Chemical Heritage Foundation

Discovery in Our Classrooms: Inquiry and the Nature of Science

LISE5

The 5th Annual Leadership Initiative in Science Education

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CHEMICAL HERITAGE FOUNDATION

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INTRODUCTION

The annual Leadership Initiative in Science Education (LISE) conferences at the Chemical Heritage Foundation (CHF) have been a forum for promoting discussion among all stakeholders in science education—science-based industries, universities, professional organizations, government agencies, teachers, and other important policy makers—to offer ideas that have immediate value and application. Twelve nationally known speakers attracted more than 110 educators, industry leaders, science professionals, museum experts, and government representatives to CHF on 27–28 April 2005 for the fifth annual LISE conference. The theme for LISE 5 was “Discovery in Our Classrooms: Inquiry and the Nature of Science.”

“Inquiry” and “nature of science” were chosen as a dual theme because they are closely related but distinct issues in teaching practice. The conference brought together expert speakers who examined the relationships between how science functions and how students can best learn science.

Inquiry-based techniques are student-centered pathways to understanding important science concepts. An increasingly large body of evidence points to such techniques as the best approach to science learning. Since inquiry-based instruction not only enhances students’ understanding of the content of science but also helps them understand the nature of science, the second focus of the conference was on how the characteristics inherent in science knowledge can be taught. Combining inquiry with the study of the nature of science enables students to learn about the cultural circumstances of the practice of science, the development of professional standards by which scientists conduct their enterprise, actual working practices in science research and industry, the history of science, and the relation-ship between scientists and society.

Among the other issues raised at the conference were the professional development of science teachers, the role that history plays in the nature of science, how museums and science centers can enhance science inquiry, the inclusion of students with learning differences, and how industry and other organizations can support inquiry education.

THE NATURE OF SCIENCE

What Is Science?

When asked to define science, a kindergarten student responded by saying, “Science is real hard. Harder than reading. We’re not allowed to have it in kindergarten.”

In his LISE 5 keynote address Norman Lederman, chair and professor of mathematics and science education at the Illinois Institute of Technology, offered a broad definition of science. Science is a body of knowledge . . . the things that fill our textbooks . . . the things we spend too much time having our students learn. It is the concepts, theories, laws, and ideas. But in addition to knowledge, Lederman pointed out, science is also a process, or method. It is the way scientists go about developing that body of knowledge, a process that is often referred to as scientific inquiry. He emphasized, though, that there is no single scientific method. There is no single set sequence of steps that is followed in all scientific investigations, which, in Lederman’s opinion, is one of the biggest misconceptions regarding science.

William McComas, an associate professor of science education in the Rossier School of Education at the University of Southern California, also offered his definition of science. Science explores and addresses questions about the natural world leading to valid and reliable generalizations and explanations, using methods of investigation and producing evidence open to review by others. It is an empirically based and empirically derived pursuit. He said, "You can have all the opinions you want, but if you don't have evidence, you don't have science."

Defining the Nature of Science

Norman Lederman defined the nature of science as "the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge." According to Lederman, these assumptions include a variety of ideas: that science and scientific knowledge are empirically based, tentative, testable, creative, amoral, and culturally and socially embedded; that they require freedom of inquiry, speech, and dissent and independence of thought and observation; that they value originality, tolerance, and mutual respect; and that they require a unified view of reality.

These assumptions about the enterprise of science were echoed by other speakers, and several emphasized the importance of evidence, tentativeness, and creativity as well as the effect of cultural factors on the way scientists function.

Teaching the Nature of Science

Is it possible to teach the nature of science to students? Is there a way to reduce the broad definition of the nature of science in a practical way? Both Lederman and McComas agreed that not only is it possible to teach K–12 students about the nature of science but that it is essential to do so. Lederman recommended focusing on the basic characteristics of the scientific knowledge that students can actually be expected to learn, and he offered this "short list" of ideas, taken from his assumptions above, that are important for students to understand.

- Science is tentative (under some conditions something may not behave the way it had always behaved before).
- Science is creative (data can be organized in different ways).
- Science is subjective.
- Science is socially and culturally embedded (science affects and is affected by society; it does not occur in a vacuum).
- Science is empirically based (scientists collect data and make observations).

In addition to these characteristics are two concepts that many students and teachers fail to understand. Both Lederman and McComas urged that the distinction between theory and law and between observation and inference be taught correctly. Both stressed that knowledge in science is inferred from the data available through observation. Both also agreed that laws generally identify relationships among observable phenomena and theories are usually inferred explanations of what has been observed.

McComas also emphasized three additional points: that while knowledge production in science shares many common features, there is no single scientific method; that science and technology are not the same; and that science and its methods cannot answer all questions.

Understanding the nature of science, both Lederman and McComas emphasized, is an issue of science literacy not only for students but also for the general public. Understanding how science is done is knowledge that can help the general public make sense of the many concepts and claims and pseudo-information they are constantly being subjected to throughout their everyday lives.

Lederman and McComas both proposed that the nature of science be a bigger part of the curriculum. They strongly suggested that teachers should be knowledgeable about the nature of science to ensure that students are getting the right messages about how science really works. Students need to understand how knowledge is created in science, and their teachers must be able to show them. Since the majority of science teachers have not been professional scientists, they do not have firsthand experience with how knowledge is created in science. It is up to science educators to help the science teaching community achieve this understanding.

Both McComas and Lederman strongly advocated that students should be able to engage in scientific processes and also be able to understand the processes. Both noted that unless teachers explicitly require students to understand concepts about the nature of science, the students will not learn them. In years past, Lederman noted, teachers assumed that students would understand the nature of science implicitly by doing hands-on investigations, but that approach has been discredited.

The explicit approach, advocated by Lederman based on the significant amount of data he has collected that shows this approach is successful, treats the understanding of the nature of science as cognitive outcome, not as a by-product. This is important, Lederman said, because students are learning skills and mental abilities that they can carry out of the classroom; they are basically learning how to learn.

With the explicit approach students are also learning how scientists developed the ideas that are being taught in the classroom. Students must understand that when scientific knowledge changes, it does not mean that scientists do not know what they are doing or that they are not informed. Scientists are able to change their ideas as additional evidence comes along. That is the way science operates.

McComas elaborated on the basic principles of the nature of science that teachers need to know to teach both inquiry and the nature of science to students effectively.

- Science is an empirically based and empirically derived pursuit. A scientist can have all the opinions he or she wants, but if there is no evidence, it is not science.

- While scientists do many things the same way, there is no single shared standard and universal scientific method. There is no step-by-step route that scientists can take that will lead them to guaranteed results; they do not get up in the morning and say, for example, "Today I shall define the problem."

- To be an effective scientist takes intuition. There is a creative step involved, a non-logical leap from facts to scientific ideas.

- Science has a strong creative component. One of the reasons that many students do not pursue advanced science in college, even though they are capable, is that they see science as noncreative.

- Science is subjective. Everyone looks at the world through his or her own lenses.

- Social, cultural, and political influences on science help explain why certain kinds of science are not done in this country and why other countries do not have a problem with certain kinds of science.

- Science and technology influence each other, but they are not the same. Most students today cannot answer the question, "Who is the scientist, Einstein or Edison?"

- Science and its methods cannot answer all questions. Knowing the limits of science is almost as important as knowing what science can do.

INQUIRY-BASED SCIENCE EDUCATION

Essentials of Inquiry

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

(National Research Council, *National Science Education Standards* [Washington, DC: National Academy Press, 1996], 23)

In his presentation Lawrence Lowery, a professor emeritus at the University of California, Berkeley, pointed out that there is one major condition that triggers inquiry in humans. That condition is a discrepant event, a set of circumstances that causes the brain to become curious about the anomaly. While scientific investigations may all begin with a question, there is no single set or sequence of steps that is followed in every scientific investigation. In fact, scientists performing the same procedures may not even get the same results.

Inquisitiveness about their surrounding world, Lowery emphasized, is one of the major traits that differentiate humans from other animals. Early humans, being advanced primates, were wanderers. The only way they could survive was to inquire into places they had never been before, to check out the discrepancies and the novelties of those places, and by those interactions to either survive or not. Those who adapted well, survived well.

By considering survival as the beginning basis for the aspects of inquiry, Lowery asserted that these aspects are now prewired in the human brain. Children do not need to be taught to observe, but they do need to learn how to observe carefully and not subjectively. The ability to communicate and to make comparisons is also built in to the human brain. The ability to organize, Lowery emphasized, is the ability that differentiates humans from all other creatures, and at higher levels organization is a defining aspect of inquiry.

Lowery discussed the work of the National Science Foundation (NSF) on developing curriculum that involves students in thinking about science rather than just passing along information—programs that involve students with the ways in which scientists find out about the world. These programs are usually described as hands on, but they tend to be inquiry-based programs.

Lack of a common definition of what constitutes inquiry, however, has been an obstacle to teaching it, according to Lederman. Teachers need more concrete examples of what is meant by inquiry. How should they do it in their classrooms; how should it be assessed; how can they get students to ask questions? Several LISE 5 speakers offered their models for teaching inquiry, which are described throughout this publication.

Most LISE 5 speakers agreed that inquiry is the best way for students to learn science. Frequently mentioned essential elements of inquiry are questioning, observing, classifying, measuring, interpreting, inferring, and predicting. Lederman emphasized that inquiry means performance—in other words, students doing things: developing questions, collecting data, analyzing data, and coming up with conclusions. As he put it, it is all in the verbs.

Teaching Inquiry

The objective of inquiry-based teaching is to teach so that students learn science in the same way that scientists learn their science. Inquiry becomes what the students do. By actually doing inquiry and by combining this with scientific reasoning and critical thinking, students develop scientific knowledge.

By showing students a discrepant event, as described by Lowery, the anomaly will arouse their curiosity. They will ask, "How come? What is that? Let me get ahold of it. Let me fool around with it." They will want to investigate it. This is how inquiry begins for students. Teachers can set this up artificially, or students may generate it themselves just by being involved. Research that looks at curiosity in the classroom shows that not everyone is curious about the same thing, nor is everyone equally curious about anything. When teachers involve students with different levels of curiosity, a positive crossover of approaches to answering the same question can occur.

Lowery also discussed the ways in which research on the brain provides greater insight into how people learn. He illustrated the positive effects that multisensory experiences have on the human brain. The brain stores a record of the neural activity that takes place in the learners' sensory and motor systems as they interact with their environment. Each record is a pattern of dendrite-synapse connections among brain cells (neurons) that can be reactivated to recreate the component parts of the experience. For the brain to construct knowledge and behaviors, it must take in data, and the only way the brain takes in data is through the sensory perceptions of the body's five senses.

The most powerful way, Lowery said, to get knowledge into the brain is through firsthand experiences so fundamental to inquiry learning. In education these are called concrete experiences. Of course, students cannot learn everything firsthand. Much of their knowledge must come from secondhand information. Secondhand experiences are valuable (students can learn about places they have never been and about things they have never seen), but they are not as powerful as firsthand experiences. Firsthand knowledge also can enhance what is learned through secondhand experiences.

Lowery emphasized that one of the real powers of inquiry is the building of brain pathways. This is because dendrites are only generated under two conditions: fright and curiosity (and he did suggest that it is much better to make students curious than to frighten them). Inquiry experiences allow many pieces of information to go in, and the more pieces stored, the greater the recall and the deeper the understanding.

McComas supported many of Lowery's insights by reinforcing the idea that science teaching comes from a number of perspectives. There must be knowledge of science content—and in higher education many professors think this is all you need—plus there must be a knowledge of effective classroom practice and of the psychology of how people learn.

The point was also made that the concept of the nature of science and scientific inquiry is not automatically translated to classroom practice. So how can a functional understanding of these concepts be communicated? Lederman confirmed that research does not support the idea that by doing science students will come to this understanding. Learning outcomes are primarily skills based. What is effective is an explicit approach that treats the understanding of the nature of science and inquiry as cognitive outcome, not as a by-product.

Inquiry also means knowledge, said Lederman. As an instructional outcome of inquiry, students must come to understand what they are doing. Students can be taught to design an experiment and to put in a control group, and they can learn to do it very well. But they also need, for example, to understand why they need a control group, other than just that they have been told they should have one. Students need to be able to step back and reflect on inquiry; they need to know what it means.

Lederman went on to state that the goal of improving students' views must be planned for, taught, and assessed. Instruction should be geared toward various aspects of the nature of science and scientific inquiry and should use elements from the history and philosophy of science. Reflection that connects aspects of the nature of science and scientific inquiry to classroom activities and the activities of scientists needs to be encouraged.

The National Science Education Standards make strong recommendations about how to teach science through inquiry, based on its definition of the nature of science, which incorporates the general themes presented by both Lederman and McComas.

- Science is a universal human endeavor.
- Scientific ideas are tentative.
- Core ideas in science are confirmed by experiment and observation.
- It is normal for scientists to differ with one another during periods of active research.
- Skepticism, questioning, and open communication are essential in science.
- Scientific explanations must be consistent with evidence, make accurate predications, include logical structure and rules of evidence, and be open to criticism. (National Research Council [Washington, DC: National Academies Press, 1996], 148)

One of the most important things that can be done to instill inquiry in students, Lowery said, is to give them opportunities to practice what teachers want them to be able to do. For example, inquiry labs where students are asked to work on their own should be initiated. Then practice time needs to be provided at the point when the students have built up confidence and are freer and when safety issues are fewer. Making practice time available requires a slow start, but it needs to be consistently employed. It can actually take years to get students ready to do high-quality inquiry because it is a process with multiple components requiring time to teach.

Learning outcomes are different when the teacher asks the questions as opposed to when students ask them in an environment in which those questions can be answered. The students should be considered the center of the instruction, not the teacher.

Models of Inquiry

As noted above, one of the problems with promoting inquiry learning is, as Lederman pointed out, that there is no uniform agreement on what constitutes inquiry methodology in the classroom. In their comments at LISE 5, Lowery, McComas, and Lederman developed their models of student inquiry by setting out essential features of the inquiry process. In addition to these models, or descriptions, of inquiry, three other models were discussed: Process Oriented Guided Inquiry Learning, or POGIL; the Exploratorium's Institute for Inquiry model; and the University of Pennsylvania's Penn Inquiry Model, or PIM. These methods of inquiry are described in later sections of this paper.

The Process Oriented Guided Inquiry Learning Project

POGIL is based on the premise that students learn better when they are actively engaged, when they are encouraged to construct knowledge and draw their own conclusions by analyzing data and discussing ideas, and when they are able to work together to understand concepts and solve problems. As presented by Rick Moog, a professor of chemistry at Franklin and Marshall College and the principal investigator for the NSF-funded National Dissemination project in POGIL, in a three-hour preconference workshop, POGIL is a classroom and laboratory technique that seeks to teach chemistry content and key process skills simultaneously, including the ability to think analytically and work effectively as part of a collaborative team.

A POGIL classroom or lab consists of students working in small groups on specially designed inquiry materials. These materials supply students with data or information along with a series of leading questions designed to guide them toward the formulation of their own valid conclusions. The instructor simply serves as facilitator, observing and periodically addressing individual and classroom-wide needs.

The foundation for POGIL is specific research that has shown that teaching by telling does not work for most students, that students who are part of an interactive community are more likely to be successful, and that knowledge is personal. Students enjoy themselves more and develop greater ownership over the material when they are given an opportunity to construct their own understanding.

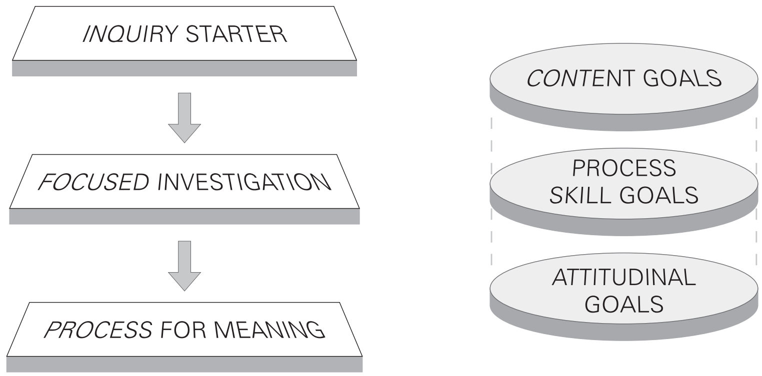
INQUIRY IN INFORMAL SETTINGS

Inquiry in Museums and Science Centers

The National Science Education Standards note that inquiry based on authentic questions generated from student experiences is a central strategy for teaching science. A museum is one of the few places that teachers can go and actually see and feel the reality of this statement. Exhibits can be used to engage the learner in unexpected or counterintuitive events. They draw the learner deeper into the phenomena. They can be used as entry points for teachers to generate questions and to provoke central dilemmas for more structured activities that can be used as a follow-up in a museum classroom.

Lynn Rankin, director of the Exploratorium's Institute for Inquiry, a national professional development center for K–8 leaders and practitioners of elementary science reform efforts, explained that an experience at a museum or science center can be used as an "inquiry starter." Students' observations generate questions, and curiosity develops. This is followed by a focused investigation where materials are gathered, a plan is generated, and purposeful exploration—measuring, predicting, testing, retesting, making models—is done. Then there is processing for meaning—formulating the content of what has been learned, through sharing and demonstrating. These steps are essential to the inquiry model developed at the Institute for Inquiry at the Exploratorium.

STRUCTURE OF INQUIRY



Source: Lynn Rankin, From the Exploratorium Institute for Inquiry. www.exploratorium.edu/ifi, ©Exploratorium

Institutions such as the Exploratorium, Rankin noted from extensive firsthand experience, provide an active, engaged atmosphere of curiosity and wonder, and this stimulating atmosphere is infectious and spreads rapidly. Being a part of this type of culture is liberating for teachers. All around them the exhibits themselves are models of innovation, imagination, and creativity—critical ingredients in the endeavor of science.

One particularly salient feature is the social dynamic that occurs in a museum. As illustrated by Rankin, in a museum learning is visible. Teachers can actually see learning as it happens when they watch people engage with exhibits. People teach each other, and they can be of any age, with the learners becoming teachers and the teachers becoming learners, which in itself provides a novel way of thinking about teaching.

The Institute for Inquiry provides a program for teachers and professional developers where they learn firsthand about inquiry. Participants spend a minimum of sixty hours in the professional development program at the Institute of Inquiry. They then have the additional opportunity to come back to attend graduate seminars. Course titles in the program include “Fundamentals of Inquiry,” “Formative Assessment and Inquiry Learning,” and “Classroom Strategies for Inquiry.”

The following quote offered by Rankin helps sum up the advantages and value of inquiry, in both formal and informal settings. At the same time it is a powerful representation of the enterprise of inquiry, not just the process of scientific inquiry itself but also how to teach it.

I think our instruction has been single-pathed. You're in a forest. You walk carefully along the path, and you reach the chest of doubloons on the other side and solve the problem. And that is the way we, I, too, teach physics. But the kids that try it get lost at each turning of the path. The trouble is that they think there is only one safe path, that they have to stick to it as close as they can, and they're afraid to go off into the deep woods. I think that the o nly way to teach path finding is make them get lost many times, to make all the false starts, to try out all the alternatives. Of course, you can't learn many paths that way, but you can learn a way of going down a path. Then, if some-one gives you another start, you might be able to find a way through yourself, hopefully, some other time.

(Philip Morrison, "Less May Be More," *American Journal of Physics* 32, no. 6 [June 1964]: 441)

PROFESSIONAL DEVELOPMENT

How Can Inquiry Be Taught to Teachers?

McComas and Lederman both strongly recommended that teachers be knowledgeable about the nature of science. The subtlety of the language and of messages that are communicated to students about how science really works can have a profound effect on the students' understanding of the bigger picture of how knowledge is created in science.

The process of teaching inquiry is complex, and teachers need a certain amount of professional development and follow-up support to make the transition. Enhanced science teaching comes from a number of perspectives: knowledge of science content, effective classroom and teaching practices, and how students learn at different levels.

The elements required for high-quality professional development in inquiry, according to Lynn Rankin, include transformative experiences (vision and motivation) and translatable experiences (practical application). Transformative experiences create a change in thinking about the nature of science and about the nature of teaching and learning. Translatable experiences develop usable knowledge and classroom strategies.

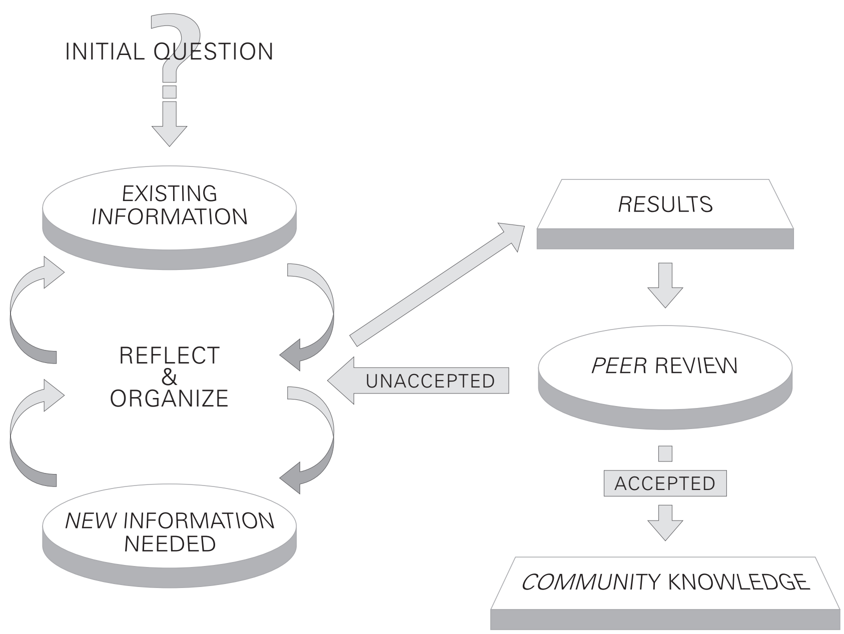
A translatable experience, Rankin said, initiates the transfer of ideas to teachers, and from teachers to their classrooms. One way of accomplishing this is to deconstruct the inquiry experience—the anatomy of the inquiry, the role of the materials and the facilitator, and the structure. The structure, which mimics the inquiry process, is also a platform that teachers can use to design their lessons. A teacher with the vision of inquiry understands that all these components are important when they design their lessons—that content goals, process goals, and attitudinal goals are all needed.

Penn Inquiry Model (PIM)— Defining a Research-Based Inquiry Model

The Penn Science Teacher Institute at the University of Pennsylvania offers two master's degree programs for middle-grade and secondary-level science teachers—the Master of Integrated Science Education Program (MISEP) and the Master of Chemistry Education Program (MCEP).

As described by Jane Horwitz, the associate director of the Penn Science Teacher Institute, the MCEP developed PIM through an ongoing collaboration between Penn chemists teaching content courses using an inquiry model and university-based science educators teaching chemistry education courses.

WHAT IS "PIM"?



Source: Jane Horwitz, Penn Science Teacher Institute, 2005.

PIM works in the classroom first by asking a question and then by looking at existing information to see what is known. This information is examined and organized, which usually leads to more questions. Then the cycle starts all over again, eventually leading to results, which are put out for peer review and, if accepted, become community knowledge.

The goals of the program are to improve the learning of science by secondary-level students by developing knowledgeable, confident teachers who are well grounded in both content and pedagogy; helping teachers emerge as science leaders; and creating and sustaining a community of learners. This program is geared toward practicing secondary-level science teachers who have been teaching for at least two years.

The Importance of History

The practice of science is a human endeavor. Its findings are the result of personal strivings of individuals interested in the world around them. Joseph Schmuckler, a professor of chemistry and science education at Temple University, stated in his presentation that part of the nature of science is the blending of thought and content with process. But most science teachers never participate in the practice of their science, carrying on no investigations of their own. They seldom participate in the scientific enterprise, nor do they consider themselves scientists. The teachers, and thus their students, never really experience the thrill of discovery.

As Schmuckler pointed out, when students are not introduced to the history of science, they do not learn about the people of science or of the extensive work that is usually behind the final discovery they are being taught in the classroom. In most science courses neither the teacher nor the textbooks present anecdotal science background. They do not teach about all the failures and the amount of work it takes to finally reach a positive result.

Students also need the background information in order to truly understand the nature of science. Students will probably not get excited about being scientists if they do not truly understand what being a scientist would be like.

Schmuckler recommended that the history of science be incorporated into high school curricula. He strongly advocated that knowledge of the history of science can play an important role in exploring and understanding the nature of science for teachers and their students.

New Ways of Working

Inquiry is the asking of questions, and in the arena of science education it is the asking of higher-order questions. Frank Sutman, a senior scholar in science education at Richard Stockton College of New Jersey, pointed out that teachers need to get their students involved in order to help them reach this level. The greater the degree of student involvement, the better the educational experience. The student, instead of the teacher, becomes the center of the instruction.

Sutman linked his concept of inquiry to the idea of student discovery, which is a student-centered method of teaching science. Sutman defined discovery as "whatever steps students need to take in order to obtain answers to the original inquiry questions."

DIVERSIFIED STUDENT POPULATIONS

Can Inquiry Be Provided for All?

Believing that science for all is a viable goal, Judith A. Summers-Gates, currently a chemist with the U.S. Food and Drug Administration, proposed that educators should work hard to include a wide range of students with learning differences in inquiry-based classrooms. Doors that have been previously closed must be opened to students with disabilities. Schools must make special provisions for these students as a result of federal legislation. They are destined to be citizens alongside everyone else, making up society as a whole, and they need to be included in the science education experience. These students, experience has shown, can also be productive scientists.

In our society there is still a tendency to have low expectations of people with disabilities and to assume that students with disabilities will not have the same level of competence or understanding as everyone else. But, as Summers-Gates, who has multiple sclerosis, succinctly stated and demonstrates, this is simply not true.

Everybody benefits when students with disabilities are included in all classrooms. Among the guidelines for including all students in the inquiry process are recognizing that all students have learning differences, encouraging students with disabilities to participate fully, and increasing the independence of students with disabilities.

She also advocated methods of adapting classes for maximizing inquiry-based science education for a diverse range of students. One method for including students with disabilities is to adapt experiments and make appropriate accommodations to fit the disability while covering the key concepts. Examples include the use of pH meters in titrations instead of colored indicators, the use of flotation devices for volume measurements, the incorporation of smell or sound into experiments, and computer-simulated experiments. Examples of other accommodations are using Braille labels on equipment, adapting meters to use voice-synthesized output, and making lab facilities wheelchair friendly.

In addition, she suggested using mentors and extra teaching assistants to help students with disabilities have the same quality of learning experience. Using note takers, having an aide perform laboratory tasks at the student's instruction, and providing mentors for special-needs students are common examples.

It is also enlightening, Summers-Gates pointed out, to consider that many of the most famous scientists have had disabilities. Alexander Graham Bell had a learning disability; Thomas Alva Edison had a learning disability and hearing impairment and was diabetic; Albert Einstein had Asperger's syndrome and dyslexia; Steven Hawking is handicapped by motor neuron disease; Temple Grandin is autistic; Isaac Newton was dyslexic and stuttered; Leonardo DaVinci was also dyslexic; and Pythagoras had epilepsy.

Universal Design for Learning

A second approach to providing equal access to quality science instruction is Universal Design for Learning (UDL). Universal Design, as presented by Steve Rissing, a professor of evolution, ecology, and organismal biology at Ohio State University, is an approach to designing course instruction, materials, and content to benefit people of all learning styles without adaptation or retrofitting. It provides equal access to learning, not simply equal access to information. UDL allows the student to control the method of accessing information, while the teacher monitors the learning process and initiates any beneficial methods.

Although UDL enables the student to be self-sufficient, the teacher is responsible for imparting knowledge and facilitating the learning process. Rissing pointed out, however, that UDL does not remove academic challenges; it does remove barriers to access through multiple formats of content material (e.g., recording lectures to audio MP3s, using concept maps to express ideas, and using Braille and image enlargement) and multiple formats of expression (e.g., measure of skills outside the domain, adjustment of the cognitive load for understanding the assignments, and assignment choices other than papers).

In addition, Rissing advocated a cooperative learning approach that allows students with variable traits and variable skills to interact within a working group and take advantage of everyone's abilities. Rissing confirms that this approach is working at Ohio State University, with 9,000 students a year.

The basic principles of UDL are to represent information in multiple formats and media, provide multiple pathways for students to demonstrate knowledge of material, and provide multiple ways to engage students' interest and motivation.

THE ROLE OF INDUSTRY

The position of DuPont, said Phyllis Buchanan, manager of the Office of Education at DuPont's Center for Collaborative Research and Education, is that science is an essential life skill. Every child is entitled to a quality science education with challenging content, inquiry-based methods, and highly qualified teachers. More than ever this requires a synergetic partnership between government, business and industry, and educators. Buchanan stated that industry today has an ongoing obligation to work with state coalitions to establish an alignment between curriculum assessment standards and teacher training institutions.

The view at DuPont is that systemic reform at the school district level involves five components: a standards-based curriculum, professional development for teachers, a science materials center, assessment, and administrative and community support.

Buchanan recounted that DuPont had been involved in a number of educational initiatives throughout its history and that the emphasis of the programs DuPont sponsors has changed. She pointed out that in 1918 DuPont began one of its first formal programs, involving forty-eight universities, designed to produce Ph.D.s in chemistry. Then, in the early 1990s, DuPont realized it was spending a large amount of its resources on higher education but that many of the problems were in K–12. In response it shifted its focus to the elementary levels K–5.

DuPont helped form the Delaware Foundation for Science and Math that allows state, industry, and educators to work together to achieve mutual educational goals. Success, Buchanan said, will require a continuing group effort in which everyone participates.

Many other industrial companies have taken a similar stance. Blouke Carus, chairman and CEO of Carus Corporation, told the LISE 5 audience that he has committed himself and his corporation to providing greater science literacy by helping to develop a new K–12 system. He stated his belief that schools today are obsolete, having been designed for a bygone era. He feels that this country not only requires a new educational system but requires the help of parents—that, in fact, a new cultural paradigm is needed.

As jobs that are no longer needed disappear, Carus pointed out, they disappear for good. The good news, he said, is that more new jobs are being created than eliminated. However, these new jobs require a new workforce that is composed of people who have the skills, knowledge, and attitudes required to adapt to these positions. There is a current shortage of skilled workers, and future projections indicate that the shortage will steadily increase. To solve this growing crisis, Carus stated that a new inquiry-based science education plan is necessary.

Among the ideas, programs, and strategies presented by Carus that he indicated have proved useful are classroom chemistry demonstrations; SWEPT (Scientific Work Experience Program for Teachers), a summer work program that provides practical, hands-on experience; Project Lead the Way (PLTW), a not-for-profit organization that promotes pre-engineering courses for middle-school and high-school students; and scholarships for children of employees of Carus Corporation.

EXECUTIVE SUMMARY

The conference theme was "Discovery in Our Classrooms: Inquiry and the Nature of Science." The dual theme brought together expert speakers whose presentations examined the relationships between how science functions and how students learn science.

Several speakers focused on the first of the LISE 5 themes, inquiry. They described their model of the inquiry process. Many speakers viewed inquiry as the best way for students to learn science, and most included the essential elements of questioning, observing, classifying, measuring, interpreting, inferring, and predicting in their views. Several presentations were aimed primarily at classroom teachers who are interested in teaching by inquiry. Various models for teaching inquiry were presented: guided inquiry, a research-based model used at the University of Pennsylvania, a developmental model based on the degree of student involvement, a model that uses the history of science as its base, and a model for teaching inquiry at museums and science centers.

Many other speakers (including some who addressed inquiry) examined the second LISE 5 theme, the nature of science. They noted that in addition to science being a body of knowledge to be learned, students also have to learn about the process scientists use to develop that body of knowledge. Encouraging students to learn about the processes of science is key to students' understanding science. It was also noted that understanding the nature of science is an issue of science literacy not only for students but also for the general public. Industry leaders urged industry and educators to work together to reform science education and to rely more on inquiry-based learning.

Providing an opportunity for all students, especially those with learning differences and disabilities, in inquiry-based science was another major focus. Speakers recommended ways to adapt labs and classrooms for the disabled learner and discussed ways to engage a wide variety of students and enable them to present their work in a variety of formats.

ACKNOWLEDGMENTS

The Chemical Heritage Foundation organized and hosted the first Leadership Initiative in Science Education (LISE) conference in 2000, with the generous financial support of Dow Chemical. Dow's continuing support made possible a second conference in 2002, and annually from that point on. The Chemical Heritage Foundation is grateful for that support.

Many individuals contributed to the success of the 2005 LISE conference and the production of this white paper. Don McKinney was the key participant in all phases of the conference, from selecting the primary theme and identifying participants to contributing to this white paper. CHF's expert events staff under the direction of Nancy Vonada and Carla Watts ensured that all aspects of the conference flowed smoothly. CHF publications staff, especially Shelley Geehr, Rob Lopata, Patricia Wieland, and Gwen Burda helped prepare promotional material for the conference and shepherded this document to print.

Our greatest thanks go to the presenters and audience of the 5th annual LISE conference. They have continued the high level of intellectual inquiry and exchange that fulfill CHF's initial vision for a *leadership* initiative in science education.

SCHEDULE OF EVENTS

The 5th Annual Leadership Initiative in Science Education

Wednesday, 27 April 2005

3:30 to 6:00 p.m. Workshop: "POGIL in Your Classroom"

Rick Moog
Principal investigator, Process Oriented Guided Inquiry Learning Project; Professor of chemistry, Franklin and Marshall College

7:45 to 8:45 p.m. Address: "Inquiry and the Nature of Science"

Norman Lederman
Chair and professor of mathematics and science education, Illinois Institute of Technology

Thursday, 28 April 2005

8:30 to 9:45 a.m. Address: "Discovering Inquiry"

Lawrence Lowery
Professor emeritus, University of California, Berkeley; Principal investigator, Full Option Science System (FOSS), Lawrence Hall of Science

9:45 to 10:45 a.m.	Address: "The Myths of Science: Considering What We Think We Know about How Science Works" **William McComas** Director, Project to Advance Science Education, Rossier School of Education, University of Southern California
11:00 to 11:45 a.m.	Panel: "Teaching Teachers about Inquiry and the Nature of Science" **Jane Horwitz** Associate program director, Penn Science Teacher Institute, University of Pennsylvania **Joseph Schmuckler** Professor of science education and chemistry, Temple University **Frank Sutman** Senior scholar in science education, Richard Stockton College of New Jersey
1:00 to 1:45 p.m.	Address: "Inquiry in Informal Settings" **Lynn Rankin** Director, Institute for Inquiry, Exploratorium, San Francisco
1:45 to 2:30 p.m.	Panel: "Supporting Best Practices in Science Education" **M. Blouke Carus** Chairman and CEO, Carus Corporation **Phyllis Buchanan** Manager, Office of Education, DuPont Company
2:45 to 3:30 p.m.	Panel: "Inquiry for All" **Steve Rissing** Director, Introductory Biology Program, and professor of biology, Ohio State University **Judith A. Summers-Gates** Chemist, U.S. Food and Drug Administration; Chair, Chemists with Disabilities Committee, American Chemical Society

SPEAKER BIOGRAPHIES

Phyllis S. Buchanan brings more than twenty-five years of experience with the DuPont Corporate Education Program to her current position as manager of the Office of Education, a division of DuPont's Center for Collaborative Research and Education. During her time with DuPont she has overseen corporate support for science education and has funded cutting-edge research at the university level, has identified and contributed to the development of national programs that promote young people's interest in science and technology, and has devoted significant resources to support K–12 science and mathematics education reform. In managing the Office of Education's ambitious agenda, she weaves together an extensive network of alliances that works across all educational levels and serves as a catalyst for educational reform and improvement.

The Office of Education is engaged in several initiatives that help promote the understanding of science. In addition to conducting the DuPont Challenge Science Essay Awards Program, the Office of Education supports science and mathematics education programs for K–12 students and their teachers, including the Science Olympiad, the Keystone Science School, FIRST robotics, and the DuPont AgriScience Institute. In 1995 DuPont launched an Elementary Science Initiative in Delaware, which fosters inquiry-based science programs in K–8 science curricula and assessment, professional development for teachers, cost-effective materials, and strategies for extending administrative and community support to additional regions of the country.

Buchanan is a board member of the Triangle Coalition for Science and Technology Education; the Delaware Valley Science Fairs, Inc.; the Delaware Foundation for Science and Mathematics Education; the FIRST Philadelphia Regional Advisory Board (Drexel University); and the National Science Resources Center's National LASER Advisory Board. She has a B.S. in management information systems and an M.Ed. in elementary education from Widener University.

M. Blouke Carus is chairman and CEO of Carus Corporation, a privately held holding company that owns Carus Chemical Company, the world's largest manufacturer of potassium permanganate and a leader in permanganate application and technology. He is also chairman of Carus Publishing Company, which includes Open Court General Books and fifteen children's magazines.

Carus obtained a B.S. in electrical engineering from the California Institute of Technology (Caltech) in 1949, after serving in the U.S. Navy from 1945 to 1946. He continued his studies in foreign languages and chemistry at Mexico City College, the University of Freiburg in Germany, and the Sorbonne in Paris. He joined Carus Chemical Company in 1951 as a development engineer and helped modernize the manufacturing process for potassium permanganate. He holds seven U.S. patents for his work during this period.

In 1962, with the family publishing house of Open Court, Carus developed a reading and language-arts program based on the work of successful teachers. Over a thirty-year period this initiative led to Open Court's "Collection for Young Scholars," an effective, research-based K–6 reading and writing program. In 1970 he launched and supported an elementary mathematics program with a much broader conception of mathematics than other programs at that time.

Carus, who has demonstrated a lifelong passion for education, served as a member of the National Council on Education Research, which established policy for the research arm of the U.S. Department of Education. He established the International Baccalaureate North America (IBNA) in 1973 and was chairman of the IBNA until June 1985; he was a council member for International Baccalaureate in Geneva, Switzerland, from 1977 to 1994.

In 2001 Carus was named "Man of the Year" by the Manufacturing Technology and Management Program at the Illinois Institute of Technology. He received the national Vanguard Award from the Chemical Educational Foundation in 2002, an honorary doctorate from Wesleyan University in 2003, and the Distinguished Alumnus Award from Caltech in 2004.

Jane Horwitz is the associate director of the Penn Science Teacher Institute at the University of Pennsylvania. For the past decade, she led the Penn-Merck Collaborative for the Enhancement of Science Education at Penn's Graduate School of Education. The National Science Foundation–funded initiative has provided professional development opportunities for teachers engaged in science instruction for students in grades K–8, focusing on public schools in Philadelphia.

Horwitz has an A.B. in biology-botany from Smith College and an M.S.T. in science education from the University of Pennsylvania, and has also completed some graduate-level coursework at Penn. She is the former director of education at the New Jersey State Aquarium and has worked at the Franklin Institute, the Morris Arboretum, and the Brooklyn Botanic Garden, where she was involved with both school and general public programming and exhibits. Horwitz consults with institutions and organizations involved in science education, helping them design, deliver, and evaluate their programming.

Norman Lederman is chair and professor of mathematics and science education at the Illinois Institute of Technology. He received his Ph.D. in science education and M.S. degrees in both biology and secondary education. He has been involved in science teacher education for the last twenty years, before which he taught high school biology and chemistry for ten years.

Lederman is internationally known for his research and scholarship on the development of students' and teachers' conceptions of the nature of science and scientific inquiry. He has been the author or editor of 10 books, has written 15 book chapters, has published over 150 articles in professional journals, and has made over 500 presentations at professional conferences around the world.

Lederman is a former president of the National Association for Research in Science Teaching (NARST) and the Association for the Education of Teachers in Science (AETS). He has also served as director of teacher education for the National Science Teachers Association (NSTA) and has served on the board of directors of NSTA, AETS, NARST, and the School Science and Mathematics Association.

He received the Illinois Outstanding Biology Teacher Award (1979), the Burlington Resources Foundation Faculty Achievement Award for Excellence in Teaching and Research (1992), and the AETS Outstanding Mentor Award (2000).

Lawrence Lowery is a professor emeritus at the University of California, Berkeley. He was the principal investigator for both the EQUALS math program and FAMILY MATH at the Lawrence Hall of Science. He remains active as the principal investigator for the Full Option Science System (FOSS), a science curriculum for grades K–8 developed at the Lawrence Hall of Science. He continues to publish and edit articles and books, the most recent being *The Nature of Inquiry* (NRC, Science, Technology, and Children, 2002), *Developing Minds* (Association for Supervision and Curriculum Development, 2001), and *Teaching for Inquiry* (National Science Education Standards Addendum, 2000).

Lowery has also received numerous awards, including the Outstanding Science Educator of the Year (1992) from the Association for the Education of Teachers of Science (AETS); the Distinguished Career in Science Award (1993) from the National Science Teachers Association (NSTA); and induction into the Science Hall of Fame (2002), state of Texas award for contributions made to science education.

William McComas is an associate professor of science education in the Rossier School of Education at the University of Southern California (USC), where he is founding director of the Program to Advance Science Education. After working as a middle-school and secondary-level science teacher in suburban Philadelphia, he received his doctorate in science education from the University of Iowa.

His research focuses on biology education, informal science learning in museums and field settings, the philosophy of science in science teaching, and science education issues for gifted and talented learners. His most recent book, *The Nature of Science in Science Education: Rationales and Strategies*, will be followed by the forthcoming *Investigating Evolutionary Biology in the Laboratory*. He has served on the board of directors of the National Science Teachers Association and is currently a fellow of the USC Center for Excellence in Teaching. He was named the 2004 winner of the Associates Award for Excellence in Teaching, the highest such honor awarded by USC.

Rick Moog has a B.A. in chemistry from Williams College and a Ph.D. in physical chemistry from Stanford University. He is currently professor of chemistry at Franklin and Marshall College. He is the project coordinator for the Middle Atlantic Discovery Chemistry Project (MADCP) and is principal investigator for the National Science Foundation–funded National Dissemination project in Process Oriented Guided Inquiry Learning (POGIL). Moog is the coauthor of materials used for guided-inquiry instruction in general chemistry and physical chemistry and has developed numerous guided-inquiry experiments for use in the general chemistry laboratory. He has organized many symposia at national American Chemical Society and Biennial Conference on Chemical Education meetings concerning active learning throughout the chemistry curriculum and has given over forty presentations, posters, and workshops on guided inquiry and group learning.

Lynn Rankin is the director of the Exploratorium's Institute for Inquiry in San Francisco, a national professional development center for K–8 leaders and practitioners of elementary science reform efforts. A former elementary teacher, she has spent the last twenty-five years working in inquiry-based science education at the Exploratorium. Through this work she explores the nature of informal learning and how informal science institutions most effectively support elementary science education in the schools. She was a founding member and served on the faculty of the Association of Science and Technology Centers' Professional Development Institutes for museum educators. She currently serves on the faculty of the Center for Informal Learning and Schools, a collaboration between the Exploratorium, Kings College London, and the University of California, Santa Cruz. She has contributed to numerous national publications and committees, including the National Science Foundation's "Foundations II: Inquiry, Thoughts, Views, and Strategies for the K–5 Classroom"; the National Academy of Science's committee to develop "Inquiry and the National Science Education Standards"; and the National Institute for Science Education's committee to examine effective professional development strategies for science education.

She also serves on a variety of advisory boards for informal education and science research institutions: the American Museum of Natural History, New York City; First Hand Learning, Buffalo, New York; and TERC, Cambridge, Massachusetts.

Steve Rissing, professor of evolution, ecology, and organismal biology at Ohio State University, directs the university's Introductory Biology Program (IBP), which teaches over 8,500 undergraduates per year. As IBP director and an instructor in his own program, Rissing has seen the value of Universal Design for Learning (UDL) firsthand. Biology courses, with their associated teaching laboratories, provide powerful opportunities for the incorporation of UDL principles in college academic settings. Rissing has served on science standards advisory panels in Arizona and Ohio. His column on biology and society appears in the *Columbus Dispatch*. Steve is a past president of the International Union for the Study of Social Insects (North American section) and holds degrees from Indiana University and the University of Washington. He has held a National Institutes of Health postdoctoral fellowship at the University of Chicago and a senior fellowship at Cornell University.

Joseph Schmuckler, professor of chemistry and science education at Temple University, earned his doctorate at the University of Pennsylvania. He taught for fifteen years at Haverford Township High School in Pennsylvania and worked part-time for ten years at the Sun Oil Company and at the Sadtler Research Laboratory in Philadelphia. He taught part-time at the University of Pennsylvania for four years.

Schmuckler is the recipient of some of the most prestigious awards in teaching, including the national James Bryant Conant Award, the Manufacturing Chemists Association Medal, the Distinguished Alumni Award from the University of Pennsylvania, and the George Washington Carver Medal. He was one of the first recipients of the Great Teachers Award of Temple University.

While at Temple University he has received grants from the National Science Foundation and other institutions for chemical education. He is the coauthor of several chemistry laboratory books and of publications based on his science education research. He has worked with the Chemical Heritage Foundation in writing activities for K–12 teachers involving the use of history in teaching science in the classroom. He was an academic consultant for the taping of the NOVA documentary on the work of Percy Julian and also served as an academic consultant for the television Discovery series *The 100 Greatest Scientific Discoveries*, hosted by Bill Nye, "The Science Guy."

His science education research is in the area of inquiry and discovery learning. He holds two honorary professorships in China and has been teaching chemical education there for more than twenty years. He has lectured in many countries in Europe. His current research centers on the efficient and effective use of classroom science demonstrations both at the secondary and college levels.

Judith Summers-Gates, born in Hazleton, Pennsylvania, and raised in Philadelphia, is an accomplished chemist whose career has involved bench-top analysis of color additives at the U.S. Food and Drug Administration (FDA). Despite being told that her visual disability would preclude her from careers in science, she persevered and attended Holy Family College and then Drexel University, where she received her B.S. degree in unified science, a combination of chemistry and biology, in 1985. While at Drexel she worked at an ink and printing company and at the U.S. Department of Agriculture's Eastern Regional Research Center as a chemical technician. She was then employed by the U.S. Department of Defense's Defense Personnel Support Center as an analyst to perform physical and chemical testing on virtually every commodity used by the armed forces, from baby diapers to tank axles. It was during her years with DOD that she acquired several additional disabilities, including multiple sclerosis. She later went on to work for the FDA, where she has been an analyst for fifteen years. She has distinguished herself as an expert in the isolation and identification of colorants and additives in foods, drugs, cosmetics, and medical products. She is an active member of the Philadelphia American Chemical Society (ACS) section and serves on its board of directors and on its publications committee, which produces the newsletter *Catalyst*. In addition, she is the chair of the National ACS's Committee on Chemists with Disabilities and the Philadelphia Mayor's Commission on Persons with Disabilities, Education Subcommittee.

Frank Sutman is presently senior scholar in science education at Richard Stockton College of New Jersey, where he is spearheading the development of a new master of arts in education program for teachers of science. He has published articles on the topic of reforming the teaching of science in the journals *Chemistry, Research in Science Teaching*, and *ENC Focus*. His articles also appear in the *Harvard Education Letter* and in the *Journal of Curriculum and Supervision*. He was founder of the graduate-level Science Education Program at Temple University and has been a visiting scholar at universities in China, Israel, India, Puerto Rico, and Egypt. He received the New Jersey Governor's Albert Einstein Medal in Education for outstanding contributions to the science education of minority students and their teachers. He has served as a program director at the National Science Foundation and has conducted research in teaching science to language minority students through the University of Miami. He is a fifty-six-year member of the American Chemical Society (ACS) and has served on the ACS's Visiting Chemist Committee and its Examinations Committee. Sutman is senior author of the forthcoming book *Re-envisioning the Teaching of Science* (Jossey-Bass, 2006).