PRESIDENTIAL ADDRESS

It's Just A Theory: Science And The Pursuit Of Truth

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Scientific knowledge continues to advance at a dizzying pace. Dr. Carol Lushbough's talk yesterday on bioinformatics illustrated the immense amount of data resulting from genome sequencing projects- so great an amount of data that a new branch of science, bioinformatics- has arisen from the interface of two very different disciplines- molecular biology and computer science. The far-sighted acquisition by the state of the old Homestake mine in Lead and its conversion into the Deep Underground Science and Engineering Laboratory (DUSEL) has generated great excitement among diverse scientists here and worldwide; from the groundbreaking experiments on neutrinos and other aspects of subatomic physics described by Dr. Kara Keeter and others to experiments to characterize the geology, hydrology, and biology of the deep subsurface environment, a window into a unique environment has been opened. The physics experiments at DUSEL will likely shed light on such questions as the nature of matter and amount of matter in the universe. In addition, DUSEL provides access to deep aquifers possibly isolated from the surface for millennia, which may contain microbial ecosystems not dependent on photosynthesis as their energy source, or which may contain microbes adapted to extreme conditions, such as high temperatures.

Despite the increasingly rapid acquisition of knowledge about the physical world, there are problems with the relationship between the community of scientists and the larger society we live in. There has been considerable concern that there is a lack of "scientific literacy" in our nation, in that a large proportion of our population has poor understanding of such concepts as geological history and the structure of matter (National Science Board, 2004). Perhaps even more troubling than the lack of knowledge about specific scientific theories is a real confusion about what constitutes science. There is certainly a lack of understanding about what scientific theories are, and how they relate to our search for truth about the physical world.

We all have heard about controversies regarding the teaching of Intelligent Design in schools as an alternative to evolution- one main objection to the evolution by natural selection being that it is a "theory" and not a "fact". The South Dakota Academy of Science passed a resolution in 1998 specifying that evolution be required in the curriculum for preparing high school biology teachers in our state, but the legislature has not yet approved this requirement.

The lack of understanding about the nature of science was even more forcefully illustrated recently in a resolution (House 1009) recently passed by the South Dakota State Legislature, which would mandate a "balanced view" in environmental science instruction: the theory of global warming due to human combustion of fossil fuels (accepted by the majority of scientists), and the view (advanced primarily by political groups), that global warming is not occurring would both be presented to students. The resolution states that "global warming is a scientific theory rather than a proven fact" which implies that scientific theories are mere speculations, not supported by repeated experimentation or systematic collection of observations.

I do not believe that even the best theory in the physical sciences can ever achieve the level of absolute certainty as, for example, a mathematical theorem. Our theories are always subject revision or even refutation based on new and compelling data. In my opinion, it is our duty to teach the children of our communities the best theories we have, without regard to political correctness. To do otherwise risks either not adequately preparing our citizens for challenges which they will face in health and environmental issues, or equally dangerous, foster the cynical idea among youth that truth does not exist, but is defined merely be one's political viewpoint. The Academy should consider how we can best educate and inform the people of our state about the nature of science, and consider how we can uphold the integrity of science education.

The confusion about scientific theories versus what people commonly call "facts" is part of a wider misunderstanding about what science is, how scientific knowledge is acquired, and what scientific knowledge can tell us. As Dr. Andy Johnson indicated to me in a recent conversation at Black Hills State University, the question of what scientific knowledge is constitutes a rather deep question of epistemology. Truth is often perceived by people as a complete and changeless entity which is passed, in the form of a rigid, dogmatic body of knowledge, from a figure of authority to a learner, who accepts this body of knowledge uncritically. All too often, this occurs in our institutions of learning, in which a wide array of "facts" are passed from instructor to students with little critical thought being elicited in the students, so that an appreciation for what the scientific method is and a desire to learn more is sacrificed to an acquisition of the largest number of "facts" which are considered useful by the educational system. The hierarchical nature of our institutions of learning and the pronounced one-sidedness in the instructor-student relationship tend to reinforce this rather dogmatic view of scientific knowledge among students. As Jay Lemke (1995) commented "The structure of our institutions conveys a more powerful message than their content."

Lynn White, Jr. (1968) stated that, to a scientist, "truth is not a citadel of certainty to be defended against error; it is a shady spot where one eats lunch before tramping on." This view may be a bit overstated; nevertheless, it illustrates that scientific theories evolve and are not rigidly fixed, static entities. Some "constructivist" philosophers would go so far as to say that truth about the physical universe does not exist apart from those ideas we construct as a framework to explain experimental observations and that theories are to be evaluated not in terms of being accurate representations of an unknown truth but rather in terms

of their viability, or coherence and ability to explain observations (Von Glasersfeld 1997). Max Jammer (1999) proposed that science consists of a somewhat abstract set of concepts which can be related to physical observations, such as the data from the senses, by a series of rules of interpretation, and notes that it is impossible for science to photographically reproduce nature, because our concepts of science are essentially products of our own minds.

It should also be borne in mid that progress in science is often not always a constant, direct progression towards greater knowledge; progress may consist of long periods of relative inactivity interspersed with revolutionary breakthroughs. There may even be occasional false starts. Thomas Kuhn (1962) emphasized this when he noted that paradigms (such as accepted concepts) in science and other fields may persist unaltered for extended times before being overthrown. In the field of molecular biology I am often amazed that, for many years after its discovery by Friedrich Miescher in 1869, DNA was generally not considered to be the genetic material of cells- rather proteins were accorded this honor. The fragments of DNA which could be characterized seemed too small and too simple, composed of only four kinds of nucleotides, to convey genetic information, while proteins, composed of 20 possible amino acids and very diverse in size and composition seemed much better candidates for genes. It took a number of well-designed experiments, including those of Frederick Griffith, Oswald Avery, Alfred Hershey and Martha Chase, and Edwin Chargaff, over a span of 24 years, to cause the paradigm shift that made molecular biology possible (Becker et al. 2006).

One might also remember that the same year in which James Watson and Francis Crick (1953) published their double-helical structure of DNA, Linus Pauling (1953), a more experienced structural biologist who had pioneered many aspects of the structural biology of proteins, also published a paper describing the structure of DNA, which he described as a triple helix.

Despite the uneven progress of science and the inexact correspondence between the conceptual models of science and the physical world, I would not go this far to say that truth does not exist, as some of the more radical constructivists propose, even if our understanding of reality is fragmentary and sometimes inaccurate, and if our views of physical reality must change as more data are gained.

In addition to the common misconception of scientific knowledge as an unchanging body of facts passed down from authority figures, such as teachers to (often reluctant) pupils is the perception among many that science and religion are incompatible. If people feel that they are forced choose between science and religion, science is often rejected because it does not provide answers to the ultimate questions regarding the meaning of human life. The flames of conflict have been fanned by those in the scientific community, such as Richard Dawkins(1986), who argue that science leads us to conclude that God does not exist and the universe is without meaning and fundamentalist Christians on the other, who hold that Scripture, including the account of the creation of world and humanity in Genesis (1:1-2:4) must be interpreted literally. While it must be conceded that the theory of evolution by natural selection cannot be reconciled with a literal interpretation of Genesis, I do believe that region and science

can, and should coexist. Dr. Michael Wanous spoke at length on this subject during his 2007 presidential address to the Academy on how these two entities can productively co-exist. Among those scientists favoring a new dialogue between biology and science is Francis Collins, director of the Human Genome Sequencing Project (2003).

I believe that it is wise for us as scientists to make no claims that science can tell us anything other than the physical universe. As Stephan Jay Gould has suggested, science and religion have largely different domains. Referring to the domains of science and religion which have been termed "magisteria" he stated (1997) "I believe, with all my heart, in a respectful, even loving concordat between our magisteria—the NOMA (non-overlapping magisteria) solution. NOMA represents a principled position on moral and intellectual grounds, not a mere diplomatic stance. NOMA also cuts both ways. If religion can no longer dictate the nature of factual conclusions properly under the magisterium of science, then scientists cannot claim higher insight into moral truth from any superior knowledge of the world's empirical constitution. This mutual humility has important practical consequences in a world of such diverse passions." I find Gould's statement particularly forceful because I understand that he was an agnostic. I also believe religion can contribute valuable insights into morality and the meaning of human life- insights which are critical to the proper application of the fruits of scientific knowledge in the world. If, for example, human lives are saved or human suffering is mitigated through the application of medical technology or if a plant or animal species is rescued from extinction, it may well be because, as a result of our religious beliefs, we consider them sacred in some sense, either as reflecting the nature of God in the case of humans or the product of God's work through evolution in the case of other life. Perhaps, as we address students about the nature of science in our lectures, or address members of the communities we belong to about science, that we acknowledge the contributions of religion, while remaining committed to teach the theories we consider to be the most descriptive and best verified by experimental evidence, such as the theory of evolution by natural selection. In this way, science, and the concept of evolution in particular, may be perceived as less threatening and more compatible with religious beliefs.

The South Dakota Academy of Science has taken an active role in the promoting science education, as evidenced by the papers presented this morning on this topic. Certainly, improving science education is one solution to the lack of understanding as to what constitutes science. In his 2005 presidential address to the Academy, Robert Tatina outlined some of the challenges to science education in our region: low wages for K-12 teachers, extremely heavy teacher workloads which leave little, if any, time for innovation; poor teacher preparation in the area of science with too few science courses required for teacher education; an over-reliance on textbooks, which excessively drive course content; the relative isolation of science instructors in many schools (one person teaching all science and math courses) and perhaps most importantly, a lack of hands-on, open ended inquiry in science laboratories.

One solution he suggested for improving the content of science courses, particularly biology, was to concentrate less on the findings of science but more on the process of conducting scientific research by learning in detail about key

experiments and how they changed ideas. Another suggestion was to remove excessive preoccupation with numerous details and concentrate more on the unifying concepts of biology, such as DNA and information flow, cell theory, and evolution by natural selection. By focusing on the process of science in classrooms, students would also be better prepared for more inquiry-based laboratory courses.

Perhaps one key to fostering an appreciation of what science truly is and how science is done is to improve laboratory experiences for science students, not only in K-12 education but also for higher education (Smith et al. 2005). For example Dr. Cyndi Anderson and Lisbeth Fayer have proposed revising some of the high-enrollment, biology survey laboratory sessions to make them more inquiry-based. Students would form semester-long groups to test a particular hypothesis of interest to them. Students would research hypotheses of their own creation, decide appropriate methods of testing them, interpret data, and re-evaluate their hypothesis. By conducting their own experiments, the process of science becomes less foreign, and students are empowered to learn about the physical world on their own, trusting their own observations, rather that accepting dogmatically ideas which have been handed to them (or cynically rejecting the idea the ideas of anyone else). I think that learning the scientific method in this fashion would benefit not only science majors but also non-scientists as they develop valuable critical thinking skills and more open minds. It should be noted, however, that considerable care must be used in creating course structures which can help students adapt to this learning environment.

We should also consider what the Academy can do to fill the void left by the termination of the "Science on the Move" program- a state-sponsored, mobile laboratory which brought laboratory projects, including some involving molecular biology, to remote school districts. It would be good to think of new ways to introduce inquiry-based lab experiences to these schools.

As an Academy I would encourage us to find ways in which our organization can foster a more open, less dogmatic, more experiment-based approach to science education at all levels. Some of this can be done through papers and symposia at our annual meetings, during which faculty involved with science education in our state, who share common challenges such as isolation, limited time, and scarce resources, can share productive instructional strategies.

While at the University of Minnesota as a postdoctoral researcher, I remember many productive, informal conversations with colleagues involved in projects not directly related to mine, yet facing some common problems, which I had simply by walking down the hall and knocking on a door. In some of the institutions in our state, unfortunately, it seems like that next door may be in Denver or Minneapolis. I think it possible that the Academy can do much to decrease the feelings of isolation many of us involved in scientific research and education may experience.

Perhaps our website can include links of use for science education, in particular for revising science laboratory courses. We can assist with workshops on science education.

I believe the Academy's participation in regional science fairs is of great value, as I have observed considerable enthusiasm for science among middle school

students and often considerable sophistication in their grasp of the scientific method. Not only do students learn about the nature of science, but they may well teach their parents, who may assist them with their projects.

I would like to see the Academy do more to foster more interest in science at the high school level, and increase participation of these students in research projects. This may be a useful way of maintaining high enrollments in science and engineering programs in state universities.

In conclusion, let us consider what we can do, especially within the sphere of science education, to foster a more accurate view of science in the community, and, in so doing, open people's minds.

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