, not as a summary to test what has been learned. It also differs from many of the more traditional approaches to inquiry learning by allowing students greater independence in sequencing and determining their own learning experiences. Student groups assume the lead role in determining what information needs to be collected and evaluated in order to complete the task or solve the problem. In an ideal setting, students take the responsibility for their group and direct their own learning. The teacher acts as a facilitator, assisting in redirecting or focusing the problem-solving strategy of the group.

This article explores the tenets of problem-based learning as an approach for teaching secondary science. It also examines how the roles of teacher and student change through this approach and what can deter implementation. Rather than advocate that PBL become a solitary model for teaching science, I will argue that the value of an approach situated in real-world problems has a place within current curricular structures.

The Process of Problem-Based Learning

Problem-based learning environments are driven by a practical problem that can be investigated within a field of knowledge. The problem helps frame the scope of research and will help focus the investigative processes. Typically, students create a form that addresses what information is given to them within the problem and a map that helps the group identify what additional knowledge must be acquired. Although there is no single way of approaching a problem, PBL usually follows the following guiding principles (Boud and Feletti 1991):

- Students are presented with a real-world problem.
- Working in groups, they identify their ideas and previous knowledge related to the problem in an attempt to better understand the scope of the problem and the factors that will affect a potential solution.
- While students engage in defining the scope of the problem, they pose "learning issues" that outline parts of the problem that they do not understand.
- In defining what the group knows and does not know, a facilitator is better able to provide focus questions that help direct the group. Students and the facilitator order the learning issues and identify potential resources available to address the issues.
- Student groups reconvene to reflect upon their progress and examine the remaining learning issues. Inevitably, new learning issues are identified and the problem is redefined.

One of the greatest challenges is in formulating the question that initiates the learning process. An example of such a problem is to design a golf course to minimize environmental impact (Ritter, Burley and Fraser 2007). When introduced at the beginning of a unit of study, the challenge can provide a context for student learning.

Students must understand the effects of grass fertilizers on surrounding pond, lake and river ecosystems. To assess the impact of fertilizers, they need to understand how nitrogen and phosphorus compounds cycle through an ecosystem. In turn, students will make a link between nutrient levels on lush green fairways and in surrounding bodies of water and the growth of plants and algae. Algal blooms affect oxygen levels in ponds and lakes. This leads to an understanding of the carbon cycle, as students begin to explore the relationship between oxygen and carbon dioxide levels. Organic carbon is held in reservoirs—the bodies of living things. The slow decomposition that follows the death of living things, such as forms of life found in bogs, returns carbon to the cycle in inorganic forms. The replacement of forests with green fairways reduces the amount of carbon held in the reservoir, thereby affecting the amount of CO_2 entering the atmosphere. Students are also required to explore the impact of long-term irrigation of fairways and consider how the replacement of forests with monocultures will impact the number and types of species within an ecosystem. By extension, students are required to grapple with the moral question of using agricultural land for recreation rather than food production.

The chart below summarizes how students might begin the challenge. By defining the scope of the problem and listing things they already know and the things they need to know, students begin working toward a solution.

Challenge: Provide a design for an environmentally friendly golf course.		
What is defined by the problem?	**What do we already know?**	**What needs to be known?**
• What is the impact of fertilizers on lakes and artificial ecosystems (fairways)? • What is the impact of replacing a complex-forest ecosystem with a monoculture (grass)? • How does irrigation of grasses affect an ecosystem?	• The nitrogen cycle. • The phosphorus cycle. • The carbon cycle. • Fertilizers increase algal growth, which affects biological oxygen demand. • Animals are drawn to the rich grasses found on fairways.	• How do we test for nitrogen, phosphates and oxygen levels? • What are biological indicator species of changes in nutrient levels on land and in surrounding water ecosystems? • Should complex, natural ecosystems be replaced by monocultures for food production or golf courses for recreation?

Key to problem-based learning is that student groups continue to reflect upon the problem and discuss their solutions with the teacher, whose job it is to ensure that student groups do not get too far off track. Rather than direct student groups, the teacher assumes a more passive role by suggesting that they look at alternative methods to solve the problem or question some of the assumptions upon which solutions are based. By researching the question, students begin to understand the scope of the question and often redefine the limits of what can be studied.

Changing Roles of Student and Teacher

Problem-based learning arose because professional faculties began to recognize that an ever-expanding knowledge base could not be accommodated by continuously adding new learner outcomes to their curriculum. Rather than take the responsibility to demonstrate that their graduates knew everything, these faculties and departments took a new approach. They attempted to create an environment that would produce problem-solvers who could readdress problems as their knowledge base expanded. Additionally, they saw the value in bringing multiple disciplines together within research, so they asked why the same couldn't be accomplished within learning. Problem-based learning is founded upon

- initiating a change in curriculum focus from outcome driven to problem-solving;
- an understanding that the knowledge base will continue to grow and that students need to be lifelong learners;
- a belief that students can work in groups to develop problem-solving skills and manage their own learning;
- a belief that students can direct their own learning; and
- making resources accessible to students during the learning and providing an approach that calls on students to evaluate the usefulness of the information in solving their problem.

Constructivist theories acknowledge that the social environment is critical to the development of an individual's understanding as well as to the development of the body of propositions we call knowledge. At the personal level, other people are a primary mechanism for testing our understanding. Hence, collaborative groups are important, because in them students can test their own understanding and examine the understanding of others as a mechanism for enriching, interweaving and expanding knowledge of particular issues or phenomena (Savery and Duffy 1996).

The biggest difference between the problem-based approach and the traditional is that in PBL the teacher does not regulate or organize subsequent learning directed at solving the problem. Students not only organize their own learning, but also construct meaning as they begin unfolding the challenge. Lebow (1993) describes a strategy for summarizing the constructivist framework in a way that may help with the interpretation of the instructional strategies. He writes about the shift in values when one takes a constructivist perspective. He notes that traditional values of replicability, reliability, communication and control contrast sharply with the seven primary constructivist values of collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance and pluralism (p 5).

The chart below compares teacher and student roles in an ideal setting for problem-based learning with a traditional lecture-based approach, where a teacher manages learning. It is important to note that not every didactic approach to learning encompasses all of the elements of passive learning, nor does every approach to problem-based learning allow students the greatest flexibility in setting their own course.

Overcoming Deterrents

Lenschow (1998) identifies frustrations that students experience, especially in the early stages of PBL, because they are required to construct a solution to an open-ended problem, rather than respond to clues provided by the teacher. Not surprisingly, new roles create new problems for both teachers and students. It has been my experience that students most resistant to change are often those who have demonstrated success in traditional approaches to learning. After all, they have the least incentive for change and, potentially, the most to lose. Michael Fullan (2001) warns those undertaking change to expect resistance. It is equally important to build small successes into the framework as classrooms move toward PBL. Students must not only be assured of the value of developing problem-solving strategies but gain confidence in their ability to work within groups to solve problems.

Heckendorn (2002) explains that projects usually require more time to complete. Charting timelines and stressing deadlines are even more important in PBL than in traditional classrooms, where the teacher has greater control over the pace of a lesson. It also raises questions about whether or not PBL approaches should be used exclusively for student learning. Hybrid models where lectures, teacher-directed laboratory investigations or computer simulations support the problem being investigated, seem to have their place within a crowded curriculum.

Heckendorn (2002) also indicates that the projects tend to be much more complex in nature and, therefore, more difficult to evaluate. Although the task better reflects the type of work students do in classrooms, assessment and, ultimately, student evaluation require sensitivity and expertise. Ideally, teachers working within professional learning groups could better resolve emerging issues. The group mark also creates some consternation for both teachers and students. Although much research supports the value of collaborative learning, questions about fairness continue to persist. There are no simple solutions.

Some studies (Sweller and Cooper 1985; Cooper and Sweller 1987) have argued that PBL approaches are less effective with younger learners or learners just beginning a new discipline, because of what they term *cognitive load*. Young students' unfamiliarity with vocabulary and the manner in which knowledge is presented make it challenging to find appropriate resources. Resources written for researchers are likely to frustrate novice learners. An alternative for younger students is to preidentify appropriate resources or use library resources that flag reading and/or cognitive level. Many of the online reference sites, such as the Science Resource Centre of the LearnAlberta website, identify reading level of articles and appropriate audiences.

Teacher-directed approaches to learning		**Problem-based learning strategies**	
Student role	**Teacher role**	**Student role**	**Teacher role**
Responds to teacher-directed questions.	Constructs and sequences multiple questions in managing the learning.	Groups respond to a challenge by constructing and defining their own question.	Sets the stage by providing a scenario or a challenge.
Uses resources identified by the teacher.	Determines resources.	Identifies and evaluates the usefulness of the resources in answering the problem.	Monitors how the student uses the resources.
Responds to the direction set by the teacher.	Determines and sequences learning activities.	Groups determine and sequence learning activities.	Acts as a guide, ensuring that the collaborative team has gone in the right direction.
Follows teacher clues to a predetermined answer.	Directs conclusions to a single end-point.	Groups provide possible solutions following research.	Checks solutions and works as a coach to encourage lateral thinking.
Solutions are submitted to the teacher.	Assessment of student work to a preconstructed rubric. Summative assessment most often dominates.	Student groups reflect upon the solution and self-assessment is encouraged.	Formative assessment is dominant.

Locating resources, even in an electronic world, presents challenges for teachers in Alberta schools. Because of greater reliance upon electronic resources, library class sets of computers must be booked in advance; many classes still compete for these resources during some class times. It is equally important to recognize that textbooks are structured at the appropriate reading level for students and address curricular outcomes. Although textbooks may not provide all the information required to solve the problem or challenge presented by PBL, they do provide a foundation of knowledge essential for students to begin to understand the problem and formulate the question. The tendency to provide a solution prior to gaining an understanding of the complexity of the challenge must be guarded against.

It is also vital that teachers spend more time with groups before they do the research. In some cases, having students do a number of core lessons in a traditional group may help prepare them for a more open-ended project. Within the preparation lessons, the teacher can help define common essential learnings that prepare the student for the challenge task. The key element is increased seminar time for the teacher and student-learning groups at the beginning stages of problem solving. Posing questions and reviewing student plans for solving the problem require the greatest time and effort. Once student groups begin collecting data and writing up their conclusions, the teacher's schedule becomes somewhat less hectic. Through self-reflection and summaries of group progress, students become more aware not only of timelines but also of the direction they are taking to solve the problem.

Does PBL Improve Learning?

A wide variety of PBL methodologies and practices makes the analysis more complex. A review by Michael Prince (2004) of the research literature indicates that PBL produces a more positive attitude in students and may improve their retention of knowledge. Maxwell, Mergendoller and Bellisimo (2005) present findings that show that student test scores in high school economics improved when PBL learning approaches were used. However, quantitative data that show a direct connection between PBL and academic achievement, as measured by test scores, are difficult to find in most other studies.

Frank and Barzilai (2004) argue that the value of PBL should not be measured on the basis of how it improves test scores. PBL was intended to improve problem-solving skills. A test that is based upon the acquisition of content knowledge, with little or no recognition of problem solving, would be an inappropriate indicator of student learning. At McMaster School of Medicine, one of five criteria for admission is a test of candidates' problem-solving skills—the medical faculty at McMaster clearly believe that physicians must have problem-solving skills.

The question should not be "Does PBL improve test scores?" but rather "What are important measures of scientific literacy and how could they be measured?" If we believe that students can gain an appreciation for science by working in collaborative groups to solve science-related problems, then PBL strategies make sense.

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Sweller, J, and G A Cooper. 1985. "The Use of Worked Examples as a Substitute for Problem Solving in Learning Algebra." *Cognition and Instruction* 2, no 1: 59–89.

Sample Problems for Problem-Based Learning

Problem-Based Learning at the University of Delaware
www.udel.edu/pbl/problems/

St Jerome School District
www.d261.k12.id.us/Technology/Goals%202000/PBL/problem_based_learning.htm#Projects

Indiana University
www.indiana.edu/~legobots/q515/pbl.html

(Websites accessed October 25, 2007.)

Problem Solving Through Technology: Conveying Authentic Images of Science–Technology Connections

Dougal MacDonald

Introduction

In 1996, a new curriculum emphasis called *problem solving through technology* (PST) was introduced into the *Alberta Elementary Science Program of Studies.* PST—also known as technological problem solving and design technology—involves having children design and make models of technological devices such as boats, bridges, vehicles, electrical mechanisms and things that fly.

Each grade level of the program of studies includes one PST unit, along with four scientific-inquiry units. Each PST unit from Grades 2 through 6 is closely connected with a corresponding scientific-inquiry unit at the same grade level. For example, in Grade 6, the PST unit is "Flight" and the scientific-inquiry unit is "Air and Aerodynamics."

Classroom teachers often teach the two connected scientific-inquiry and PST units at the same time. Authentic integration of the two kinds of units may be difficult due to

- misconception that science (developing knowledge about the natural world) and technology (creating objects and devices to meet human needs and wants) are one and the same;
- gaps in key scientific and technological knowledge;
- lack of awareness that conceptual knowledge is an important component of technology and hence of technological problem solving;
- difficulty in discerning what scientific and technological concepts underlie the specific learning expectations (SLEs) of the *Alberta Elementary Science Program of Studies,* since most SLEs are framed behaviourally ("Students will be able to…") instead of conceptually ("Students will understand that…"); or
- overemphasis on the product goals of technological problem solving (eg, "Students will build a model of a cantilever bridge") and de-emphasis or omission of the teaching goals (eg, "Students will realize that triangles are strong building shapes").

Nature of Science–Technology Relationships

Another major difficulty in integrating science and technology relates to misconceptions of the relationships between science and technology. A pervasive myth is that the only connection is that technology is applied science; however, science–technology relationships are much more complex. A useful consensus in this regard is 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 the nature of the relationships between science and technology is validated by the lengthy collaboration of over 400 scientists, engineers, science educators, philosophers of science and others who contributed to it. (An overview of Project 2061 can be found in *Science for All Americans* [AAAS 1989] and online at www.project2061.org.)

The Project 2061 (AAAS 1989) view of science–technology relationships can be summed up as follows:

- Technology is informed by both practical know-how (eg, strength of materials) and scientific understanding (physical laws of nature).

- Scientific understanding provides a means of predicting the behaviour of things before we observe them (eg, building materials) and can lead to new technologies by suggesting new kinds of behaviours of things (eg, using a material in a new way).
- The more sophisticated technologies become, the stronger their links to science. In some fields science and technology are almost inseparable. For example, in physics (science), studying particles of matter requires accelerators (technology) that cause particles to collide at very high energies.
- New technology (eg, superconductors used in MRI machines) often requires new scientific understanding (eg, better theories to explain why superconductors have zero resistance to a flow of electrical current). New scientific investigations often require new technology. For example, exploring interstellar space may require new propulsion methods for space probes.
- Technology is essential to science for measurement (seismograph), data collection (graphing calculator), transportation (deep-sea submersible) and communication (computer).
- Technology makes it possible to advance scientific research. For example, nanotechnology, which involves control of matter on a very small scale, has advanced research on semiconductors, the key components of computers and cell phones.
- Technology provides motivation for scientific theory and research. For example, the technology of genetic analysis enabled the mapping of the human genome.

One way to simplify the above concepts for classroom purposes is to reduce them to the following five statements about the relationships between science and technology:

- Science is theoretical technology (technology precedes science) (Mitcham 1994).
- Science explains why and how technology works or does not work.
- Physical laws of nature constrain technology.
- Technology helps us to acquire scientific knowledge.
- Technology is applied science (science precedes technology).

Teaching About the Nature of Science–Technology Relationships

The above statements about science–technology relationships help clarify an aspect of the nature of science and technology. By *nature of* we mean the *defining characteristics* or *attributes of*. Teaching students about the nature of science has historically been an important goal of science teaching, while teaching about the nature of technology is becoming increasingly important as technological problem solving continues to be integrated into science curricula.

Science teachers convey images of the relationships between science and technology to their students, even if they do not do so explicitly. For example, referring only to modern technologies in classrooms may erroneously convey to students that science always precedes technology. However, the technology of the bow and arrow long preceded scientists' conceptualization of potential (drawn-back bowstring) and kinetic energy (arrow in flight), and the conversion of one form to the other. To give another example, indigenous peoples used mouldy corn to stop infection long before scientists conceptualized that antibiotics work by mechanisms such as inhibiting protein synthesis and blocking cell-wall development. This suggests that science teachers should (1) consciously teach about the nature of the relationships between science and technology and (2) try to convey authentic notions of those relationships when doing so.

A Framework for Authentic Integration

It is useful to develop a framework to guide elementary teachers in authentically and explicitly integrating scientific-inquiry and PST units. The approach suggested is to map the five succinct statements about the relationships between science and technology (above) onto the Grade 2 through Grade 6 pairs of scientific-inquiry and PST units in the *Alberta Elementary Science Program of Studies*. Suggested topics for relevant student activities can then be entered into the cells where the statements and the units intersect. One possible result is displayed in Figure 1.

Figure 1: Integrating Scientific-Inquiry and Problem Solving Through Technology Units

Scientific Inquiry Units	Science is theoretical technology (technology precedes science).	Science explains why/how technology works/does not work.	Physical laws of nature constrain technology.	Technology helps us acquire scientific knowledge.	Technology is applied science (science precedes technology).	Problem-Solving Through Technology Units
Exploring Liquids	*Sailboat* Uses wind as its primary means of propulsion.	*Buoyant Force* Upward force exerted by a fluid on an immersed object.	*Stokes's Law* An object's shape affects its speed moving through a fluid.	*Hydrometer* Measures specific gravity/density of a fluid.	*Jet Boat* Air exiting a balloon pushes the boat forward.	**Buoyancy and Boats**
Testing Materials and Designs	*Column* A vertical structural element.	*Compression/Tension* "Squeezing together" and "pulling apart" forces.	*Hooke's Law* How much a body deforms depends on the force applied to it.	*Load Cell* Measures compression and tension forces on an object.	*Modern Suspension Bridge* Bridge deck is suspended from cables held up by towers.	**Building with a Variety of Materials**
Wheels and Levers	*Wheel and Axle* A simple machine made up of two circular objects of different sizes.	*Force of Friction* Force that opposes the relative motion of two surfaces in contact.	*Newton's Third Law of Motion* For every action there is an equal and opposite reaction.	*Spring Scale* Measures force of gravity on an object (its weight).	*Motorized Vehicle* Stored energy of a wound-up rubber band turns the vehicle's rear wheels.	**Building Vehicles That Move**
Electricity and Magnetism	*Voltaic Pile* Chemical energy is converted to electrical energy.	*Electron Theory* Current is the flow of electrons through a conductor.	*Laws of Magnetism* Like magnetic poles repel (electric motor).	*Ammeter* Measures rate of flow of charge.	*Fairground Ride* An electric motor powers the ride.	**Mechanisms Using Electricity**
Air and Aerodynamics	*Glider* Is towed into the sky, then powered by gravity and air currents.	*Bernoulli's Principle* An increase in velocity of a fluid correlates with a decrease in pressure.	*Law of Gravity* Every object in the universe attracts every other object.	*Wind Tunnel* Helps study effects of air moving over or around objects.	*Hovercraft* A fan lifts the craft by forcing air beneath it. Air is retained by a rubber skirt.	**Flight**

Using the Framework

The framework provides practical direction concerning the authentic integration of scientific inquiry and problem solving through technology. Specifically, it helps teachers set out definite intentions for both what is to be taught *in* science and technology as well as what is to be taught *about* the nature of science and technology relationships.

Students will not necessarily develop authentic notions about the nature of science and technology relationships simply by doing an activity, no matter how relevant. For example, students will not necessarily better understand that technology helps us acquire scientific knowledge just by placing different airfoils in a wind tunnel and collecting data about airflow patterns. Gustafson and MacDonald (2005) point out that, more realistically, the teacher needs to

- decide on the appropriate nature of science and technology goals;
- meaningfully intertwine nature of science and technology goals with the other lesson goals (eg, concepts, skills, attitudes and everyday applications); and
- make nature of science and technology goals explicit to students during the lesson (eg, by explicitly pointing out that the technology of the wind tunnel helps us gain scientific knowledge about the effects of air moving over and around objects).

The following two sample lessons illustrate how the framework in Figure 1 can be used to develop lessons that authentically integrate scientific-inquiry and problem solving through technology units. The two lessons could be part of the linked units "Behaviour of Liquids" and "Buoyancy and Boats." The first two concepts in each sample lesson relate to knowledge *in* science and technology while the third and fourth concepts relate to knowledge *about* science and technology relationships.

Sample Lesson 1: What a Drag!

Major Concepts

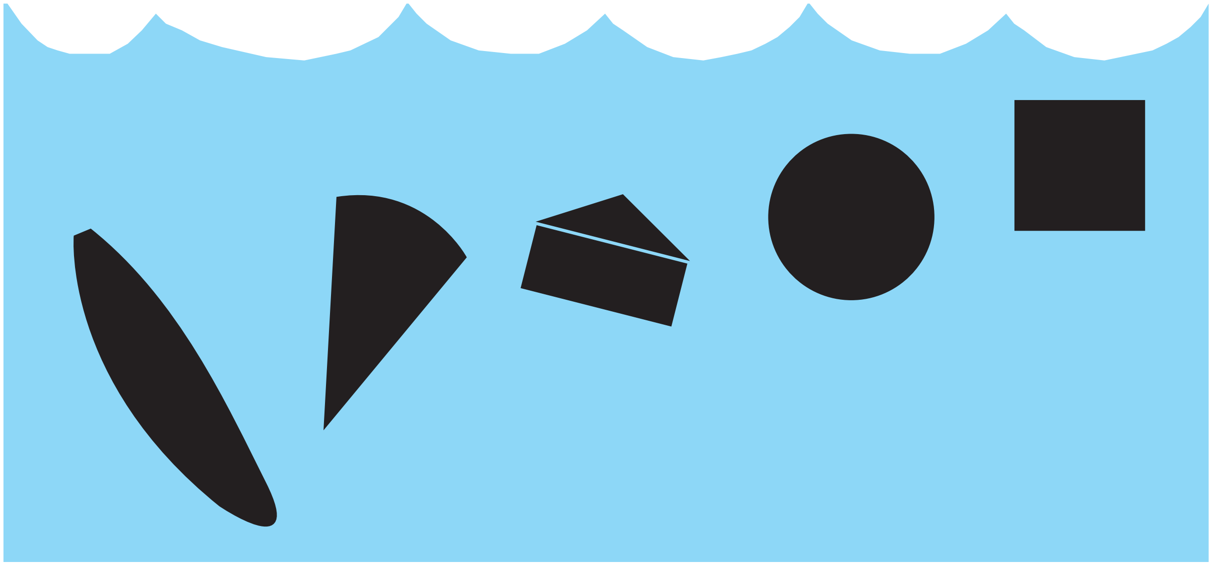
1. The density of a liquid affects how fast an object can travel through it.
2. The shape of an object affects how fast it can travel through the liquid.
3. Physical laws of nature constrain technology.
4. Scientific understanding provides a means of predicting the behaviour of things before we observe them.

Materials

Lump of plasticine, piece of strong thread, large graduated cylinder, water, glycerine, stopwatch.

What to Do

- Ask students to brainstorm possible shapes to test. Focus them on shapes such as a torpedo, a cone, a wedge, a sphere and a cube.



- Ask students to predict which shapes will fall fastest through the liquid. Be sure that they give a reason for each prediction.
- Demonstrate the test setup as follows. Create a shape out of plasticine. Push one end of the piece of thread through the shape, securing it with a knot. Show students how fast the shape falls when it is dropped into a graduated cylinder filled with water. Point out to students that the shape drops so fast that it is hard to time it. State that instead of water they will use a more dense liquid, glycerine, so that the clay shape will drop more slowly. Demonstrate again.
- Ask students how they can make this a fair test by controlling as many variables as possible (eg, always using the same lump of plasticine, cleaning and drying the plasticine and thread after each trial, performing several trials for each shape, and having the same person run the timer each trial and the same person release the clay each trial).
- Help students fill their graduated cylinders to the same level with glycerine. Have them use a stop watch to record the time it takes for the shape to fall through the glycerine. Give students data tables for recording their times, and test until three consistent trials have occurred.
- Once students have collected their data, ask them to look back at their predictions and check them against their results.
- Students should find that the shapes fall from fastest to slowest in this order: torpedo, cone, wedge, sphere and cube.

Questions

1. Which shape fell fastest? Why?
2. Which shape fell most slowly? Why?
3. How does the shape of an object affect its speed through water?
4. How could the results of tests like these assist boat designers in building faster boats?

Background Knowledge

Stokes's Law states that a solid object moving through a fluid creates pressure in front of the object and a slight vacuum behind it as it moves through the fluid. These forces act to slow the object down as it travels through the fluid. This is usually referred to as the *drag force* on an object.

According to Stokes's Law, the following three relationships hold:

- The more the shape of the object helps the pressure on the object move from the front of the object to the rear of the object, the less the drag force. For example, smoother, teardrop shapes tend to help the pressure on the front move to the vacuum in the back, reducing drag.
- The faster the object moves through the fluid, the greater the drag force.
- The denser (more viscous) the fluid, the greater the drag force.

Sample Lesson 2: How Dense?

Major Concepts

1. The density of a liquid is its mass divided by its unit volume.
2. The density (relative to water) of a liquid can be determined by placing a hydrometer in the liquid and recording the level at which it floats.
3. Technology helps us acquire scientific knowledge.
4. Technology makes it possible to advance scientific research.

Materials

Graduated cylinder, water, ruler, lead BB pellets, clear plastic straw, permanent marker, plasticine, salt, various liquids.

What to Do

- Fill the graduated cylinder with water to a known level.
- Seal one end of the straw with plasticine.
- Place two BB pellets inside the straw and set it upright in the graduated cylinder.
- Add BB pellets until the straw is floating, with about three centimetres above water.
- Mark the level on the straw as W.
- Ask students what will happen if salt is added to the water and the straw hydrometer is placed in the salt water. Have them explain why they think so. Have them test their predictions, then explain the results.
- Have students test other known (and safe) liquids, predicting each time what the result might be and why: olive oil (density 0.8), corn oil (0.9), sunflower oil (0.92), castor oil (0.96), whole milk (1.05), glycerine (1.26), corn syrup (1.5).

Questions

1. Which liquid was the least dense?
2. Which liquid was the most dense?
3. How does the hydrometer measure the density of the liquid?
4. Would a boat float better in plain water or salt water? Why?

Background Knowledge

A hydrometer is usually made of glass and consists of a cylindrical stem and a bulb weighted with mercury or shot to make it float upright. Liquid is poured into a tall jar, and the hydrometer is gently lowered into the liquid until it floats freely.

The point where the surface of the liquid touches the stem of the hydrometer is noted. Hydrometers usually contain a paper scale inside the stem, so that the specific gravity (or density relative to water) can be read directly in grams per cubic centimetre.

In less dense liquids, the hydrometer must sink deeper to displace its weight of liquid than in more dense liquids. It is usual to have two separate instruments: one for more dense liquids, on which the mark 1.000 for water is near the top, and one for less dense liquids, on which the mark 1.000 is near the bottom of the stem.

The hydrometer is based on Archimedes' principle that a solid suspended in a liquid will be buoyed up by a force equal to the weight of the liquid displaced. The lower the hydrometer sinks, the lower the density of the liquid.

Conclusion

The integration of related scientific-inquiry and problem solving through technology units is a reality in Alberta science classrooms. The integration of the two kinds of units has the potential to convey messages to students about the nature of the relationships between science and technology. Teaching should convey authentic rather than inauthentic messages about these relationships, both implicitly and explicitly. The framework proposed in this article provides one possible guide to authentic integration.

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Scientific Ethics and Authorship of Scientific Papers

Frank Weichman and Wytze Brouwer

Incidences of scientific fraud—plagiarism, falsification and fabrication of data—have appeared regularly in the scientific literature in the past several decades. In fact, the situation has become so serious that the University of Alberta now requires each of its graduate students to obtain a number of credits in scientific ethics. Part of this requirement can be achieved online, but part of the ethical education now rests on the shoulders of the home departments of the students. Since fraudulent practices have begun to appear even in physics, the Department of Physics has asked some of its senior members to give a presentation on aspects of scientific ethics to graduate students in physics. In the present article we focus on authorship—who has the right to be an author, and what kind of responsibility should rest with each of the coauthors of a paper.

When should my name appear as author or coauthor on a paper?

There may be several reasons why a scientist's name may, or may not, be included as one of the authors of a paper. We have based the following discussion mainly on our own practices and experiences, throughout careers that span 40 to 50 years.

1. **I should be an author because I had the main idea for the research.**

Frank—The idea may be brilliant, but unless you have made a good start into making it work or proving that it will work, you don't have a leg to stand on. However, it would be common courtesy for the person who picks up the idea and does the work to acknowledge the source of the idea. Acknowledgements are a common form of saying "Thank you" in research papers.

Wytze—Newton ran into a controversy of this sort. Apparently, Robert Hooke had conjectured that gravity probably spreads out as $1/r^2$, but he could not prove it. When Newton published the *Principia Mathematica*, he gave a full proof of the theorem and clearly deserved credit for it. Some acknowledgement of Hooke might have been tactful and might have prevented some of the acrimonious letter writing and name calling that followed.

2. **I should be a coauthor, because I did the technical work, or the analysis.**

Frank—Technicians or computer specialists are often indispensable in getting the work done. Many a theorist in this department would readily admit that without Bob Teshima their problems would not have been solved. I certainly depended on George Christie, Willy Siewert and, later on, Ken Marsh to build the equipment I needed. Even the occasional summer student provided me with breakthroughs. Here is a guide: many of the technical personnel have training which we, the researchers, lack. At the same time they don't, and often don't want to, know what you are trying to prove. All they want or need to know is what you think you need in their area of training. It is up to you to ask them for the relevant advice or gadget, and if you asked the wrong question, that is your tough luck. As before, acknowledgements are important; coauthorship is rare.

A recent example: I do demonstrations for science classes in local schools and needed a high sensitivity galvanometer to show small electrical effects on the lecture bench. There are portable galvanometers of barely sufficient sensitivity and they *do* work. They are also temperamental. Modern operational amplifiers and a small battery can be hidden inside the case of a cheap galvanometer, and the cheap galvanometer, at the flick of a switch, becomes a highly sensitive detector. The electronics that accompany the chip can prevent overloads and even provide temperature compensation. Lars Holm designed the amplifier; the physics electronics shop built the device; I published a short paper and expressed my indebtedness to Lars Holm in the paper.

Wytze—My experience is similar to Frank's. There have been times that a project would not have worked without a technician's help, beyond what his or her job description demands. In cases like that, I have always included the technician as a coauthor of the paper. The simplest way to decide is that if the technician did only what his or her job description demands, an acknowledgement should suffice. If the technical support and advice goes well beyond this, then coauthorship should be considered.

3. **I should be an author because I got the money for the work (regardless of who had the idea in the first place). Otherwise known as "I was the principal investigator."**

Frank—This is a nasty one. I had a research contract from a corporation for some very practical applications. A graduate student of mine designed and built a temperature controller as part of the system needed for the measurements. He wrote a short paper for an instrumentation journal; it was published. I refused to have my name on the paper; it was his work, from beginning to end, and though I provided the money, I had no other role in that aspect of the research. Some years later, I had a postdoctoral student who worked on GaAs research I had initiated, and he wrote papers in which he explored the theory behind the electronic behaviour of GaAs. Here, too, I felt that he went well beyond what I had to contribute. His written English was below most journals' standards, so I spent hours editing the draft. Yes, I had input, but I felt the work was his, not mine, and should carry his name, not mine. If I remember correctly, he felt insulted.

Wytze—As Frank says, this is a tough one. I have found in the past that our graduate students, even if they have done most of the work, would like our names on the publication. In my own graduate studies, the first paper my supervisor and I wrote was 90 per cent his work, but he corrected my version—Pathria and Brouwer—and put my name first. The next two papers were probably 95 per cent my own work, since he was now out of the country, but I wanted the authors to be Brouwer and Pathria also, and so it usually turns out.

One episode in my experience illustrates the advisability of a senior researcher at least considering putting his name on a paper, even if his contribution is fairly minor. About 15 years ago I was approached by a medical intern at the University of Alberta Hospital to see if we could do some modelling of tumour sizes to calculate more accurately what dosages of chemotherapy were sufficient. With the help of Bob Teshima, we managed to do some nice modelling, and the intern was able to suggest different chemotherapy dosages on the basis of this work. When the intern asked me if we should write a joint paper on the project, I suggested that Bob and I were not in it for the glory, and we would let him publish the paper under his own name with acknowledgement of our help. What happened? The paper never got written. The intern probably felt that it was not important enough in our minds, and he did not have the confidence to write and publish it himself. I regret this mistake, and in retrospect, it would have been a kindness to the intern to indicate that we would love to have our names on the paper.

However, there have been quite a number of occasions in the past few decades in which a graduate student or young professor has committed plagiarism or has fabricated the data on which the paper was based. The funding agencies have usually only held the "criminal" responsible, and not the coauthors. Both Frank and I feel that this is an injustice. If you are a coauthor of a paper, you should be fully responsible for the contents of the paper. If you are willing to share in the credit for a paper, you must also be willing to ensure the validity of the paper.

4. **I should be a coauthor because I supplied the specialized equipment with which the work was done.**

Frank—We have, in the past, done some far infrared absorption spectroscopy work on GaAs. Now it so happened that I had a friend in the chemistry department, Dr John Bertie, who had a laboratory full of FTIR (Fourier Transform Infrared Spectroscopy) equipment. He taught my graduate student, Chin Teh, how to use the equipment. We built a special low-temperature Dewar flask to hold the samples, and the measurements went ahead. Should Dr Bertie's name have been on the papers? Acknowledgements, yes, and even a payment for his expenses to the chemistry department from my research contract, but Dr Bertie did not consider himself to be a coauthor.

Some years earlier, when I was still working on the semiconductor Cu_2O, I suspected that there were minute copper precipitates forming in the material. My colleague Dr Gwyn Hughes was doing nuclear magnetic resonance (NMR), which could prove the point. He did. And he even obtained information on the size distribution of the precipitates. The idea was mine, the samples were mine, but he did all the NMR related work; he became a coauthor.

Wytze—There have been colleagues who have coauthored papers to which their only contribution was to make some equipment available. I fully agree with Frank that such contributions should be acknowledged, but not by coauthorship.

5. **I should be a coauthor, because I had a special skill indispensable to the research (I grew a special crystal, dug up the rock samples, wrote the computer program, and so on).**

Frank—There are labs or people that can make special materials or find meteorites that others would love to investigate with their specialized equipment. The supplier of the material is indispensable and automatically a coauthor.

There can be difficulties; again, I made state-of-the-art Cu_2O crystals and became a known expert on this material. A Japanese visitor took some crystals home with him, made some measurements and published a paper with my name as a coauthor. I was less than pleased, because the other authors made a series of unreliable measurements, not realizing that this material has surface characteristics that dominate over its bulk properties. They made the strategic error of not showing me a draft of the paper before sending it for publication.

Wytze—The only experience I had that was similar occurred long ago—in 1968, when Rice University published a monograph (by Biedenharn, Brouwer and Sharp) that contained large sections of my MSc thesis. However, several errors had crept into the transcription, which my coauthors did not catch. And since they did not show me a draft, I could only correct the errors in my own copies of the monograph. My coauthors were correct in including me as a coauthor, but they should have shown me the galley proofs, so that I could also take full responsibility for the monograph.

6. **I became a coauthor because someone wanted to do me a favour!**

Frank—I have some good friends and former coworkers in Prague, the Czech Republic. They wanted me to come to Prague for a visit, in part to pay me back for my hospitality to some of them in Edmonton. They were unable to pay for my travel costs to Prague, so they put my name as a coauthor on some poster papers, which I did not even understand, and they snuck me

into a conference of the European Physical Society, for free.

Ethics? I have never claimed the papers on any of my publication lists. I was also already retired and unfunded, so I could not charge the costs of the trip to any grant. I accepted the honours, limited as they were, from a grateful bunch of physicists whom I enjoyed meeting again. The conference coincided with a family visit to England, so the extra travel expenses I incurred were small.

But then there is the possibility of future favours from potential coworkers or someone with influence on a granting committee. It has happened that such name(s) appear on a paper "for future consideration" without their having done any of the work. Payoff? Possibly. Ethics? Zero.

Wytze—I suppose I have bent some ethical rules in the past by including undergraduate students and once even a Grade 11 student as coauthors on research in which they played a minor part. But to see the pride on the faces of these students at having a paper published on which their name appeared seemed to me worth the slight bending of the rules.

7. I should be an automatic coauthor because I am the head of the laboratory (or the chairman of the department).

Frank—Hopefully, this item is of historical interest only. At the time of my own graduate studies, I noted that there were many, many papers in *Physics Abstracts* that included the name of a chairman of a well-known university. It was common knowledge that this person was head of the physics department there and that all papers from his department automatically carried his coauthorship. Enough said.

Wytze—I'm afraid this is not only historical. You only have to Google *fraud in science* (even in physics) to realize that most cases of fraud, falsification or fabrication of data are in papers with many authors, including the heads of laboratories. In general, the heads of laboratories have not been held responsible for the fraud committed. As I mentioned before, I would hold all coauthors fully responsible for such fraud. If this sounds harsh, you had better limit your name, as author, to papers you have contributed to and approve of fully.

8. I should be a coauthor because I am a member of the team.

Frank—In some fields of physics—and high energy/particle physics is a well-known example—papers have been published in which the length of the list of authors exceeds the length of the body of the paper. Yes, maybe one person or a small group of people had the idea. They, plus others, got the funds together. Then it took many more people, working for many years, to build the instruments, write the computer code, do the detailed theory and carry out the experiment. It is accepted that everyone even remotely connected to the project receives some sort of recognition, particularly because so few publishable results come out of long and costly experiments. There are rumours that they even give credit to someone who stayed out of the way and thereby prevented bad luck, or someone who walked by and things just happened to work better. The University of Alberta has built a small but highly complex detector worth a few million that eventually became an indispensable part of an experiment that costs hundreds of millions. Keep in mind that the U of A contribution was that of a highly skilled team working many months, if not years.

So who deserves the credit? There is an internal pecking order, and people who work in the field know who the real brains are and who should share in the Nobel Prize. However, even the minor actors who spend years on a subassembly need to get publication credits for their own advancement at their home institution. That is how it is done, and it is part of a large-team reward system that chairmen and deans have learned to accept.

Wytze—Deans may have learned to accept the situation, but it is still extremely difficult to know what significance to ascribe to such publications in tenure or promotion hearings. Here, more than anywhere else, an application for tenure or promotion needs external referee support from well-known and respected scientists before a dean or chair can feel confident in recommending a candidate.

We hope to address some other fraudulent practices in science in future issues, and we invite any reader to submit articles about the issue of scientific fraud or ideas on how to teach students the value of an ethical approach to science.

From Physics to the Bomb

A N Kamal

In the predawn darkness in the desert near Alamogordo, New Mexico, the first atom bomb was exploded. Thus, the era of nuclear weapons dawned at 5:29 AM on July 16, 1945. The explosion produced a ball of fire that could be seen 290 kilometres away. It was an experimental atomic bomb, code named Trinity, and it was made out of plutonium, an element that was not found in nature: it had to be synthesized through a nuclear reaction based on uranium.

On August 6, 1945, a high-flying B-29 bomber nicknamed Enola Gay dropped the first atom bomb in warfare, named Little Boy, on Hiroshima, Japan. More than 92,000 people were killed or went missing. Uranium, found abundantly in nature, was used in creating Little Boy. Three days later, Fat Man was dropped on Nagasaki, and killed at least 40,000 people. The core of Fat Man was made out of highly compressed plutonium atoms. The lingering effects of radiation sickness killed thousands more, and the accumulated death toll from the two explosions turned out to be 340,000 people.

On August 10, 1945, Japan opened peace negotiations.

The Story of the Atomic Bomb

The story of the atomic bomb is fascinating and yet regrettable.

In the 1930s, there was so much talk in the media about harnessing the energy of atoms that Ernest Rutherford, the father of nuclear energy, felt compelled to defuse these conjectures by calling them "moonshine."

Towards the end of 1938, Otto Hahn and Fritz Strassmann, German physical chemists, found that when a uranium atom was bombarded with neutrons (which had been discovered by a British physicist, Sir James Chadwick, in 1932), they were able to detect barium, which lies in the middle of the periodic table. This discovery was not recognized officially until January, 1939, when Lisa Meitner and Otto Frisch confirmed the results of the Hahn–Strassmann experiment. Meitner and Frisch interpreted the new phenomenon as the breaking up of the uranium atom into two roughly equal fragments, one of which was barium. What is more, Meitner and Frisch had developed a mathematical theory to calculate the energy released in the process, which they named nuclear fission. Their theory showed that each fission reaction released thousands of times more energy than was released in any chemical reaction. The result of the Hahn-Strassmann experiment and the explanation of it by Meitner and Frisch were important events in the development of the atom bomb and other uses of nuclear energy.

In 1938, a Danish physicist, Niels Bohr, the director of the Institute of Theoretical Physics, at the University of Copenhagen, came to visit the Institute for Advanced Study in Princeton, New Jersey, to discuss with Albert Einstein an arcane problem that had to do with the newly discovered theory of quantum mechanics. While Bohr was in Princeton, his European colleagues relayed the information about Meitner and Frisch's verification of the Hahn–Strassmann experiment. In early 1939, Bohr attended a large meeting of physicists in Washington, DC, and announced that Meitner and Frisch had proved without a shadow of doubt that the fission of uranium was experimentally verified. The effect of Bohr's announcement was so electrifying that even before he had finished his lecture, physicists rushed to phone their colleagues to urge them to reproduce the result of the experiment. Within days, nuclear fission was widely accepted as a real phenomenon.

Many questions quickly came to mind:

- What was the abundance of the heavier isotope (heavier type) of uranium, U-238, and of the lighter isotope, U-235, which was more useful in nuclear reactions?
- What about the speed of the neutrons? Do the neutrons have to be slowed down so they could be absorbed by the U-235?

- Were any neutrons emitted in the fission reactions?
- If several neutrons were emitted in one single fission reaction, would that be enough to set up a self-sustainable chain reaction?
- If a self-sustainable chain reaction could be achieved, could it be controlled to serve as an energy generator (ie, a nuclear reactor)?
- If the chain reaction was running out of control, would it release all the energy almost instantaneously, as in a bomb?

Enter Leo Szilard, a Hungarian émigré at Columbia University, New York City, who was overflowing with ideas and vigour. His forte was to spur others to action. Although research was progressing in several American laboratories in the first half of 1939, its scope and intensity were unsatisfactory, according to Szilard. He felt that in the interest of US citizens, the government should fund nuclear research at a higher level. He was motivated by the fact that many excellent scientists had remained in Germany, and the concern that if Hitler provided enough funds, the German scientists could perfect a nuclear weapon before the Americans. Accompanied by two Hungarian colleagues, Eugene Wigner and Edward Teller, he convinced Albert Einstein to write a letter to President Franklin D Roosevelt, urging support for nuclear research. Einstein's fame assured that the president would take the matter seriously and, indeed, a modest fund was initiated towards the end of 1939.

With America's entry into the war in December 1941, after the Japanese attack on Pearl Harbor, nuclear research and development projects received much more financial support. The goal of producing an atomic bomb was established, but the means to that end were still very uncertain.

The results of nuclear research were hopeful, and in 1942 the US government authorized the US Army to make an atomic bomb. The Manhattan Engineer District of the Corps of Engineers (for short, the Manhattan Project) was empowered to achieve this goal. General Leslie R Groves was appointed the director of the project.

General Groves, in turn, selected Julius Robert Oppenheimer, an eclectic liberal and devotee of Eastern philosophy (who learned Sanskrit and read the Bhagavad Gita, a sacred Hindu text, in the original language) to be the scientific head of the Manhattan Project. General Groves knew that Oppenheimer had dabbled in left-wing politics, as had many young intellectuals in the 1930s in England and Europe; later, Oppenheimer called his left-wing wandering an affectation. Even though there were questions about Oppenheimer's loyalty, Groves appointed him the project's scientific director in 1943. "He is the best person for the job," said General Groves. Oppenheimer also invited Linus Pauling to head the chemistry division of the Manhattan Project, but Pauling refused, saying that he was an ardent pacifist and had strong reservations about using science to develop such a devastating weapon.

By 1942, several elements of the atom-bomb jigsaw were beginning to come together: for example, understanding the necessary speed of uranium atoms, the conditions for achieving a self-sustaining nuclear reaction, and how to control the chain nuclear reaction. Until 1942, nuclear research was done at several universities and laboratories across United States; this clearly presented a problem of security. Groves and Oppenheimer proposed to centralize the research in a single secret laboratory. Thus, on a mesa near Santa Fe, New Mexico, the Los Alamos Laboratory was expeditiously built on the site of a private boys' school. There Oppenheimer assembled a stellar group of the top international physicists of the time, including Enrico Fermi, Robert R Wilson, James Franck, Victor Weisskopf, Hans Bethe, Edward Teller and Richard Feynman. Before joining the elite group of physicists it was obligatory for the scientists to become US citizens. Fermi, Franck, Weisskopf, Bethe, Teller and others did so; the British scientists, however, were allowed to keep their British citizenship. In the British contingent were Sir James Chadwick, the discoverer of neutron; Rudolf Peierls; Joseph Rotblat; and a taciturn theoretical physicist, Klaus Fuchs, a native of East Germany, who had become a British citizen in 1942.

After the war, Klaus Fuchs, the son of a Lutheran clergyman, was arrested in 1950 for espionage activities in Britain. He admitted to passing information to the Soviet Union and was sentenced to 14 years in Wakefield prison. After his release in 1959 for good behaviour, Fuchs returned to East Germany and became the deputy director of the Central Institute for Nuclear Research, Rossendorf. Fuchs led a scientifically productive life for many years and passed away in 1988.

In 1939 Joseph Rotblat, a citizen of Poland, went to Liverpool University to work with Sir James Chadwick. Early in 1944, he went to the United States to work on the Manhattan Project at Los Alamos, New Mexico. At a private dinner at the Chadwick residence in March 1944, he was shocked to hear General Groves saying, "Of course, the real purpose in making the bomb was to subdue the Soviets." By the end of 1944, when it became apparent that Germany had not been successful in the development of its own bomb, Rotblat asked to leave the project and returned to Britain. After the war, Rotblat shifted the focus of his research to medical physics and, in 1950, became a professor of physics at St Bartholomew's Hospital Medical College, at the University of London. In July 1957, Rotblat, having become interested in stopping the nuclear arms race, organized the very first Pugwash Conference, at the village of Pugwash, in Nova Scotia. The Pugwash Conferences were funded by philanthropist and Pugwash native Cyrus Eaton, and were designed to allow scientists and politicians from all countries to help plan nuclear disarmament. Rotblat served as secretary-general of the organization from its inception until 1973. At the inaugural meeting of the Pugwash Conferences, among the attendees were Leo Szilard—who had taken the initiative in writing the 1939 letter to President Roosevelt—and Victor F Weisskopf, who had worked on the atomic bomb. The Japanese Nobel Prize winner in physics, Hideki Yukawa, was also present.

In 1995, the Pugwash Conferences and Joseph Rotblat were jointly awarded the Nobel Peace Prize.

In 2003, at the age of 94, Rotblat presented a paper titled "The Nuclear Issues: Pugwash and the Bush Policies" at the Pugwash Conference, in which he castigated the policies of the George W Bush administration. He died on August 31, 2005.

The Physics Behind the Bomb

Enrico Fermi, a native of Rome, was awarded the 1938 Nobel Prize for physics, in Stockholm. He used the occasion to emigrate from his home in fascist Italy to the United States, together with his Jewish wife and family, and became a professor of physics at the University of Chicago. In December 1942, he and a small dedicated group of scientists and engineers got together to demonstrate, by building the first nuclear reactor, that it was possible to achieve a chain reaction. The first reactor, the so-called Chicago Pile-1, was large—9.75 m long, 5.65 m wide and 6.1 m high—and it needed a lot of space. It was, in fact, built on a disused squash court under the football stadium of the University of Chicago. A team of scientists assembled the pile by stacking graphite bricks and drilling holes in the bricks at places that Fermi had carefully calculated. Finally, they filled the holes with lumps of uranium and introduced a few wafers of cadmium so that they could be inserted or withdrawn, as required. The purpose of cadmium wafers was to control the nuclear reaction: cadmium absorbs neutrons and could shut down the reactor if necessary. Fermi's reactor was really an experimental one to study the properties of uranium and its isotopes and to synthesize other exotic atoms.

Several problems had to be resolved before an atomic bomb could be made. First, the naturally occurring uranium contained 99.3 per cent of U-238 and only 0.7 per cent of U-235. Bombarding U-238 with neutrons demonstrated that U-238 would transmute into another isotope of uranium: U-239. Finally, through an intermediary process of radioactivity, it turned into plutonium-239. Pu-239 was fissile (fissionable) material, and could be used in producing an atomic bomb. Moreover, uranium was the only element that was fissile and could still be found in nature. Pu-239 was not found in nature, since its lifetime was short enough that any plutonium present when the Earth was formed had already decayed naturally; it had to be synthesized.

U-235 was also capable of undergoing nuclear fission readily and yielding extra energy. In the nuclear physicist's parlance, U-235 was a fissile material, which was needed to construct a nuclear reactor or to make an atomic bomb. To increase the percentage of U-235, natural uranium needed to be enriched by using processes such as diffusion, centrifugation and several other methods. In the case of the Chicago Pile-1, U-235 was enriched up to 26.5 percentage purity. If uranium were enriched up to the point of 90 percentage purity, it could be used in making an atomic bomb.

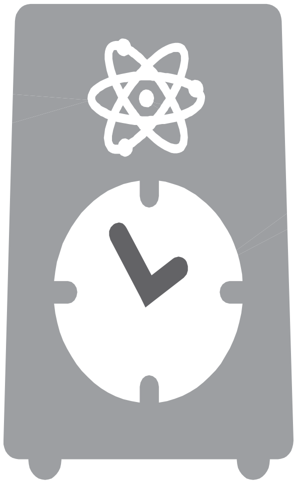
Fermi and others showed that by hitting an atom of U-235 with an initial neutron, three things occurred:

(1) U-235 broke up into several smaller pieces.
(2) Each reaction ejected at least two extra neutrons.
(3) Each reaction produced energy in the form of heat.

The key to running a self-sustaining chain reaction was to provide just the right conditions such that the second generation of neutrons would collide with other U-235 atoms rather than escape the reaction domain. If these conditions were met, the number of neutrons would multiply quickly, and the rate of energy production would rise proportionately.

These just-right conditions could be extrapolated into the total mass of fissile material. The minimum mass of fissile material needed to support a self-sustained nuclear reaction is called the critical mass in a nuclear reactor or in an atomic bomb. More precisely, the critical mass of a reactor implies that it is producing power at a constant rate, and the temperature and the number of neutrons remain constant, too. (Considering a spherical geometry, the critical mass of U-235 is about 50 kg and of Pu-239 approximately 10 kg.)

A subcritical mass cannot sustain a chain reaction. In such a case, the rate of nuclear reactions will decline and the temperature of the fissile material will return to room temperature. If a subcritical sphere of fissile material were detonated, it would be called a dirty bomb, due to an incomplete fission process. Depending on the size of the explosion and some other parameters, it could spread radiation debris around a large area, kill or damage living plants, animals and human beings, and cause cancer; the subsequent fallout would fall on earth for years.



A mass of fissile material larger than critical mass is called a supercritical mass, which is what is necessary to make an atomic bomb. Since a supercritical mass of fissile material would blow up spontaneously, it was necessary to assemble the bomb in two parts such that each part had less than critical mass. A triggering device was used to bring the two parts together. The uranium bomb, Little Boy, used a gun-type trigger. The plutonium bomb, Fat Man, employed an implosion-type trigger.

The Atomic Bomb

During April and May, 1945, two far-reaching events came to pass. First, in the afternoon of April 12, 1945, the vice-president of the United States, Harry Truman, was summoned to the White House. Mrs Eleanor Roosevelt met him and said, “Harry, the president is dead.” At 7:09 PM, Truman took the oath of office. Second, Germany surrendered, and the atomic bomb designed to be used on Germany was no longer needed for that purpose.

Following the end of the war in Europe, President Truman went to Potsdam, Germany, in July, for talks with Prime Minister Winston Churchill, of the UK, and Communist Party General Secretary Joseph Stalin, of the USSR. While in Potsdam, Truman received news that American and British scientists had successfully tested an atomic bomb at Alamogordo, New Mexico. While he was on his way home, against the advice of scientists like Leo Szilard and James Franck—and even of General Eisenhower, the Supreme Allied Commander—Truman, to hasten the end of the war and to demonstrate America’s superior weaponry, ordered American pilots to drop the atomic bombs on Japan.

The first bomb fell on Hiroshima on August 6, 1945. Three days later, the second atomic bomb dropped on Nagasaki. One day later Japan opened peace negotiations, and the war ended on August 14.

And the Cold War began.

The Bertram Millsap Series

Millsap and the God Particle

Wytze Brouwer

"I'm tired, Brouwer, I can't go any farther."

Predictably, Millsap was tired. We were on a long weekend visit to the Rockies and, while our wives were enjoying tea at Chateau Lake Louise, Millsap had been adamant about hiking around the lake and up to the Plain of the Six Glaciers. Geri and I had done the hike many times, but I was rather skeptical about Bert's ability to complete the hike.

"OK, Bert, let's just sit down on a log and rest awhile. We're almost a third of the way." We might have been a third of the way, but the next two-thirds was uphill all the way.

Bert had been on a fitness kick for a while now, and he had actually impressed me by being able to go to the first of the Johnston Canyon waterfalls the day before. Still, many decades of neglect and 40 pounds of extra flesh do take their toll.

We found a pretty sizable log, and I searched through my backpack for something to drink and a cookie or two to regenerate ourselves. Meanwhile, after much effort, Millsap managed to cross one leg over the other and leaned his back against the side of one of the mountains. He was getting comfortable and settling in for the duration.

"We can always tell Helen and Geri that we hiked all the way to the teahouse, if we time our return properly. Let's say we sit here for an hour and a half and then walk back; we should be able to convince them we actually did it." I trust that the reader realizes this was Millsap and not me (or I) that came up with that subterfuge.

"Sorry, Millsap, I hate to be a spoilsport, but I will not lie for you, at least not when I know they won't believe us."

"Well, if you won't support me, you won't, I guess. But I want to ask you something about what we were talking about yesterday. Here, little squirrel, have a bite."

Here Millsap was referring to an article in the *New Scientist* about the "God particle," which was described in the article as the final answer to the structure of matter in the universe. The article had set Millsap off on one of his favourite rants about the arrogance of physicists. And I suppose, for the readers' sake, I had better bring them up to date. As far as I can remember, we had been sitting around the fire in our cabin and Millsap, taking a deep swallow of the inexpensive Merlot we were drinking, went on:

"Who do they think they are? Do they seriously believe that physicists in the 21st century might be close to the final theory of matter and that scientists in the distant future would have nothing to do but to fill in an extra decimal place?"

I had a lot of sympathy for Millsap's position, but I couldn't let him know this, at least, not yet.

"But Bert, if scientists at CERN, or one of the other accelerators, actually find this elusive particle, they will be able to explain why protons, neutrons, electrons and all the other particles have the masses they have. Isn't that a pretty impressive accomplishment?"

"Why do physicists feel the need to explain why particles have the masses they have? Some things in nature just are. There are always going to be some fundamental facts physicists just have to accept. Human beings are part of nature and can't step outside and explain everything."

This was still part of yesterday's discussion, because Millsap still wouldn't have enough breath to complete a speech of this length after our hike. So, back to the present. The little chipmunk—not squirrel—smelled the crumbs Millsap had offered it, turned up its nose, and went off to greener pastures. Millsap was a bit miffed, as if the insult were personal, but turned back to me.

"I thought a lot about our discussion yesterday, Brouwer, and I am going to make a prediction: PHYSICISTS WILL NOT FIND THIS PARTICLE!"

"Wow, Millsap, that's going out on a limb. They expect to have definite evidence before the end of '08 whether the particle exists or not."

"Then you should be willing to risk 100 bucks on it, Brouwer. I say they won't find it, you say they will; it's a simple bet."

"Well, not actually so simple, Bert. The predictions are that the Higgs particle should itself have a mass of 100 to 300 times the mass of a proton. But if they don't find it in this range, they may have to look outside this range."

"Well, I'm easy—I'll give you this whole range. I bet that physicists don't find this particle in the range of 100 to 300 times the proton mass. You bet they do. You should actually give me odds, but I'm so confident, I'll waive the odds."

So here, sitting on a path overlooking a beautiful mountain lake, seeing some of the six glaciers still far above us, Millsap had decided that nature would not allow physicists to get to know its ultimate secrets. It's funny, you know, but most of my colleagues not directly in the subatomic physics field secretly, and not so secretly, hope that Millsap's conclusion is correct. If physicists found the Higg's boson more or less where they expected to find it, the standard model of matter would seem to be essentially correct, and some basic questions would be answered. But if physicists did not find the Higgs particle, then the standard model would be basically flawed and the elementary particle field would suddenly be wide open for other theories and hypotheses. And I share some of Millsap's feelings—it might well be a disaster for physics if too many of the fundamental questions of nature were answered in our generation.

But a more important question is: Should I tell Millsap that I secretly share his views, that I hope he wins the bet, and not me? There is, after all, a lot of other evidence that the standard model might be flawed. In particular, physicists now believe that we see only about 4 per cent of all the matter in the universe, that there is another type of matter that is responsible for the shape of the galaxies and the expansion of the universe. So we actually know less about the universe today than we thought we knew thirty years ago. At times like this, I appreciate Millsap. I may not always agree with him, and he doesn't look like a great scientist, but he has a pretty good mind on him.

His feet are another matter, however, as he has just removed his socks and shown me the beginnings of some major blisters. I think we had better head back down the mountain and walk around the lake again. Maybe I will back Millsap up if he insists on pretending we had actually made it to the Six Glaciers. And if I win the bet, Geri and I will take Bert and Helen out for a nice dinner at the Faculty Club. If Millsap wins, well, I've overcome greater disasters in my life and I will even live that down in a few years.

Millsap and the Grumpy Physicist

Wytze Brouwer

Millsap and I had settled into the routine of a new academic year, our hikes in the Rockies well behind us. As Millsap wandered into the Faculty Club after his late Wednesday lecture, we all greeted him with a fond wave. I noticed, by the speed that he approached us, that the blisters he had contracted on the hikes had almost healed. Or, as became more probable, he had something on his mind.

I had always had the fond hope that Millsap would take up poker. His emotions were so evident in his facial expressions that a dependable source of income could be obtained by challenging him to a game. However, the only bet I currently had with Millsap was on his prediction that physicists would not find the Higgs particle, the so-called God particle, whose existence would explain why all other particles had mass. Outside of such wild intellectual predictions, Millsap was not a gambler.

Bert was so steamed this afternoon that he just ordered a pint of draft, the first time in recorded history that he had changed his order from his usual Rosemary Sunset.

"What's up, Bert, did you have a difficult class?" Jenny Platt, our biology regular at our table near the window, smiled in anticipation of the usual entertaining session when Bert was in a snit about something.

"I've got a bone to pick with Brouwer." Millsap looked at me accusingly. As usual, I had no idea what I might have done to irk my colleague from the psychology department, but I was willing to learn.

"What have I done, Bert, to have you look at me as if you want me to sink through the Faculty Club floor?"

"Don't be facetious, Brouwer! You physicists don't appear to have even the smallest concept of consideration for other people."

How do I answer Bert? Such a global judgment is difficult to refute. I have always been of the view that physicists are generally fairly kind and helpful people, but I'm sure I will learn about someone who fell well outside the norm.

"You know, Brouwer, that Helen is involved with the Polaris theatre group that is putting on Durrenmatt's *The Physicist*?"

"Yes, I've been looking forward to seeing it. It's one of the most interesting plays I've ever read."

"Well, Helen thought it would be nice to have a few scientific instruments on the set to give it an appearance of a lab where some actual science is done. So she phoned one of your colleagues, Dr Helmut Springer, to ask if he could suggest some equipment that she could borrow. Guess what he said."

"Well, Dr Springer is one of our grumpier physicists, and I imagine he didn't want to spend any of his valuable time helping your wife."

"Exactly! He was extremely rude, and complained about his time being wasted by people who had no business calling him. I have a good mind to report him to the dean."

"What can I say, Bert? I sympathize with Helen, but Dr Springer is close enough to retirement that he isn't going to care what the dean says. By the way, why didn't Helen call me? I have some excellent colleagues in experimental physics who would love to help with some equipment."

"Well, Helen will probably call you, but you must admit that I've run into more arrogant or impolite physicists than in any other discipline."

"That's because you stick your nose into physics more than into any other subject. Try some of my colleagues sometime. I'm sure they can be just as rude to you as Brouwer's colleagues." I'm not sure if Jenny's comments lifted Bert's spirit much, judging by his response.

"I'm willing to bet that you could find more grumpy physicists than grumpy psychologists or even biologists."

"Well, now you've raised the conjecture to one that could be tested, but I doubt if there is any agency that would fund it," was my response. "Maybe the US Department of Defense. They've sponsored some weird research projects in the past. I personally know of only one historical episode of an arrogant or rude physicist who won a Nobel Prize. Well, maybe two." Actually I didn't want to think too hard, because quite a number of our Nobel laureates in physics have had their less-than-tactful interactions with their public or with colleagues.

"Tell us, Brouwer, we'd like to know what physicists consider rude."

"Well, this episode took place in around 1896, in Holland. A graduate student, Pieter Zeeman, wanted to do a PhD with a professor Kamerlingh Onnes, at the University of Leiden. Zeeman had an idea for research that Onnes didn't think much of. Zeeman wanted to see what happened to the spectrum of a sodium flame when you put it between the poles of a strong magnet, but only Kamerlingh Onnes had magnets that were strong enough. And he wouldn't let Zeeman waste his time doing unimportant research. However, as so often happens, Professor Onnes went to speak at a conference and Zeeman had the lab to himself for three days! So he borrowed the magnets and studied the sodium flame when it was inside the magnetic field, and what he had expected actually happened. The spectrum line spread out to about four times the thickness and Zeeman thought that in stronger magnetic fields it might even split into several spectral lines. So he eagerly waited for Professor Onnes to return. And guess what?"

"I guess it's your turn to buy the next round. I'll have a Rosemary Sunset this time."

Well, it was a bit expensive, but an indication that Bert had calmed down somewhat. They seemed ready to go on to another topic, but I wasn't going to let them get away without finishing my story.

"Do you guys want me to finish the story or not?" And before waiting for an answer, I continued. "Young Pieter explained what he had done and how excited he was about the potential of the discovery, but Onnes looked at him stonefaced and said, 'I want you out of here by noon. I will not have my graduate students disobey me and borrow my equipment without my consent.' So young Zeeman had to find another place to do his research; he got accepted in Amsterdam and continued his own research with more powerful magnets. And in 1902 he was awarded a Nobel Prize in Physics."

"What an arrogant bastard this Onnes must have been. I guess justice does triumph once in a while."

"Well, yes, there was some justice, but Kamerlingh Onnes won his own Nobel Prize in 1913. He may have been arrogant or grumpy, but he was an excellent physicist. Even great physicists can be wrong sometimes."

"Often, Brouwer, often," was Millsap's summary.

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