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Nature of Science, Scientific Inquiry, and Socio-Scientific Issues Arising from Genetics: A Pathway to Developing a Scientifically Literate Citizenry

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Abstract The primary focus of this article is to illustrate how teachers can use contemporary socio-scientific issues to teach students about nature of scientific knowledge as well as address the science subject matter embedded in the issues. The article provides an initial discussion about the various aspects of nature of scientific knowledge that are addressed. It is important to remember that the aspects of nature of scientific knowledge are not considered to be a comprehensive list, but rather a set of important ideas for adolescent students to learn about scientific knowledge. These ideas have been advocated as important for secondary students by numerous reform documents internationally. Then, several examples are used to illustrate how genetically based socio-scientific issues can be used by teachers to improve students' understandings of the discussed aspects of nature of scientific knowledge.

1 Introduction

The phrase "scientific literacy" has been around for over half a century and its connection to an understanding of nature of scientific knowledge and scientific inquiry was, perhaps, most formalized by the work of Showalter (1975) and by a National Science Teachers Association position statement on science-technology-society (NSTA 1982). According to the National Research Council (1996), the scientifically literate individual possesses the knowledge and understanding of scientific concepts and processes that are necessary for making informed decisions on personal and societal issues. Although the aforementioned citations are from a US author and a US professional organization, scientific literacy has become a primary goal of science education throughout the world (Roberts 2007). Beyond the aforementioned documents' general descriptions of scientific literacy, one finds much variability in the specific lists of attributes that characterize a scientifically literate person. For example, Roberts (2007) in his exhaustive review of how literacy is conceptualized within the science education community found two different "visions" of literacy, often

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used synonymously, but that really have two very different meanings. These different visions are labeled as "science literacy" and "scientific literacy." Science literacy, the phrase used by the American Association for the Advancement of Science (1993) focuses on the knowledge, processes, and products of science. Scientific literacy includes the knowledge of science, but also extends to applications of this knowledge to make decisions about personal and societal situations that have science and non-science components. The purpose here is not to debate the relative merits of these two different visions. Indeed, the vision focused upon in this paper is more aligned with scientific literacy as opposed to science literacy.

Details aside, scientific literacy has always been at least partially associated with an individual's ability to make informed decisions about scientifically-based personal and societal issues. However, meeting the stipulations of what it means to be scientifically literate requires that an individual understand subject matter, nature of scientific knowledge (NOS), and scientific inquiry (SI). In short, for an individual to make informed decisions about scientifically-based issues he/she must be able to weigh the claims and evidence against the characteristics inherent to scientific knowledge (NOS) and its development (SI).

Unfortunately, after over 60 years of research on nature of scientific knowledge (NOS) there remains some confusion about the meaning of the construct. The situation, although shorter-lived, is the same for scientific inquiry (SI). Consequently, it is important that a clarification of these two important constructs be provided.

2 What Do We Mean by Nature of Scientific Knowledge (NOS)?

Before being specific about NOS, it is important to stress that we (my colleagues and fellow researchers) *are not* advocating a definitive or universal definition of the construct. We have never advocated that our "list" is *the* only list/definition. Unfortunately, readers have read past our words (Lederman 2007; Matthews 2012; Irzik and Nola 2011) and think we are stressing more than we are. Debates about a "definitive" description of NOS abound, but are hardly productive. What we prefer readers to focus on are the understandings we want students to have. The understandings need not be limited to those we have selected, but we welcome discussions about whether our focus is scientifically, developmentally, and educationally appropriate. The same is true for our discussion of scientific inquiry that follows later. That said, let us begin to unpack the construct of NOS.

The phrase "nature of scientific knowledge" typically refers to characteristics of scientific knowledge that are inherently derived from the manner in which it is produced, that is scientific inquiry (Lederman 1992). Beyond these general characterizations, no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS. This lack of consensus, however, should neither be disconcerting nor surprising given the multifaceted nature and complexity of the scientific endeavor. Conceptions of NOS have changed throughout the development of science and systematic thinking about science and are reflected in the ways the scientific and science education communities have defined the phrase "nature of scientific knowledge" during the past 100 years (e.g., AAAS 1990, 1993; Center of Unified Science Education 1974; Central Association of Science and Mathematics Teachers 1907; Klopfer and Watson 1957; NSTA 1982). Indeed, during the 1980s the phrase "nature of scientific knowledge" was shortened to "nature of science." There is little doubt that this shift in language introduced some confusion that continues today. Nature of science, in the research literature, refers to the nature of scientific knowledge and this is the definition that is used in this paper.

It is our view, however, that many of the disagreements about the definition or meaning of NOS that continue to exist among philosophers, historians, and science educators are irrelevant to K-12 instruction. The issue of the existence of an objective reality as compared to phenomenal realities is a case in point. While fodder for a lively discussion in a philosophy of science class, it makes little sense to engage young science students in a discussion of whether *all* observation is actually a function of human inference. We must keep in mind the goal, which is to develop students' understanding of the difference between observation and inference and the implication for the development of scientific knowledge. To this point, we argue that there is a developmentally appropriate level of generality regarding NOS that is accessible to K-12 students and relevant to their daily lives. Moreover, at this developmental level, little disagreement exists among philosophers, historians, and science educators (American Association for the Advancement of Science 1993; NRC 1996). Among the characteristics of the scientific enterprise corresponding to this level of generality are that scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective, necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws. What follows is a brief consideration of these characteristics of science and scientific knowledge.

First, students should be aware of the crucial distinction between observation and inference. In the K-12 science classroom observations are presented as descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. For example, objects released above ground level tend to fall and hit the ground. By contrast, inferences are presented as statements about phenomena that are not "directly" accessible to the senses. For example, objects tend to fall to the ground because of "gravity." The notion of gravity is inferential in the sense that it can *only* be accessed and/or measured through its manifestations or effects. Examples of such effects include the perturbations in predicted planetary orbits due to inter-planetary "attractions," and the bending of light coming from the stars as its rays pass through the sun's "gravitational" field.

Second, closely related to the distinction between observations and inferences is the distinction between scientific laws and theories. Individuals often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. It follows from this notion that scientific laws have a higher status than scientific theories. Both notions, however, are inappropriate because, among other things, theories and laws are different kinds of knowledge and one cannot develop or be transformed into the other. *Laws are statements or descriptions of the relationships among observable phenomena.* Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. *Theories, by contrast, are inferred explanations for observable phenomena.* The kinetic molecular theory, which explains Boyle's law, is one example. Moreover, theories are as legitimate a product of science as laws. Scientists do not usually formulate theories in the hope that 1 day they will acquire the status of "law." Scientific theories, in their own right, serve important roles, such as guiding investigations and generating new research problems in addition to explaining relatively huge sets of seemingly unrelated observations in more than one field of investigation. For example, the kinetic molecular theory serves to explain phenomena that relate to changes in the physical states of matter, others that relate to the rates of chemical reactions, and still other phenomena that relate to heat and its transfer, to mention just a few. While philosophers of science may contend that our descriptions of laws and theories leaves something to be desired, this level of generality has evidenced itself as appropriate and accessible to K-12 science students.

Third, even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a totally lifeless, rational, and orderly activity. Science involves the *invention* of explanations and the generation of ideas and this requires a great deal of creativity by scientists. The "leap" from atomic spectral lines to Bohr's model of the atom with its elaborate orbits and energy levels is a case in point. This aspect of science, coupled with its inferential nature, entails that scientific concepts, such as atoms, black holes, and species, are functional theoretical models rather than faithful copies of reality.

Fourth, scientific knowledge is subjective. Scientists' beliefs, previous knowledge, training, experiences, and expectations, in addition to any theoretical commitments, actually influence their work. All these background factors form a *mind-set* that *affects* the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge; while not intended, it is, nonetheless, unavoidable. It is noteworthy that, contrary to common belief, science never starts with neutral observations (Chalmers 1982). Observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives. For example, a researcher operating from a Darwinian framework might focus his/her efforts on the location of transitional species. By contrast, from a punctuated equilibrist perspective transitional species would not be expected nor would what a Darwinian considered a transitional species be considered as such (see Gould and Eldridge 1977).

Fifth, science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion. An example may help to illustrate how social and cultural factors impact scientific knowledge. Telling the story of the evolution of humans (*Homo sapiens*) over the course of the past seven million years is central to the biosocial sciences. Scientists have formulated several elaborate and differing story lines about this evolution. Until recently, the dominant story was centered about "the man-hunter" and *his* crucial role in the evolution of humans to the form we now know (Lovejoy 1981). This scenario was consistent with the white-male culture that dominated scientific circles up to the 1960s and early 1970s. As the feminist movement grew stronger and women were able to claim recognition in the various scientific disciplines, the story about hominid evolution started to change. One story that is more consistent with a feminist approach is centered about "the female-gatherer" and *her* central role in the evolution of humans (Hrdy 1986). It is noteworthy that both story lines are consistent with the available evidence.

Sixth, it follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including “facts,” theories, and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in *theory* and technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs. It should be emphasized that tentativeness in science does not only arise from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded. There are also compelling logical arguments that lend credence to the notion of tentativeness in science. Indeed, contrary to common belief, scientific hypotheses, theories, and laws can *never* be absolutely “proven.” This holds irrespective of the amount of empirical evidence gathered in the support of one of these ideas or the other (Popper 1963, 1988). For example, to be “proven,” a certain scientific law should account for *every single instance* of the phenomenon it purports to describe *at all times*. It can logically be argued that one such future instance, of which we have no knowledge whatsoever, may behave in a manner contrary to what the law states. As such, the law can never acquire an absolutely “proven” status. This equally holds in the case of hypotheses and theories.

Finally, it is important to note that individuals often conflate NOS with science processes (which are more consistent with scientific inquiry). Although these aspects of science overlap and interact in important ways, it is nonetheless important to distinguish the two. Scientific processes are activities related to collecting and analyzing data, and drawing conclusions (AAAS 1990, 1993; NRC 1996). For example, observing and inferring are scientific processes. On the other hand, NOS refers to the epistemological underpinnings of the activities and products of science. As such, realizing that observations are necessarily constrained by our perceptual apparatus belongs within the realm of NOS.

Professional development efforts designed for teachers must not conclude, as they have in the past, with the development of adequate teacher understandings. The research is quite clear that teachers’ understandings do not automatically translate into classroom practice (Lederman 2007). Certainly, teachers must have an in-depth understanding of what they are expected to teach. However, professional development efforts must also emphasize how teachers can successfully facilitate the development of students’ understandings of NOS.

3 What Do We Mean by Scientific Inquiry (SI)?

Although closely related to science processes, scientific inquiry (SI) extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. From the perspective of the *National Science Education Standards* (NRC 1996), students are expected to be able to develop scientific questions and then design and conduct investigations that will yield the data necessary for arriving at conclusions for the stated questions. The *Benchmarks for Science Literacy* (AAAS 1993) are a bit less ambitious as they do not advocate that all students be able to design and conduct investigations in total. Rather, it is expected that all students at least be able to understand the rationale of an investigation and be able to critically analyze the claims made from the data collected. Scientific inquiry, in short, refers to the systematic approaches used by scientists in an effort to answer their questions of interest. Pre-college students, and the general public for that matter, believe in a distorted view of SI that has resulted from schooling, the media, and the format of most scientific reports. This distorted view is called 'The Scientific Method'. That is, a fixed set and sequence of steps that all scientists follow when attempting to answer scientific questions. A more critical description would characterize 'The Method' as an algorithm that students are expected to memorize, recite, and follow as a recipe for success. The visions of reform, however, are quick to point out that there is no single fixed set or sequence of steps that all scientific investigations follow. The contemporary view of SI advocated is that the questions guide the approach and the approaches vary widely within and across scientific disciplines and fields.

At a general level, SI can be seen to take several forms (i.e., descriptive, correlational, and experimental). Descriptive research is the form of research that often characterizes the beginning of a line of research. This is the type of research that derives the variables and factors important to a particular situation of interest. Whether descriptive research gives rise to correlational approaches depends upon the field and topic. For example, much of the research in anatomy and taxonomy are descriptive in nature and do not necessarily progress to experimental or correlational types of research. The purpose of research in these areas is very often simply to describe. On the other hand, there are numerous examples in the history of anatomical research that have led to more than description. The initial research concerning the cardiovascular system by William Harvey was descriptive in nature. However, once the anatomy of blood vessels had been described, questions arose concerning the circulation of blood through the vessels. Such questions led to research that correlated anatomical structures with blood flow and experiments based on models of the cardiovascular system. To briefly distinguish correlational from experimental research, the former explicates relationships among variables identified in descriptive research and the latter involves a planned intervention and manipulation of variables related in correlational research in an attempt to derive causal relationships. In some cases, lines of research can been seen to progress from descriptive to correlational to experimental, while in other cases (e.g., descriptive astronomy) such a progression is not necessarily relevant.

The perception that a single scientific method exists owes much to the status of classical experimental design. Experimental designs very often conform to what is presented as 'The Scientific Method' and the examples of scientific investigations presented in science textbooks most often are experimental in nature. The problem, of course, is not that investigations consistent with "the scientific method" do not exist. The problem is that experimental research is not representative of scientific investigations as a whole. Consequently, a very narrow and distorted view of SI is promoted in our K-12 students.

Scientific inquiry has always been ambiguous in its presentation within science education reforms. In particular, inquiry is perceived in three different ways. It can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation. It can also be viewed as a cognitive outcome that students are to achieve. In particular, the current visions of reform are very clear (at least in written words) in distinguishing between the performance of inquiry (i.e., what students will be able to do) and what students know about inquiry (i.e., what students should know). For example, it is one thing to have students set up a control group for an experiment, while it is another to expect students to understand the logical necessity for a control within an experimental design. Unfortunately, the subtle difference in wording noted in the reform documents (i.e., "know" versus "do") is often missed by everyone except the most careful reader. The third use of "inquiry" in reform documents relates strictly to pedagogy and further muddies the water. In particular, current wisdom advocates that students best learn science through an inquiry-oriented teaching approach. It is believed that students will best learn scientific concepts by doing science. In this sense, "scientific inquiry" is viewed as a teaching approach used to communicate scientific knowledge to students (or allow students to construct their own knowledge) as opposed to an educational outcome that students are expected to learn about and learn how to do. Indeed, it is the pedagogical sense of inquiry that it is unwittingly communicated to most teachers by science education reform documents, with the two former senses lost in the shuffle. Just to reiterate, we definitely do not want to communicate, through our separate discussions, that NOS and SI are discrete aspects of science. Clearly they overlap and intimately interact in the development and ontological status of scientific knowledge.

At the risk of further beating a dead horse, or being repetitive, we feel obliged to once again remind readers about the "lens" we use with regard to what students and teachers need to know about nature of scientific knowledge and scientific inquiry. We focus on learning outcomes that are developmentally appropriate, have empirical support for learning, and are arguably important for all students to learn so they can achieve the goal of scientific literacy. At this level of appropriate generality, there are few disagreements, as evidenced by the numerous reform documents worldwide. It is not the K-12 teacher's goal to create philosophers of science. The goal is to develop informed citizens so decisions can be made concerning personal and societal issues that are scientifically-based. Nevertheless, the community of philosophers and historians of science, and learning scientists, many of whom are readers of this journal, consistently ignore, or do not care about, the audience for which these learning goals are designed (Allchin 2011; Matthews 2012; Irzik and Nola 2011; Sandoval 2005; Wong and Hodson 2009, 2010), as well as the over 50 years of research related to learning about nature of scientific knowledge and scientific inquiry (see Lederman 2007). Indeed, one might question how familiar they are with K-12 curriculum and instruction.

Now that the reader is clear on the perspectives of NOS and SI used here and as presented in current reform documents, we can now return to the main thesis of this discussion, how the socio-scientific issues arising from genetics can be used to promote understandings of NOS and SI and promote achievement of the goal of scientific literacy. What follows are several practical examples of how this may be accomplished in secondary level classrooms. While these issues may not be considered "hot button" issues in the scientific community, they do represent controversial topics that are prevalent, to varying degrees, in the "public eye." This distinction should not be of concern for the reader. Sadler (2004) emphasizes that "the topics described by the phrase 'socioscientific issues' display a unique degree of societal interest, effect, and consequence" (p. 513), and it is the implications of these issues at the level of society, and not of the scientist, that are explored in the following pages.

Further, while much of what follows involves biology content with a substantial technical component, our focus is on the scientific knowledge and its generation. It is when this knowledge is applied, which oftentimes does involve the application or even development of various technologies, that certain socioscientific issues invariably arise. The impact of scientific knowledge on society is oftentimes not easily recognized until it is seemingly manifested in these related technologies. That manifestation, however, does not negate the characteristics of the knowledge itself due to the nature of its development. Those characteristics and understandings about that knowledge, NOS, and SI are emphasized in this discussion. It is our belief that with adequate understandings of NOS, SI, and the related limits of the scientific knowledge produced, that the public will be better positioned to understand decisions regarding these issues.

4 The Example of Genetically Modified Foods

Selective breeding of plants and animals is a hallmark of civilization. Humans have manipulated gene strains for thousands of years in an attempt to maximize agricultural yield and to sustain growing populations. The application of technological advances in genetic engineering to foods is similarly motivated and has moved beyond selective breeding by manipulating the genetic material of an organism in a way that cannot naturally occur. Transgenic crops, for example, utilize bacterial plasmids that have been modified with foreign DNA. These plasmids are incorporated to ultimately facilitate the expression of various targeted genes in the host plant. The recombinant DNA technology used can enable increased yields, resistance to certain diseases and herbicides, and therefore increased food security. However, there are significant controversies surrounding genetically modified organisms (GMO). These include the loss of biodiversity and concerns about food safety.

These are social, scientific and ethical issues that arise given the nature of genetic manipulation. In addition to technical and scientific questions of advantages and disadvantages, there are also ethical questions of whether such technologies are acceptable. The production and consumption of these foods are a polarizing issue on both local and international scales, despite the fact that they are grounded in technologies and concepts that are not widely understood by consumers. The intent here is not to support or refute the biological implications associated with GMO production but rather to utilize this socio-scientific issue as a context for facilitating the development of scientific literacy through student reflection on NOS and SI. The concerns related to the development, production and consumption of these foods offer a context for students to reflect on the nature of scientific knowledge and its interpretation in a given sociocultural context.

Secondary classrooms support the development of a foundational knowledge base of genetics and associated technologies. Conceptual understanding cannot singularly prepare students to understand the controversies surrounding GMO's, however. Through explicit, reflective instruction (see Abd-El-Khalick and Lederman 2000 for more details) about scientific epistemology in the context of GMO's students may both develop the understandings associated with scientific literacy and a more complete picture of the issue itself. While the influence of these understandings on decision-making is questionable (Bell and Lederman 2003), an understanding of the epistemology of science does provide a broader lens through which students may consider the context of their choices. Consider, for example, a case in point: maize.

Far beyond what makes it onto our dinner plates, corn is used in the production of a myriad of products: livestock feed, cosmetics, construction materials, adhesives, cleaning products, pharmaceuticals and fuels to name a few. In other words, corn is ubiquitous in our lives. Genetically modified corn is controversial because of its pervasiveness and because the public perceives that the indiscriminate fertilization practices of the corn plant impact food supplies and compromise public health. The uppermost part of the corn stalk, the male tassel, distributes pollen to fertilize the female eggs on the cobs below. That pollen may be carried onto another plant brings with it the potential for the pollen of a field of modified plants to pollinate cobs of a neighboring field of plants that are not modified. Although this poses little risk when the resulting seeds are not cultivated for future planting, the perception of risk has emerged as an area of public concern. Despite the risks and concerns, the application of technologies to maintain the pace of production are undertaken in nations such as the United States given that it is the largest crop.

While other nations are significant producers, 39 % of the world's corn was grown in the US in 2010 (US Grains Council 2010). The development of technologies that support the pace of production might be viewed very favorably given the scale of the corn economy in the United States. As with other socioscientific issues, the sociocultural landscape influences the scientific knowledge that is pursued. In turn, that knowledge itself influences society. In the early twentieth century in the US, corn was a crop that was important to the economy and critical to the Midwestern states but was nowhere near the extent of its present impact. In recent decades, corn yield is five times greater and the diversification of the products developed from that increased yield, and through the research supported by a society with a growing dependence on corn, has a much greater impact on society. This impact is so far reaching, at this point, that many Americans are unaware of the presence of GMO's. In contrast, European nations have strict labeling requirements for foods containing genetically modified ingredients and a general public awareness about their use.

There is widespread concern across Europe regarding the production and consumption of these foods and food products such as corn because of perceptions about environmental and health risks. The US does not yet require that products containing genetically modified foods be labeled and much of the public remains relatively unaware of the extent to which these foods are included in their diet. In contrast, Europe's labeling requirements result in a population that is comparatively aware on a large scale about their consumption. It is more common, therefore, that people in nations such as Germany are opposed to the production of such foods. While the scientific phenomena and related technologies may not vary across nations in this case, the reaction to their manipulation certainly does.

The extent of this polarization illustrates the sociocultural-embededness of science and explicit, reflective instruction related to the interactions between science and society may help students address the social implications of genetics research. Consider a culminating, problem based learning activity where students are asked to investigate the issue of corn production using GMO technologies. The issues that have the potential to influence perceptions and decisions associated with the production of genetically modified foods vary across societal and social contexts, as with the corn example. While the controversies associated with their use may be concerns across many nations and cultures, they are weighed against the benefits in a specific social and cultural context.

Student groups, therefore, may be asked to represent the concerns of specific cultural contexts (China, US, a developing nation, EU nations, etc.) and must therefore attempt to address the balance between consumer demands and concerns in their particular sociocultural landscape. Ethical issues of genetic manipulation may ground the views of some in opposition, but in developing nations with inadequate agricultural infrastructure and an over dependence on foreign aid, food security may outweigh all other concerns. Students might model the roles of a scientist, a public health official, a politician, and individuals with business interests within several socio-cultural contexts and be asked to develop and support recommendations for the use of these food technologies given food and consumer goods needs. This activity would facilitate explicit discussions within student groups and ultimately across classrooms culminating in teacher assessment of both content and epistemological understandings about the technologies themselves, the validity of concerns about their use and the socio-cultural implications therein. These issues are not a straightforward matter explained away by a better understanding of recombinant DNA technology or genomics, but have the potential to be more aptly viewed through an epistemological lens. Consider an additional food that students have most likely been consuming since their infancy: the banana.

The plight of the fragile banana has received increased attention among the public who have become aware that the fruit most familiar to us is threatened (Koeppel 2008). Prior to the adoption of the most common type presently in production, the Cavendish, another variety had faced a similar fate and was quickly replaced with the present banana that was believed to be resistant to the strain of infection, a strain of Panama disease, that was then compromising crops. Interestingly, every banana we have ever eaten is a clone of every other. The bananas common today, which are actually berries and not fruits, are not reproduced without human intervention and it is this lack of biodiversity that leaves them vulnerable to disease. Given the familiarity of this food to western nations, its extinction from our kitchens would undoubtedly create a void. To some nations, however, it is a staple of local diets and would create a crisis of nutrition. GMO technology is being used to save the banana by limiting its vulnerability to disease but this is not without controversy. The issue itself does provide additional insight into the influence of the sociocultural context on scientific issues.

The tensions associated with the application and investigation of GMO technologies lie between an understanding of the science concepts themselves, an understanding of the attributes of that knowledge given the nature of its development, and, at times, convictions that are of a pseudo-scientific nature. Take, for example, the assumption that these foods are necessarily health risks because they are unnatural. Were those that possess this perception of the risks of GM foods to understand the empirical nature of scientific knowledge, would the tension between a pseudo-scientific belief (that *natural* is necessarily healthy) and nature of scientific knowledge understanding (that the assertions that GM foods are safe are informed by data) influence their consumption decisions? Would an understanding that due, in part, to its empirical nature scientific knowledge is subject to change support their concerns? Facilitating explicit considerations of questions like these within science classrooms have the potential to inform an understanding of science concepts that also communicate the complexity of science. That complexity reflects the nature of the development of scientific knowledge, as well as the attributes that knowledge possesses, which ultimately serves to support a more holistic decision making process.

It is, ideally, the marriage between conceptual and epistemological understanding of science that should characterize individuals' decisions with regard to socioscientific issues. Epistemological understandings of science, however, would seem to play a more central role given that conceptual understanding of complex phenomena is unlikely on a large scale among the public. For example, consider any single support or concern associated with GM foods. Individually, each factor is grounded in research and presents a very compelling argument for their omission or inclusion. Given this, in the absence of epistemological understandings the issue may appear more dichotomous to some individuals with a simple right or wrong conclusion depending on the factor they feel is most compelling. When the epistemological reality is considered, however, the complexity of the questions of the inclusion or exclusion of these foods begins to emerge. The many backgrounds and views of different scientists, utilizing different procedures and supporting their claims using *their* resulting data, have resulted in a series of supports and concerns about the use GM foods that do not inform a simple conclusion.

The complex and value-laden nature of scientific knowledge does not detract from what we can learn, instead it enriches the questions that scientists ask and the interpretations that they make. Abd-El-Khalick (2003) has emphasized that in a classroom context student decision-making regarding socioscientific issues is analogous to the process that scientists undergo when justifying scientific knowledge. That process is rational, critical, and necessarily involves value judgments. Incorporating discussions in the science classroom of genetically modified foods, and the decisions that their production and consumption require, are one context through which the interrelationships of student understanding of science content, NOS and SI can become illuminated. Where students are instructed to see this complexity their decisions may be supported by a more holistic consideration of all sides of an issue. This, it is believed, can be accomplished through an understanding of the nature of the development of the knowledge itself and the attributes that knowledge possesses as a result.

5 The Example of Genetic Testing

Genetic testing, in general, can potentially provide individuals with information regarding vulnerabilities to various genetically inherited diseases, and also in helping estimate the risks regarding various disorders that may subsequently impact their health and the health of their offspring. While many of these procedures are not currently available or allowed, and may not be in the near future, they nonetheless provide myriad opportunities for explicating NOS and SI in the context of some very provocative socio-scientific issues. As previously noted, while the issues that arise may be non-issues in the scientific community, such is not necessarily the case for the general public.

With over 10 million people in the United States alone possessing some form of genetic disorder, a couple currently faces about a 3 % chance that their child will possess some genetic disorder (Klug and Cummings 1991). In addition to the availability of diagnostic and carrier tests that can be performed at any time, current screening procedures also allow for the prenatal identification of hundreds of genetic disorders, often with the potential to inform couples decision on whether to potentially abort a pregnancy. The decisions place a premium on a doctor or genetic counselor's interpretation of potentially ambiguous data.

One particular family of procedures, preimplantation genetic diagnoses (PGD; Sermon et al. 2004), involves the genetic testing of embryos prior to implantation, as is done during in vitro fertilization (IVF). As IVF usually results in multiple eggs, PGD allows for the screening of the entire sample of embryos prior to cell differentiation and implantation in the uterus. In the majority of IVF cases PGD is offered to help ensure that children of parents deemed 'at risk' for passing along potentially serious genetic maladies are able to increase their chances of producing healthy, unaffected offspring. While mostly used to provide a statistical snap-shot of an off-spring's predisposition to a genetically-linked disease, the development of tests focusing on late-onset illnesses provides an additional dimension to the power of these screening procedures. Disability-rights advocates have cautioned against the potential of PGD to foster negative attitudes toward those who are disabled or sick, and have warned that its increased use would constitute a eugenic-tool, of sorts, as more information becomes available about the human genome and the spectrum of genetic diseases and afflictions. Despite these and similar concerns, PGD is currently offered at the majority of fertility clinics in the US.

Emerging from PGD and other related technologies are a family of procedures that have the potential to dramatically alter the landscape of contemporary reproductive practices. The first is the use of PGD as a tool for sex-selection. While few argue against its utility in controlling against the proliferation of sex-linked diseases, it is its potential use as a tool for "gender balancing" and other non-medical uses that concern its critics (to the point that current medical ethics standards currently do not permit them). In addition to the fear of potentially focusing valuable medical and technological resources on predominantly nonessential procedures, critics are also concerned that the use of PGD in this manner would serve as a catalyst for the funding and development of nonessential genetic testing technologies.

The American Society of Reproductive Medicine (ASRM) provides little guidance regarding this issue, as it offers two contrasting views on the use of PGD and IVF in matters of sex selection, stating that these procedures “hold an even greater risk of unwarranted gender bias, social harm and diversion of medical resources from genuine medical need. [They] therefore should be discouraged” (ASRM 1999, p. 597). Two years later, the ASRM (2001) posited that doctors “should be free to offer preconception gender selection in clinical settings to couples who are seeking gender variety in their offspring” (p. 863) provided the couples are counseled regarding the possibility of failure (i.e. opposite sex), affirm their acceptance of child regardless of sex, and are further informed about realistic expectations for the behavior of the child of the desired gender. The ASRM appears to be balancing the use of PGD as a preventative screening mechanism for sex-linked genetic diseases with the rights of their professional membership to offer a desired service. These two conflicting opinions communicated by the ASRM, which it should be noted are discussed in ASRM (2001), could certainly provide a foundation for rich discussion of this issue and its potential impact on society.

The wealth of research conducted by the Human Genome Project, coupled with the shortcomings in contemporary medicine to identify and prevent diseases with a genetic component, both have served, in part, as catalysts for the development of somatic gene therapies in humans. Evidence has provided some indication that somatic gene therapies could be efficacious in treating a variety of genetic disorders and acquired diseases (e.g., various cancers, inherited blindness, and Parkinson’s disease to name a few; Human Genome Project 2011). These therapies have further spurred the hope of “biomedical intervention[s] that can be expected to modify the genome that a person can transfer to his or her offspring” (Frankel and Chapman 2000, p. 2). Inheritable Genetic Modification (IGM), or Human Germline Genetic Modification (HGGM, Matthews and Curiel 2007) as they are now often referred to, is a family of therapies that involve the “modification of the inheritable genetic information…so that the alteration or added trait(s) corresponding to the transferred gene(s) are passed on to descendants” (Rasko and Jolly 2006, p. 17). IGM also refers to other types of early-intervention strategies that result in large-scale cellular modifications of the individual without a specific focus on inheritable transmission, though inadvertent germ-line alterations may result nonetheless.

IGM is mainly regarded by proponents as either a viable fertility treatment or as an additional line of defense against the inheritable transmission of genetic disorders. It could potentially provide a means for allowing parents, both of whom are homozygous for a particular mutation, to avoid passing it on to their child. While our current understanding of the mechanisms needed to treat various genetic maladies in human beings make the use of IGM for these purposes highly unlikely in the near future, proponents see enormous potential in the use of IGM for more “designer” or “enhancement” purposes. These technologies, it is presumed, would provide parents with the means for selecting, or at least increasing the probability, that their off-spring would exhibit certain desirable phenotypes. Most of these desirable characteristics, it should be noted, are too complex, too dynamic, and do not appear to be “under the control” of more readily identifiable genes.

Critics of IGM, on the other hand, see it as an unnecessary tool for empowering parents to design their own child from a menu of desirable traits. With access to these technologies potentially limited to those who can afford them, critics further fear the development of a “genetic caste system” through high-tech eugenics, per se, operating as a function of wealth. Furthermore, the impact of this type of experimentation would be impossible to predict due to the difficulties inherent in predicating phenotypic “response” to specific genetic modifications, but would impact all future generations, thus impacting the evolutionary trajectory of the population.

While the full potential for these particular genetic technologies has yet to be realized, and in the views of many it is “highly speculative…whether technologies to alter the human germ line will develop to a point that they are deemed safe and effective” (Scott 2006, p. 223), particularly since they are currently prohibited, they do present a plethora of socio-scientific issues that can be better processed and evaluated through an understanding of NOS and SI.

The issues surrounding PGD and IGM provide a fertile landscape for examining the bi-directional influence of science and society. Though a now archaic conception, the potential selection, by parents, of desired traits (as opposed to avoiding certain genetic maladies) from what Nozick (1974) decades ago coined the ‘genetic supermarket’ can still provide the impetus for a discussion of certain social impacts. Singer (2003) identifies three as most prominent. The first centers on the selection of traits. While it may be desirable to increase one’s lifespan through genetic engineering, and the selection of traits deemed essential to this goal, this practice, if successful, would have long-lasting impact on the environment and on the sustainability of the population. Further, the challenges that arise out of the impact of IGM and PGD on society would subsequently drive the development of additional technologies as a means to support this artificial population growth. This provides an opportunity to address the socially and culturally-embedded nature of scientific knowledge. Specifically, the impact on the environment and on health care costs arising from both marked increase in life-span, and through the propagation of traits affording merely comparative advantages (e.g., those believed to be related to intelligence), as opposed to those deemed medically essential, offer additional opportunities to discuss this relationship.

The qualification of genetic variations identified during PGD, and similar difficulties in determining the underlying genotype related to a desired phenotype, are the context for Singer’s second arena of social impact. The lack of a complete understanding of the extent to which a particular genetic variation, influences one’s susceptibility to a disease, what information could and should be provided by doctors to parents to inform their decisions, and what information doctors would deem essential for guiding their subsequent recommendations all provide examples of the inferential nature of scientific knowledge, and how subjectivity is unavoidable as we seek to make sense of ambiguous data. For example, as doctors or genetic counselors attempt to make sense of data that are rarely straightforward, the inferences they draw are due in part to their professional training, past experiences, and theoretical and philosophical commitments.

The role that the government or professional governing boards could play in influencing accepted or typical practices in genetic counseling matters of this type, and how their decisions would thus influence further scientific research and funding by defining what constitutes important research provide further context for discussing the influence of society on science. Students could consider how these issues of policy impact the designation of funds for further research, and thus drive the development of further research and technological innovation. These advancements, in turn, impact our understandings of these specifically targeted domains. These examples provide impetus for a discussion of how scientific knowledge changes and evolves with the development of new technologies, resulting in both the generation of new data and the potential for the reinterpretations of existing data.

Lastly, the widening of the gap between the wealthy and the poor, with money as the *de facto* gatekeeper to IGM and HGGM technologies and procedures, is Singer’s final area of potentially powerful societal impact. Again, it is important to examine how political power (and access to it) influences the steering of funds to various areas in genetic engineering and drives the development of new technologies and procedures in cell therapy, and in general. This arena provides further evidence of the interplay between science and the society in which scientific knowledge is developed. The potentially disparate ease of availability of IGM for the wealthy, and how this access, over generations, would continue to widen the gap between rich and poor in terms of desired (and thus target by PGD) human characteristics like intelligence, longevity, and success could also be examined.

Almost the entirety of the discussions involving IGT is speculative in nature, as it not known whether technologies to alter the human germ-line will ever be safe and efficacious or, in other words, whether we will ever have enough data to support its use. This point allows for an examination of how scientific knowledge is partially the product of human inference and subjectivity, in this case, regarding what constitutes evidence in the face of seemingly ambiguous data for a particular position or decision, and how personal and political commitments may influence these decisions.

6 The Example of Stem Cell Research

The issue of stem cell research also illustrates the role of human inference and creativity and their interaction with personal and political agendas. The development of a human embryo, and ultimately an individual, begins with the combination of genetic materials from a male and female gamete. At fertilization the cells begin to divide and after less than 1 week, a group of approximately 50–200 undifferentiated cells form a blastocyst. This cell mass consists of two, distinct layers: an outer layer that will develop into the placenta and an inner cell mass that will differentiate itself into the approximately 300 cell types found in the human body. If implanted successfully in the uterine wall, this blastocyst has the potential to develop into an individual and therein lays the controversy around embryonic stem cell research.

The undifferentiated stem cells of the blastocyst will not develop into the specialized cells of the human body until they are given the proper combination of genetic "signals" to do so. Each stem cell contains the same approximately 20,000 genes and it is the act of "turning on" certain genes that facilitates differentiation. Were physicians able to use this process to essentially reprogram a sick individual's cells, diseases with a genetic basis might be treated more successfully. They might also be able to regrow damaged organs such as spinal cords. Diseases such as Type I diabetes, Alzheimer's, Parkinson's, and sickle cell anemia are each viewed as viable candidates for the benefits of stem cell therapies as are various conditions leading to paralysis. Sickle cell anemia, for example, results from a single change in one of the two copies (alleles) of a single gene with debilitating effects. In addition to the potential of stem cell therapies to inform the development of treatments for illnesses, this science and associated technologies offer researchers a window into the development of these diseases and thus, potentially, insight into their prevention, diagnosis and treatment.

Despite the promise of this developing technology, the progression of stem cell research has been characterized by a tension between the science itself and the larger culture in which it is becoming understood. Scientific knowledge is developed from within a cultural context. Its value is interpreted within that context and as such is influenced by the sociocultural landscape from which it came. It is also ultimately influential within that landscape. While researchers around the globe refined and developed stem cell technologies, nations such as the United States and Germany passed legislation to limit such development using human embryos. The primary resource for embryonic stem cells is IVF clinics and although the embryos would go unused they are nevertheless capable of developing into individuals.

The question of life, its origins and its rights are pervasive points of debate in the US, among other nations. From reproductive health to capital punishment, the US continuously grapples with questions of balance between preserving life and protecting it. Although stem cell research may lead to medical advances that save lives, through what compromise of life are those advances had? The nature of this question echoes the concerns that stymied much of the funding for and progress of stem cell research in some nations, while shaping its future in others. In contrast to the tension regarding research in the US, a fatwa issued in Iran necessitates that this knowledge be pursued.

One technology used to develop stem cells for research on therapies uses an egg from a female that has had its genetic material removed and replaced through nuclear transfer with that of a cell from an individual of the type for whom the treatment is focused. Division of the egg is then chemically initiated and the resulting blastocyst is genetically optimized for the individual for whom the treatment is focused. Even in this circumstance, however, the potential for life looms and research has been shaped by the tension surrounding that potential.

Students are prone to come away from the lessons of their science classrooms with a narrow perception of the boundaries between science, culture and day-to-day experience. In addition to the socio-cultural embededness of the scientific knowledge, an exploration of the different veins of research within work on stem cells illustrates the role of problem solving and creativity on the part of scientists. Perhaps more obviously to students than other areas of scientific research, stem cell researchers have had to call upon their creativity to work around the problem of life as illustrated by the following example.

The outer layer of the blastocyst, the layer that will ultimately develop into the placenta that enables embryonic development, was among the first alternate routes used to bypass the potential for life among research materials that might ultimately be destroyed. If the placenta were not present, the potential for life may no longer be at issue and the cells might be used without controversy (at least among those that hold that life begins at implantation). The same process would be used; the DNA of a specific cell type would replace that of a host egg, but a virus would be used to interrupt the development of what would become the placenta. The classroom discussion and activities around stem cell research might be facilitated so that students can make suggestions at a general level for how scientists may further their understandings of stem cell applications and understandings without compromising the potential for life. Of course, the types of suggestions they might generate would not be conceptually sophisticated given the science. Students' general understanding of the processes of pre-implantation through embryonic implantation could be drawn upon in this type of discussion though. Secondary students are unlikely to have the conceptual knowledge to realize that viruses may be used to alter the blastocyst development, they may reasonably be expected, though, to suggest that the potential for the placenta could be a starting point. Among researchers, this methodology was not without its own controversy given the controversy surrounding the question of the definition of life and its starting point.

Each solution in the short history of stem cell research generated its own set of questions and concerns, prompting a cascade of creativity that advances research design and perspective. The stem cells that compose the blastocyst are pluripotent, that is they may develop into any cell type in the human body. Both bench top and database research ultimately informed the development of induced pluripotent stem cells in which cells from an adult were essentially reprogrammed into an undifferentiated stem cell. This area of research is that of the modern day and therefore gives students a lens through which they might view nature of scientific knowledge and inquiry unfold. The interplay between the sociocultural concerns and the development of this scientific field provides insight into the inevitable role of subjectivity in science, how different scientists come to view a problem and to seek a solution; and how our scientific questions, influenced by the culture in which they are embedded, inform the design of the research and thus the data that results. Although induced pluripotent stem cells might seem to be a solution, the development of scientific knowledge surrounding them ultimately resulted in more questions and further concerns, though research on stem cell technologies continues. It is that very tentative nature, where understandings are furthered by new research as well as reinterpreted, that makes this cutting-edge area of research an opportunity to contribute to the development of students' understanding about scientific inquiry and the nature of the knowledge that results.

7 Summary

The previous examples have illustrated how a reflective, explicit approach (Lederman 2007) to teaching NOS and SI can be used along with attention to a relevant socio-scientific issue, derived from contemporary genetics, to improve students' understandings of subject matter, NOS, and SI.

Although these socio-scientific issues and the NOS and SI instruction associated with their use in classrooms may appear to "steal away" time from typical genetics subject matter, this perception is misguided. It is our belief that the context that NOS and SI provide for this content, and the explicit reflective approach that we advocate, provide for deeper understandings and conceptualizations than what is generally achieved in classroom practice where it is absent.

For the classroom science teacher, the use of these socio-scientific issues arising in the arena of genetics may, because of the complexity of the subject matter involved, take the form of engaging students in purposeful ancillary reading activities with a related set of thought provoking questions around which to frame a classroom discussion.

Further, we recognize, and reaffirm our emphasis on the importance of focused, professional development efforts and continued support to both facilitate and support teachers' efforts to include NOS and SI in all phases (i.e., planning, enactment, assessment) of their classroom practice (Lederman 2007). By providing explicit attention to the context in which scientific knowledge is developed and verified, teachers can enhance students' understanding of traditional content, and take essential steps toward developing their own pedagogical content knowledge for teaching both NOS and SI.

Of course, the final goal is to help develop scientific literacy in our school students. The examples here were derived from genetics, but can easily be adapted to any science discipline whose advancement has created personal or social issues. Armed with subject matter knowledge, knowledge of NOS, and knowledge of SI students are able to make more informed decisions with respect to scientifically-based issues as well as to recognize the nature of those issues they may be confronted with. This is the *sine qua non* of what it means to be scientifically literate.

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