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Reflections on Scientific Literacy, Worldviews, and Education

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INTRODUCTION

Science is at the core of many of the political, social, and economic issues that dominate modern society. These issues demand that citizens have a level of scientific literacy sufficient to understand the science on which policy arguments and decisions need to be based. Scientific literacy is also vital to maintaining a workforce increasingly reliant on science, and to link with the humanities in a search for truth to better understand our world as a whole.

Scientific literacy can be defined as consisting " … of a knowledge of certain important scientific facts, concepts, and theories; the exercise of scientific habits of mind; and an understanding of the nature of science, its connections to mathematics and technology, its impact on individuals and its role in society." This definition emerged from two publications by Project 2061 of the American Association for the Advancement of Science (AAAS), titled *Science for all Americans* (Rutherford & Ahlgren, 1989) and *Benchmarks for Science Literacy* (1993). The AAAS, the National Academy of Sciences, and the National Science Teachers Association officially adopted this definition in 1996 (Wren, 2014). More specifically, scientific literacy has been called *civic scientific literacy*, to distinguish it from practical scientific literacy (knowledge that assists in consumer decisions) or cultural scientific literacy (science as a way of knowing) (Shen, 1975). Miller (1998) has referred to the minimum civic scientific literacy as a level of understanding of scientific terms and constructs sufficient to read the Tuesday science section of the *New York Times*, or comprehend an episode of Nova, and to understand the essence of competing arguments on a given dispute or controversy. I will use the term "scientific literacy" throughout this paper to denote civic science literacy, since that is the level at which many of the measurements of scientific literacy are made.

Scientific literacy is an integral part of the wider concept of civic literacy, the knowledge of how to actively participate and initiate change in one's community and the larger society, the foundation on which democratic society functions. A low level of scientific literacy is detrimental to society because it results in less than optimal policymaking in areas requiring scientific knowledge. The essential connection of wide public scientific literacy to the making of sound policy was incisively articulated by Neil Lane, former head of the National Science Foundation: "The successful application of new knowledge and breakthrough technologies … will require an entirely new interdisciplinary approach to policy making: one that operates in an agile problem-solving environment and works effectively at the interface where science and technology meet business and public policy" (Lane, 2006).

This paper is intended to be a series of reflections on the level of scientific literacy in the United States and the relationships between scientific literacy, political and religious ideologies, and the education system within which the acquisition of literacy in general takes place. These relationships play a large role in determining the level of scientific understanding by the public and policymakers and the degree to which scientific concepts and discoveries are accepted or rejected.

MEASURES OF SCIENTIFIC LITERACY

What is the current state of scientific literacy in the United States? In a classic video made at a Harvard graduation ceremony, 25 of 29 graduates interviewed gave an incorrect answer to the question of what causes the seasons. They attributed seasonal climate change to variations in the earth's distance from the sun (such variations are real), but then were unable to explain by this answer why summer and winter are reversed in the northern and southern hemispheres (Nelson, 1999). The correct explanation is that the earth's axis is tilted 23 degrees with respect to the orbital plane. This tilt does not change over the orbital cycle, so the northern hemisphere receives more sunlight six months out of the year, and the southern hemisphere receives more sunlight during the other six months, reversing summer and winter in the hemispheres.

While different surveys vary somewhat in their results, they indicate that scientific literacy in the United States is low. According to the latest Science and Engineering Indicators report (2014) published by the National Science Foundation, 65% of 2,200 Americans surveyed correctly answered an average of 5.8 factual items on a 9-item test, a performance that has changed little over the past 20 years since the test was adopted. Broken down by educational level, this average was attained by 45% of those who did not complete high school, 78% of those who had completed a bachelor's degree, and 83% of those who had taken three or more science and mathematics courses in college, indicating that factual knowledge of science is strongly related to level of formal education. The most amazing result, however, was that 25% of the respondents did not know that the earth revolves around the sun.

This report also compared performance from 1999-2012 on five questions designed to assess understanding of how science generates and assesses evidence; 33% of those surveyed were able to answer all five questions in both 1999 and 2012. Subsets of these questions assessed understanding of probability (two questions), experimental design (one question), and the scientific method (two questions). Sixty-five percent of those tested answered both probability questions correctly, but only 34% and 20% answered the questions on experimental design and scientific method, respectively.

Miller (2010a, b, c; 2012) conducted a 20-year longitudinal study of 5,000 adults, using a set of open-ended questions (What is a molecule? What is a stem cell?), as well as closed-ended questions (agree or disagree with a statement). He found that only 15% of American adults can explain what a molecule is, and 20% can define what a stem cell is. Even fewer can explain the differences between adult and embryonic stem cells. Nevertheless, the proportion of adults scoring 70 or higher on a scale of zero to 100 nearly tripled from 1988 (10%) to 2008 (29%). In a comparison of 34 countries, the United States was second only to Sweden with respect to scientific literacy. The bad news is that this level is insufficient with respect to the increased scope and complexity of problems today that require scientific understanding, and this insufficiency is a threat to our basic commitment to meaningful democracy, meaning that the science required to argue policy positions is incomprehensible to most citizens (Miller, 2012).

The use of textbook-type general knowledge indicators to measure scientific literacy has been criticized in favor of using a more "asset-based" approach that would measure specific subsets of knowledge, skills, and experience held by different segments of the population to find out what kinds of scientific knowledge matter to the public (Stocklmayer & Bryant, 2012). The problem with this approach is that what appears to matter most to the public is not science, but technology and how to use it, particularly electronic technology. While extremely useful and exciting, awareness of and knowing how to use technology becomes a proxy for basic scientific knowledge of the type discussed above. The best approach would measure both asset-based and general scientific knowledge. Tests of general scientific knowledge, however, need to be re-designed to include a wide array of factual questions that encompass all broad scientific disciplines and require a greater depth of knowledge, while including more items on scientific process. Asset-based measures, to my knowledge, have yet to be designed, but might include subsets of questions from manufacturing, agriculture, business, and medicine. Finally, an important question that remains to be answered is how to define acceptable qualitative and quantitative baseline levels of scientific literacy.

POLITICS, RELIGION, AND FEAR CLOUD THE PUBLIC VIEW ON SOME SCIENTIFIC ISSUES

A survey of AAAS scientists and non-scientist members of the public by the Pew Research Center (Funk & Rainie, 2015) found that although nearly 80% of the public believe that science has made their life easier and that investments in science pay off in the long run, only 54% view U. S. science and scientists as the best in the world, in contrast to 92% of scientists. The survey also found that scientists and the public are polarized with respect to a number of scientific issues. Scientists are much more likely than the public to view as beneficial such things as vaccination, genetically modified foods, use of pesticides, and use of animals for research. They are also much more likely than the public to view climate change as caused by human activity, and to believe that humans have evolved over time. This polarization in many ways reflects the lower level of scientific literacy of the public compared to scientists, but it also reflects religious and political views, as well as fears based on false or discredited information, as illustrated by the following topics.

The MMR Vaccine

The winter of 2015 saw a nationwide outbreak of measles, a highly contagious childhood disease that by 2000 had been virtually eradicated by vaccination with the combined measles, mumps, and rubella (MMR) vaccine. The resurgence of measles was linked to a refusal by many parents to vaccinate their children against measles out of fear that the vaccine is toxic or causes autism. These fears were reflected in the Pew survey (Funk & Rainie, 2015) in which only 68% of the public favored mandatory vaccination for childhood diseases, versus 86% of scientists. The origin of the resistance to MMR vaccination was a 1998 paper by scientist Andrew Wakefield published in the prestigious medical journal *The Lancet*, claiming that the MMR vaccine was linked to autism and colitis. Several large epidemiological studies subsequently failed to confirm such a link. The paper was eventually determined to be fraudulent and was retracted, but the fear generated by the continued repetition of the falsity has been long lasting and in some cases, deadly.

Safety of GMO Foods

The Pew survey (Funk & Rainie, 2015) indicates that the gap between the public and scientists is greatest over the safety of eating genetically modified (GMO) foods. Only 37% of the public believes these foods are safe, as opposed to 88% of scientists. The Executive Summary of the *ad hoc* Working Group of the Society of Toxicology (2003) reviewed the evidence comparing GMO foods with foods derived by conventional breeding practices and concluded there is little or no reason to believe that genetically modified foods are harmful. Jon Entine, writing in *Forbes Magazine* (2014) has drawn a similar conclusion. Yet groups that are against eating GMO foods continue to portray them to the public as "Frankenfoods" with potentially dangerous side effects.

Much of the information put out by GMO food opponents is incomplete, distorted, or completely false. Most GMOs are grains and fruits grown from seeds genetically engineered for resistance to drought, cold, herbicides, and pests to increase yields. The main GMO crops are rice, corn, soybeans, cotton, canola, alfalfa, sugar beets, and squash. They constitute a large part of the agricultural economy and are present in supermarkets across the country. The science of GMO foods is embedded in the wider topic of genetic engineering. The sentiment against them might reflect wider fears and religious attitudes toward the biomedical applications of genetic engineering.

Human Evolution

While the Pew survey (Funk & Rainie, 2015) indicated that 65% of the public believes that over time humans have evolved, this is still far below the 98% of scientists who do so. The principle of Darwinian evolution by natural selection over vast spans of time is opposed by creationism, which posits the simultaneous creation of species by a supernatural being. The hypothesis that species diversity has a supernatural cause cannot be tested, and therefore creationism is not by definition a scientific idea, whereas the hypothesis of evolution is falsifiable by geological and biological evidence if it is incorrect. In the 156 years since the publication of Darwin's *The Origin of Species*, however, evolution by the action of natural selection on genetic variation stands as the best explanation for species diversity, based on mountains of anatomical, cellular, and molecular data of extant and extinct species. [For those interested in a fascinating molecular analysis of the evolution of modern humans, see *Neanderthal Man*, by paleogeneticist Svante Pääbo (2014)].

A major issue for the acquisition of scientific literacy about origins is whether creationism, or its pseudoscientific variant, intelligent design, should be taught in the public schools alongside evolution. This issue was settled, at least judicially, in the 2005 bench trial of Kitzmiller v. the Dover Area School District of Pennsylvania (Miller, 2008). After hearing testimony from proponents on both sides of the issue, Judge John E. Jones III issued a 139-page finding of fact and a ruling that intelligent design is not a scientific hypothesis and should not be taught in the schools as science. The judge concluded that the school board was engaging in religious proselytizing under the guise of science. The full text of the ruling can be found at www.talkorigins.org/faqs/dover/kitzmiller_v_dover_decision.html.

Climate Change

The dawn of the industrial age appears to have marked the beginning of a rise in global temperature that has become progressively steeper. Most of the data presented by climatologists suggests that warming is being driven by the destruction of carbon dioxide sinks through deforestation and production of greenhouse gases by the industrial use of fossil fuels. There is a 97% consensus among climatologists that there is a correlation between temperature rise and human activity. The Pew survey (Funk & Rainie, 2015) found that 87% of scientists (most of whom are not climatologists) subscribe to anthropogenic causes of warming, compared to only 50% of the public. Regardless of cause, the climate change discussion is important because environmental changes brought on by warming presents issues of ecosystem changes, species adaptability, and risks to coastal dwellers by rising sea levels that will have major effects on food chains, health, and economies (McNutt, 2013). Global warming has been linked to the drought currently affecting California and other western areas of the United States; it is speculated that the Central Plains and Southwest will in the future be subjected to long-lasting mega-droughts even more severe than the ones which resulted in the collapse of the Ancestral Pueblo civilizations (Cook, Seager, Miller, & Mason, 2013; Cook, Ault, & Smerdon, 2015).

Anthropogenic contribution to global warming is an issue with major overtones of economic and political ideologies. Those who oppose the human-driven warming hypothesis fear that economic interests will suffer if legislative policies are adopted curtailing the use of fossil fuels in the name of environmental protection and advocating the development of alternative sources of energy. There is a minority of scientists knowledgeable about the physics and chemistry of climate change that do not believe that warming is occurring at an alarming rate, and that natural, non-anthropogenic forces are the primary drivers of warming. The causes and directions of climate change are complex, and we need to have a much more complete understanding of climate variation than we currently possess to make major policy decisions on energy use and other issues (Ash et al., 2013). At the same time, we would be foolish to ignore planning for climate change scenarios just because we don't yet have definitive evidence to be reasonably certain of climate prognosis. Although the US Senate recently voted to state that warming of the climate is not the hoax that a number of politicians have claimed, human contribution to global warming—or even whether warming is occurring at all—is still probably our most politically-charged scientific issue.

Religion and politics, as it turns out, are major forces that both inhibit the acquisition of scientific literacy and constrain the interpretation and use of scientific facts and concepts. I will return to this problem under the topic of scientific literacy and worldview, after first discussing the major role of our educational system in acquiring scientific literacy.

THE ROLE OF OUR EDUCATIONAL SYSTEMS IN ACQUIRING SCIENTIFIC LITERACY

There are many venues by which to acquire scientific literacy: Science and natural history museums, children's museums, zoos, libraries, the Internet (though an argument can be made that access to the Internet decreases literacy of any kind), and scientists such as Neil deGrasse Tyson and Michio Kaku who inform the public through the medium of television. Public scientific presentations are made in libraries and pubs. These are all wonderful educational experiences, and worthy of support. Nevertheless, the primary avenue for acquisition of scientific literacy is our public education system, consisting of grades K-12 and colleges and universities. Our K-12 and higher education system is where worldviews are expanded and solidified, so this system is crucial for learning scientific facts and understanding how science is practiced. The impact that elementary, high school, and university teachers have on students is enormous, as indicated by the fact that virtually everyone can remember a teacher at any of these levels who made a significant impression on them. If, as Miller (2012) found, scientific literacy has increased by a factor of three over 20 years, it is likely that formal education has played a strong role in the increase, which warrants increased effort to strengthen scientific literacy via our educational system, particularly at the elementary and secondary school levels.

Content and Organization of Science Instruction in the K-12 System

The Pew survey (Funk & Rainie, 2015) indicated that both the public and scientists are critical of the quality of science, engineering, and mathematics taught in K-12. Only 16% of scientists and 29% of the public think that K-12 science education is the best in the world. Twenty-nine percent of the public and 46% of scientists rank it as below average. Seventy-five percent of scientists say an inadequate amount of K-12 science education is a major factor in the public's limited scientific literacy, while another 22% think it is a minor factor.

The content and organization of science and mathematics curricula is of prime importance to the development of scientific literacy. Research on best designs of K-12 science curricula is beyond the scope of this paper, but I would like to make a few general remarks based on personal experiences giving talks to elementary students, judging science fairs, consulting with teachers on high school science curricula, and mentoring high school students on research projects. These experiences have led me to believe that the elementary grades are the most crucial time to begin developing science literacy and connecting science to society at large. Children are naturally curious, with many insightful questions, and have many spontaneous and interesting ideas. They respond well to interactive situations such as demonstrations or hands-on simple experiments. Teachers of elementary science should encourage this curiosity, while showing their students how to use the scientific method to answer questions about the world around them.

To strengthen scientific literacy at the high school level, I have long felt that a makeover with regard to curriculum content and organization is needed. Bruce Alberts, former head of the National Academy of Sciences, has argued that "factoid-filled" K-12 textbooks that provide only overviews of a subject should be replaced with "much shorter curriculum units, each designed to facilitate the active exploration of one important topic in depth for a month or so" (Alberts, 2012). The National Academies has published *A Framework for K-12 Science Education* (2012) that stresses minimizing the number of disciplinary core ideas to be taught to standards and instead emphasizing student participation in key science and engineering practices such as asking questions and defining problems, developing and using models, engaging in argument from evidence; and learning cross-cutting concepts such as energy and matter, cause and effect, and structure and function. Coffey and Alberts (2013) have pointed out that the Framework will require new methods and mechanisms of assessment to avoid using the wrong quantitative measures of success.

The organization of the high school science curriculum is, in my view, backwards. We begin with a general science course or with Biology as a freshman or sophomore. Historically (I am remembering the 10th grade), Biology seems be the starting point for specific science disciplinary content because it is fairly easy to learn on a superficial level and is directly related to our own structure and function. Chemistry and Physics are viewed as two rungs higher in difficulty and are deferred to the junior and senior years, respectively. Physics last is based on the notion that physics requires four years of mathematics, which is pursued in parallel with science instruction.

Physics is the most fundamental and elemental science of matter, energy, and forces. Chemistry represents the next order of complexity, describing the structural relationships between atoms and molecules, and their functional interactions in chemical reactions. Biological structure, development, and function of individual organisms represents the most complex organization, requiring knowledge of physics, chemistry, and mathematics to understand the functional relationships among organelles, cells, tissues, organs, anatomical systems, morphology, behavior, and disease, and how natural selection evolves populations of organisms. The sequence of physics followed by chemistry, and biology is more logical in terms of organizing our knowledge of how the universe as we know it is built and evolves life, and is followed in European high schools. Clearly, the Europeans do not consider a lack of mathematics to be an impediment to learning physics prior to chemistry and biology. The American Association of Physics Teachers also advocates for Physics First in the American high school science curriculum (AAPT, 2002). Their data indicate that placing physics first in the high school science curriculum has proven equally or more successful in learning physics than the traditional sequence (see Physics First Resources at www.aapt.org/Resources/physicsfirst.cfm).

Other approaches that have been suggested are to teach physics, chemistry and biology each year from the seventh grade on as integrated subjects, or organizing science teaching around broad unifying themes such as health, environment, evolution, and energy (Steen, 1991). The AAAS (1993) and the National Research Council (1996) defined several overarching concepts that appear in all scientific disciplines and build connections between these disciplines. The concepts are (1) systems, order and organization, (2) evidence, models and explanation, (3) constancy, change and measurement, (4) evolution and equilibrium, (5) form and function, and (6) energy. For example, Kitzmann & Otto (2008) have described how these themes can be used in teaching chemistry.

Clearly, the quality of instruction, and thus science literacy, in the K-12 curriculum depends on the extent and quality of training given the teachers who will be designing and implementing science curricula. Assurance of this quality is the responsibility of the university programs that educate K-12 teachers. University teacher education programs, however, vary widely in their mix of emphasis on disciplinary content and education courses and are often looked upon by the “hard science” disciplines as lacking in rigor due to their perceived emphasis on education courses. Science instruction at the elementary level is considered ineffective by most scientists because it is too low in quality and too infrequent. This is due to an inadequate science background of elementary teachers traceable to the fact that of all their college courses, they dislike science the most and avoid it as much as possible (Tilgner, 1990). This dislike is transferred to our children and compromises their potential to be discerning citizens. Change is possible, however, by demanding greater and more rigorous exposure to science in elementary teacher education curricula.

In my view, the best curricula for preparation of high school teachers are those requiring a major in a discipline such as biology, physics, or mathematics with a minor in education. The need for rigorous instruction in subject matter cannot be overemphasized. Berkman and Plutzer (2015) found, for example, that over half of biology teachers did a poor job of teaching evolution or avoided the subject altogether because they lacked the necessary knowledge to teach evolution properly. In addition, a lack of opportunity to explore and discuss evolution in the light of their personal beliefs also contributed to student's avoidance of the subject, leaving them unable to reconcile their religious beliefs with what they learned about evolution. Interestingly, this problem was greatest in secular universities, which were reluctant to discuss evolution in connection with religious beliefs. Students in Catholic universities, where such discussion took place, were much more comfortable with, and better prepared to teach, evolution.

Knowledge of content matter alone is not enough to ensure that someone will be a good science teacher, although the argument has been made that a disciplinary major is all that is required and that people with university science degrees should be able to bypass requirements for education courses and teacher training to become certified as teachers. Many people with science degrees only who have worked in industry or universities do have an enthusiasm and knack for explaining science, particularly to more advanced students. Most, if not all, however, could profit from research on pedagogy and the developmental and social psychology of children and teenagers, and particularly from the experience of veteran teachers. Students develop at different rates intellectually and socially and have different levels of emotional maturity that affect their response to learning situations. Good teachers understand the best ways to develop their students' mental capacities and personal maturation, and inspire them to want to learn. This requires an ability to integrate age-appropriate science and mathematics content with developmental age, a skill that requires the kind of knowledge obtained through education research.

Another problem in developing scientific literacy is the chronic shortage of high school science teachers, especially in schools that have high numbers of disadvantaged and minority students. The reasons for this are many, but include low prestige and salary, and difficult working conditions, to say nothing of the often impoverished and violent conditions in which these students grow up. Mervis (2015) has reviewed some approaches to increasing the number and quality of science teachers. For example, K-12 schools might take advantage of retired scientists within their communities as volunteers or people who desire to have second careers. The AAAS sponsors a program called Senior Scientists and Engineers (SSE) to promote this idea (Swan, 2013). The NSF-supported Robert Noyce Teacher Scholarship Program has sought since 2002 to increase the number of qualified science teachers in the poorest schools of every state by awarding scholarships to undergraduates who want to be science teachers, and fellowships to persons who already hold an undergraduate degree so they can earn MS degrees in science education. A recent evaluation, however, indicated that the program has made little overall difference in the level of student achievement or teacher production, despite some individual successes. An argument that makes more sense is that spending money on retaining current science teachers would be more effective, particularly by identifying master teachers and paying them to become models and mentors for less-experienced teachers.

Attempts to inject politics and religion into the schools constitute another impediment to the development of scientific literacy during the K-12 years. This happens most often when teachers introduce such controversial issues as climate change. For example, teachers and administrators have come under attack in their communities for discussion of the hypothesis that human activity is playing a role in warming of the climate (Reardon, 2011). Much of the science taught in the schools is not controversial, but there is nothing wrong with having students explore and discuss controversial science, since such exploration requires more rigorous examination of evidence and thinking that can only enhance scientific literacy. Doing so does require that teachers be well versed on the issues and honest with students about what is known and not known. Scientists, for their part, need to engage with and be supportive of those who are responsible for creating the environment in which students learn.

Public University Education Does Little to Encourage Scientific Literacy

Higher education appears to do little or nothing for scientific literacy, or civic literacy in general. In the eyes of scientists and corporate CEOs, both university provosts and students have an overinflated view of the knowledge and competency acquired by college graduates (Grasgreen, 2014; Funk & Rainie, 2015), consistent with an analysis by Arum and Roska (2011) indicating that undergraduates learn very little during their university years. In studies carried out from 2006-2010, the Intercollegiate Studies Institute (ISI, 2011) found the overall civic literacy of college freshmen and seniors to be extremely low. Furthermore, a university education appeared to exert no influence one way or another on the engagement of graduates in the political process beyond voting. Civic knowledge gained by self-education was more effective than a college degree in encouraging active civic engagement.

In a longitudinal study of young adults (Generation Xers) Miller (2012) found that 44% were scientifically literate, much higher than the general public average of 29%. Miller attributes this performance to the fact that many universities in the United States have a general education requirement to take at least one science course. I do not believe, however, that this finding indicates our universities are doing a good job of undergraduate education. There has always been a strong view that universities (particularly large state universities) are more interested in research and big-time athletics than undergraduate education (this does not apply to most liberal arts colleges, or community colleges). This view has intensified over the last two decades as tuition has skyrocketed and people have begun to realize that universities constantly try to convince " … otherwise intelligent people that their children must have a sub-par, dubiously useful product and then charge them through the nose for it" (Schlichter, 2013, p. 2).

While acknowledging the exceptions, undergraduate science teaching is particularly poor in the public research universities, which are held up as shining symbols by their states. Introductory science courses are the largest and most poorly organized and taught. For the majority of students enrolled in them, these courses fulfill a general education requirement, and they often turn off even those students who want to be science majors. They are filters rather than enablers. Quoting Steen (1991, p.19), "At their best, they offer the two-dimensional shadow of a rich, multi-dimensional world; at their worst—which is all too often—they dash motivation and produce another wave of science avoiders ready to convey their attitudes about science to their children."

To increase scientific literacy, the quality of entry-level science courses clearly needs to be improved in all public universities. The quality of more advanced instruction provided to science majors is also important to scientific literacy in general, because the professions taken up by college graduates so often intersect with public interests and issues. Many universities have adopted undergraduate research experiences (UREs) to provide hands-on learning for science majors, and these have been popular with students. However, UREs take up a great deal of faculty and student time, money and effort (Linn et al., 2015). Having been a faculty mentor for UREs, I have found their implementation to be poorly designed. Most students enroll late in their college career for one or two semesters in a mentor's laboratory. Course work competes for laboratory time, and there is little opportunity for truly independent work. To be effective, a URE needs to be part of a structured university program, not just a hit-or-miss encounter with an individual laboratory. Such a program would immerse students in research at progressively deeper levels over the whole course of their undergraduate career and carefully integrate research and course work.

An interesting and less costly alternative to UREs is C.R.E.A.T.E., which stands for Consider, Read, Elucidate hypotheses, Analyze and interpret data, and Think of the next Experiment (Hoskins, Stevens, & Nehm, 2007; Hoskins, Lopatto, & Stevens, 2011). This approach uses intensive analysis of the primary literature to demystify and humanize science. C.R.E.A.T.E. has been demonstrated to increase student's confidence in their ability to analyze primary literature, improve their ability for critical thinking and content integration, enhance their understanding of who does science and why, and enable insight into the processes of science and the student's own beliefs about learning. The purpose of C.R.E.A.T.E. is to enhance the retention of students interested in a biology career, but some version of the approach might be valuable for increasing the science literacy of undergraduates for whom a science course is a general education requirement.

I wish now to turn to a more fundamental problem, widely discussed but steadfastly ignored, that is the major contributor to poor undergraduate teaching and thus an impediment to the acquisition of scientific literacy. By far the largest share of undergraduate teaching in public higher education is done in medium-sized public universities, and community colleges. The available state resources for public university education, however, flow disproportionately to the huge research universities that have assumed the mantle of "flagships." Driven by an insatiable arms race for research and athletic prestige that has become the end-all of their existence, these universities have transformed public higher education into a dysfunctional caste system (Fairweather, 1996; Astin, 1999; Rhode, 2006; Nichol, 2008; Wilson, 2010; Stocum, 2001; 2013; Berlinerblau, 2015). The archetype scholarly history of this transformation is Page Smith's *Killing the Spirit: Higher Education in America.* Written in 1990, this fascinating book details the long-standing arrogance of the research university and its cynicism toward undergraduate education, which has become even more pronounced over the intervening 25 years.

The flagships sell undergraduate education, but reward only research that produces grants and publications (Smith, 1990; Fairweather, 1996; Remler & Pema, 2009). They have devalued undergraduate learning to the point where the prestige (and salary) of individual professors is inversely proportional to the amount of teaching they do. Sperber (2000) argued that flagship public universities substitute alcohol-fueled sports entertainment for education. Armstrong and Hamilton (2013) in their book *Paying for the Party: How College Maintains Inequality* describe how a large Midwestern flagship provides young women of privileged social status with a non-rigorous "party pathway" through the university and into subsequent careers. The quality of undergraduate education at most flagships is marginal at best, yet incredibly their "brands" set the standards for respect by which other less-resourced public universities are measured. The increasing financial and social inequality between flagships and other state universities has also resulted in a structure with two tiers of faculty: a high-paid tenured research faculty and a lower paid non-tenured teaching faculty featuring a high percentage of adjunct instructors and graduate teaching assistants. This division clearly reflects the idea that teaching is a less worthy mission than research, which undermines undergraduate education as the core mission of higher education and damages efforts to promote scientific literacy.

The caste system is justified under the euphemism of "mission differentiation," a half-baked notion that has no real educational value, but serves only to preserve and exacerbate institutional inequalities (Stocum, 2001; 2013). To increase the quality of undergraduate education across the board it will be essential to eliminate funding formulas based on research prestige and make quality undergraduate education the highest priority for state funding and use of tuition dollars. Teaching professors should be paid on a par with research professors. Reforms are needed to eliminate the inequities suffered by adjunct professors, who have assumed the heaviest role in undergraduate education. A model for such reform has been implemented at the University of Denver that hopefully will galvanize reforms elsewhere (Flaherty, 2015). We must stop overemphasizing research as a prestige marker, synergize research excellence *per se* with teaching, put research professors back in the undergraduate classroom, and decrease the size of PhD programs. More extreme solutions would be to spin the university research function off into institutes (Stocum, 2013) and big-time athletics into semi-pro leagues (Duderstadt, 2002). Where universities are part of a system, the flagships should not be allowed to dominate and suppress the development of other campuses. Ultimately, if the flagships cannot kick their addiction to research prestige, money, and power, high school students should be counseled to choose colleges that view teaching and research as equally valuable, or which make teaching their sole focus, depending on how they choose to use their resources.

In a recent book titled *The End of College*, Kevin Carey (2015) makes a case for doing an end-run around the lack of research university interest in undergraduate education by offering a rigorous, high-quality and low-cost education through MOOCs (massive open online courses—actually curricula). The lectures for such curricula would be those given by famous professors at research universities known for their teaching excellence, and distributed by platforms such as Coursera and EdX to anyone in the world who has access to the Internet. The advocates of this approach believe it is possible, based on the huge amount of data currently being collected about how students learn to use this online technology to personalize instruction. These developments are viewed by their proponents as the educational equivalent of the asteroid that did in the dinosaurs, allowing the small mammals to diversify across the globe. Because literally billions of people across the planet can be taught through the Internet in this way, the level of basic scientific literacy could be elevated. Detractors say this kind of education may be suitable for mature adults, but that most 18-22 year olds learn best by face-to-face interaction with professors. Still others (I count myself among them) think a combination of face-to-face interaction augmented by electronic learning is best. The next five years will be an interesting sorting out period.

SCIENTIFIC LITERACY IS SUBORDINATED TO WORLDVIEW

Returning to the subject of the effects of religion and politics on acquiring and using scientific literacy, scientists and educators like to think that having an open mind, data, logic, statistics, and probability will lead people to converge on correct conclusions. Social science research strongly suggests that this is not so (Suhay & Druckman, 2015). The types of science that are funded, the data gathered, the applications of scientific research, and even the way the scientific method is employed are all influenced by moral, religious, and political value systems that constitute our worldviews, or ideologies (Storr, 2014; Suhay & Druckman, 2015). This means that the general public evaluates information within the context of their worldview, or ideology.

Development of our worldview begins early in life through interactions with our parents, who we love and want to please. Their worldviews are often transferred to us and provide a context within which our intellectual and emotional growth takes place. As we mature and seek our own personal identity, our views will be both solidified and modified to some degree through interactions with peers and teachers. By the time we are adults, the worldview we will carry for the rest of our lives has been largely established by the interplay of these forces. This is not to say, however that our views cannot be changed by compelling evidence (see ahead), or intense experiences that transform our thinking.

Psychological research suggests that our worldviews are maintained by channeling our reasoning through an emotional filter designed to create self-deception (Deweese-Boyd, 2010; Bortolotti & Mameli, 2012). Thus people tend to search for, interpret or recall information that confirms their worldview, regardless of whether or not the information is true (Nickerson, 1998). This phenomenon, termed “confirmation bias” has long been known to psychologists and is the basis for the feeling of “truthiness,” a clever term introduced by Stephen

Colbert. We tend to divide along what we call left biased (liberal) and right biased (conservative) ideologies defined by the proportions of collectivist vs. individualist leanings we have. Some research even suggests that the development of left vs. right worldviews may be the result of genetic- or epigenetic-based physiological and psychological predispositions fortified by environment (Doll, Hutchinson, & Frank, 2011; Hibbing, Smith, & Alford, 2014; Weeden & Kurzban, 2014).

Confirmation bias is well illustrated in the debate over the risks posed by climate change. In general, those who think the risks are high have a liberal worldview and those who are skeptical of such risks have a conservative worldview. Kahan et al. (2012) tested whether the level of perceived risk in either group correlates with their level of scientific literacy (the "Science Comprehension Thesis," SCT) or with their ideology (the "Cultural Cognition Thesis," CCT). The scientific and mathematical literacy of all subjects was measured using the NSF Science and Engineering Indicators plus a set of 14 mathematical questions. The SCT predicted that level of scientific literacy would correlate with degree of perceived risk, whereas the CCT predicted that risk level would correlate with worldview. The result was that risk perception correlated with worldview, not scientific literacy. Furthermore, the study indicated that acquisition of more data on climate change changed no one's mind, but simply strengthened the correlation via confirmation bias. One would predict the same to be true for other controversial issues.

In his insightful book *The Unpersuadables*, Will Storr (2014) describes several cases of extreme belief in the "truthiness" of unlikely things such as alien abduction. Storr probes the psychology underlying such beliefs, using insights gained from interviews with the believers themselves and the research of those who have written on the subject of confirmation bias (e.g., Nickerson, 1998; Klein, 2011). He makes the case that as we develop, the brain uses our experiences to build and use virtual models of reality for us to exist in. These models have a high unconscious emotional content and are defended throughout life; they serve to preserve positive emotions, deny unpleasant or disturbing facts, or satisfy some other pressing psychological need. We preserve mental models through confabulation, the generation of powerful stories and false memories to explain and justify what we do and believe, becoming the Hero who thinks we control our own destiny. In essence, we are delusional, which explains, as Storr writes, " … why intelligence is no force-field and facts are no bullets (Storr, 2014, p. 310).

Is the existence of confirmation bias inevitable? The answer, I think, is yes. The only totally objective beings are the fictional Mr. Spock and Mr. Data of *Star Trek*. Is it an incurable disease? Yes, it is incurable, but it is not a disease. As much of an impediment as it may seem, I would argue that evolution has built confirmation bias into our DNA. On the individual level it aids us in forming and maintaining relationships; on the population level it serves the purpose of generating group cohesiveness. Furthermore, the existence of confirmation bias can serve the function of forcing us to think more deeply about our ideas and concepts in ways that lead to replacing old concepts with better ones. This is certainly what the professional lives of academics in general is based upon, and which in the form of the scientific method, or other means of acquiring evidence, can change worldview. The history of science and philosophy is replete with examples, such as the work of Kepler, Galileo, Descartes, and Newton in the 17th century.

THE SCIENTIFIC METHOD CAN ALTER WORLDVIEW

Anyone who has worked in science knows that scientists have their own worldviews and confirmation biases about what is correct and what isn't, based on the current state of the evidence, and on their own ego-involvement. These biases change as new ideas emerge that are able to reconcile seemingly opposing sets of data and which have greater explanatory and predictive power. The reputations of scientists depend on their ability to see when ideology opposed to evidence and predictive power no longer makes sense. Adherence to the scientific method, willingness to take all the evidence into account, and peer review is what keeps scientists honest. The scientific method is the reason why, despite the impediments of confirmation bias, we have been able to advance our science and technology over the last four centuries. This is perhaps the major reason to foster scientific literacy to the greatest degree possible.

At any given time, we have "settled" science vs. "unsettled" science. Settled science rests on evidence that points consistently in one direction. Thus, there is high consensus among scientists and to a lesser extent the public for the correctness of ideas such as the big bang theory of the origin of the universe, movement of tectonic plates, climate change over hundreds or tens of thousands of years, mass extinctions, and the sequence of bases in DNA as the blueprint of life. In mathematics, rigorous proofs have established the correctness of many theorems.

Unsettled science, on the other hand involves data that can be interpreted in multiple ways; for example data collected on the effects of diet on heart disease, which have been wildly contradictory (Harcombe et al., 2015). I wish to point out here that a central tenet of science is that every scientific consensus is nevertheless provisional and must be modified if new evidence demands it, and/or new ideas prove to have better explanatory power than established ones.

When radical new ideas threaten the scientific status quo, a struggle erupts and the innovators know they will be subjected to the intense critique and demand for proof necessary to supplant an old idea with a new one. In the end, the new idea, if successful, is stronger for the vetting it must endure. Any confirmation bias, no matter how strong, must crumble in the face of greater evidentiary strength and explanatory power. (This does not necessarily apply, however, to confirmation bias scientists may hold in arenas other than science!)

A good example of how a strong scientific confirmation bias has been broken by a new idea is illustrated by the search for the cause of spongiform neurodegenerative diseases, which include Kuru, once suffered by inhabitants of the northern highlands of New Guinea, bovine spongiform encephalitis (BSE, mad cow disease), and its human counterpart Creutzfeldt-Jakob disease. These mysterious ailments are infectious and take a long time to develop. A staple of biomedical science is that microorganisms transmit infectious diseases; thus infection by a slow-acting virus was postulated to be the cause of these neurodegenerative aliments. However, all attempts to isolate the virus (or any other infective microorganism) and demonstrate its infectivity were unsuccessful.

In the 1980s, Stanley Prusiner at UCSF postulated a radical new mechanism of infectivity in these diseases: the mutation of a cell membrane protein called the prion protein to a form that enabled it to recruit and convert normal prion proteins to the mutant form. In his fascinating autobiography *Madness and Memory* (2014), Prusiner recounts his experiments that proved the prion hypothesis to be correct, for which he was awarded the Nobel Prize in 1997, amidst the bitter opposition of those who clung to the slow virus hypothesis. Mutant prions could be transmitted by ingestion of the tissues harboring them, allowing them to spread their molecular subversion. The transmission of Kuru was due to the practice of ritual cannibalism, in which the living ate the brains of those who died from the disease. Kuru disappeared once this practice had ceased. The prion hypothesis has provided a unifying framework to explain the increasing chance of developing a neurodegenerative disease with age. Today, Parkinson's disease, Alzheimer's disease and amyotrophic lateral sclerosis (ALS, Lou Gehrig's disease) are also strongly suspected of being prion-like diseases (Polymenidou & Cleveland, 2011; Jucker & Walker, 2013).

CONNECTING SCIENCE TO SOCIETY

The evidence suggests that *convincing people to change their minds* on contentious issues through more and better science alone is not the most viable approach to the creation of rational policies that require scientific knowledge. While we should always strive for elevating the public level of scientific literacy and giving more accurate and better-explained science to policymakers, the notion is growing that scientists should listen as well as speak (Leshner, 2015), and frame their communications and arguments with the public and policymakers in terms of their relevance to things that are common to, and have a clear connection with, the basic needs and aspirations of people rather than stressing the idealistic "rightness" of the arguments (Nisbet & Scheufele, 2007). These frames predominantly revolve around economic, physical, and social wellbeing. Kahan et al. (2012) suggest that science communicators should adopt methods of communication in which accepting the best available science does not threaten any group's values. Effective strategies would include using communicators whose affinity with different communities enhances their credibility and framing policy solutions that resonate with diverse groups. We need to include in our discussions how alternative policies on issues such as environmental protection, renewable energy and climate change would affect us economically, health-wise, and socially. Perhaps most importantly, scientists and policymakers alike need to respect each other's knowledge base and insights.

Hoffman (2015) points out that most scholars do not see a role for themselves in public engagement and are reluctant to make their voices heard on matters of public policy and decision-making. Quoting Hoffman, “Academic success lies in publishing academic journal articles that make incremental contributions to theory, not in summarizing the broader contributions of the community of scholars” (Hoffman, 2015, p. A48). Academics are fixated on being “brick makers,” rather than policy shapers. Joanne Carney, Director of Government Relations at AAAS, has pointed out that many younger scientists would like to contribute to the intersection between science and society by becoming better communicators to lay audiences (Carney, 2014). She stresses, however, that to be effective requires understanding the broader context within which the debate over science policy is conducted, and cites the success of the AAAS Science and Technology Policy Fellowships in fostering effective communication.

Nisbet and Scheufele (2007) bring up another problem getting in the way of effective communication with special interest groups, citizens, and stakeholders. In their chase for grant funding, publication, and prestige, scientists too often engage in hyperbole and false spin. In framing our arguments, we need to present the evidence for and against hypotheses without hyperbole, and be honest about what is known and what is not. Related to this problem is the tendency of many science writers to inject too much wow-factor into their reports for newspapers, press releases, and other short publications. This is to be contrasted with serious first-rate science journalists such as Natalie Angier, Gina Kolata, Nicholas Wade, and Cynthia Fox, who avoid uncritical wonder-of-science stories, are willing to analyze or comment on controversial issues, and also do a public service by exposing the seamy side of science involving unproven and unethical cures for diseases, vested interests, and outright frauds (Watts, 2014). And it goes without saying that good science journalists constitute a wonderful source of science literacy to the general public.

CONCLUSION

Scientific literacy is essential to live fully in a society that has been constructed on science and technology. Our current measures, however, indicate a low level of public scientific literacy in the Unites States relative to the scope and complexity of the issues we face that require scientific knowledge. Politics, religious beliefs, and fear cloud our ability to evaluate important scientific issues such as vaccination, GMO foods, evolution, and climate change. Information, regardless of its validity, is used to support ideology, making voting decisions and the formulation of legislative policies requiring scientific knowledge more value-laden than objective. Our worldview, however, may be essential for our individual psychological wellbeing and social cohesiveness, and thus must be taken into consideration in connecting the dots between science and society. Though scientists themselves are ideological, the necessity to follow the scientific method ultimately favors evidence over ideology, and can trump worldview. Our educational system is the primary venue for developing scientific literacy, but will not be maximally effective until changes are made in K-12 teacher education curricula and the elimination of the public university caste system that devalues undergraduate education. Meanwhile, scientists can do much to promote science literacy and help connect science to policy-making through communication with schools, civic organizations, and governing bodies.

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