# Introducing Students to the Genetic Information Age

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As an instructor of college introductory biology I hope that a little knowledge is not a dangerous thing (for clichés I prefer the one in which a little goes a long way). I wonder, however, how my former students with only a semester or two of biology behind them react to the increasingly frequent accounts in the popular press of genetic determinants of traits. I am especially apprehensive of how they interpret reports of genetic influences on human behavior, which sometimes attribute genetic versus environmental effects with decimal precision.

For most students, their formal lessons in genetics will not go beyond what is received in a general biology course. For pedagogical reasons, instructors start with simplicity. Like Mendel, we turn to traits that are influenced primarily by a single gene, are little affected by interactions with other genes or the environment, and which can be categorized as easily as color varieties of pea seeds or fruit fly eyes. Almost always, these single genes cause major mutations that are not present at appreciable frequencies in wild populations. Like Mendel, we also disregard variation within the "discrete" categories of outcomes. Mendel may have chosen such traits purposely to clarify patterns of inheritance. He began with 34 varieties of peas, settled on 7 that were suitable, and knowingly kept environmental conditions constant. The clarity of Mendel's work on single genes should not keep us from introducing students to the complicated relationship between genotype and phenotype. Most often we bring up environmental effects on organisms (e.g. diet on heart disease, or sensory stimuli that trigger behavior) at some disconnected point in the course. Genetic and environmental effects on organisms usually will remain divorced from one another in the curriculum, both singularly important in their own right, but not cooperating to shape the characteristics of organisms.

As might be expected in an introductory course, students are rarely asked to deal with such complexities as penetrance of genes, polygenic traits, norms of reaction or heritability estimates that vary depending on the type of environment sampled. For most topics in general biology, I feel comfortable teaching the less complicated version. Students who do not go on in biology will receive only the unelaborated account of natural selection or photosynthesis. If these students do not know which end is up when it comes to hierarchical levels of selection or the electron transport chain, I feel they will still manage in the post-baccalaureate world.

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I am no longer so comfortable with a simplistic presentation of genetics in the general biology curriculum. Will my students who hear about genes for homosexuality, for breast cancer, and for schizophrenia on the nightly news be able to make sense of this information? Are they aware of the limits of the "gene for" language when applied to a diverse population experiencing very different worlds? Do they understand the difference between probability and certainty? It is sobering to recall that during the rise of eugenics in the early 1900s, well-educated people who had been introduced to genetic concepts did not seem to understand the futility of attempts to eliminate rare, recessive traits. Perhaps the insights of Hardy and Weinberg were deemed too recent and complex to make it out of the advanced curriculum.

## Scientific Information & Objectivity

Too often media reports seem to resemble a genetic scoreboard rather than a discussion of how genetics and environments influence traits. According to the latest updates, for example, the batting average of the breast cancer gene has fallen from 0.850 to 0.500. There would be less cause for concern if the information available to the public was likely to be unbiased. While objectivity is the ideal of science, there are two situations where we tend to fall short. The first occurs when we are challenged to re-think what it means to be human. The second occurs when the applications of science put money and power at stake. Perhaps more than any previous advance in science, the revolution in genetics as exemplified by the Human Genome Project will do both.

The reactions to the works of Copernicus and Darwin are two often-cited examples of how objectivity can be lost when we are forced to consider humanity in a different light. The Human Genome

Project has a similar potential to challenge notions of ourselves. The chosen label for this multibillion dollar project, by itself, appears to validate genetic determinism of human characteristics. Are health, personality and moral behavior largely determined by our genetic makeup? If genes help to determine career possibilities, success in relationships, and criminal behavior, is there a role for free will? Instructors of introductory biology must be aware of the possibility that new information on genetic determinants of human characteristics might spur a new eugenics movement, or in reaction, an over-emphasis on environmental determinism. Students who have been presented only the simplest examples of either genetic or environmental determinism may be drawn to either extreme. Both extremes of determinism have caused suffering in the 20th century, although there can be little doubt that genetic determinism has been the more destructive.

One may ask what is wrong with a little too much environmental determinism. While environmental determinism has not been associated with anything as collectively evil as the Nazi ideal of a genetically pure race, it has led to considerable individual pain. The notions that autism, mental illness and criminal behavior were direct products of harmful environments, especially during childhood, have been responsible for untold familial anguish. *A priori* discounting of genetic contributions may lead to simplistic and misguided attempts to re-mold behavior. It is not surprising that reports of a complex and little understood interplay of environmental and genetic contributors are greeted with relief by many.

Objectivity in science also suffers when money and power revolve around technological applications of science. It is not surprising that many people distrust any voice that speaks on matters such as nuclear power or global climate change. Messengers bearing the good news of the genetic revolution are beginning to encounter a similar response. In the midst of every revolution, visions of the future tend toward the grandiose. While promoters are sowing many promises, an uninformed populace is unlikely to reap a bountiful harvest. Gene therapy, the replacement of faulty genes with corrected or novel genes, has been just around the corner for the last 15 years. The payoffs of gene therapy will be substantial, but we may be years away from widespread applications that are not cost prohibitive. For many of us, the more immediate products coming from our understanding of genetics will be diagnostic services that enable us to obtain insight into our genetic makeup. The coming promotion of diagnostic information may overwhelm the unprepared. Based on current presentation of genetic concepts in the general biology curriculum, I am not confident that my students will be knowledgeable consumers of information regarding probabilities, susceptibilities, and the need to modify environments in light of genetic tests. One day we may live in a science fiction future in which parents come home from the hospital with a blueprint of behavioral tendencies, likely areas of talent, and areas of medical concern for their newborn (instructors of biology can perform an immediate service by finding metaphors for the genetic material that connote less determinism than "blueprint"). Will this information be limiting or liberating?

The promise is that genetic insights will lead to the design of environments which compensate for genetic vulnerabilities and nurture genetic strengths. The fears, already being realized, are that unfavorable diagnostic results will restrict employment, insurance and educational options. It is particularly disturbing to think that someday society or "informed" parents will steer, manipulate or coerce children toward or away from interests based on statistical deviations from the "average." In such cases, a little knowledge of genetic effects may indeed be a dangerous thing.

## Monkey See, Monkey Fear

As with the single gene effects that Mendel uncovered, it would be useful to have simple pedagogical examples of gene-environment interactions, a notion that is nearly oxymoronic. One candidate has emerged out of experiments by Michael Cook and Susan Mineka on the acquisition of fear in rhesus monkeys (Cook & Mineka 1989, 1990). Naive monkeys show low levels of fear to novel objects such as toy snakes and toy rabbits. Individuals can acquire a fear of some objects by observing a fear response in another monkey that is apparently interacting with an object (videotapes of the fear response were manipulated to control for variation in reactions to different objects). The expression of fear, however, is not completely determined by the learning environment. Individuals will acquire a fear if they observe monkeys reacting fearfully to toy snakes, but not to toy rabbits. Presumably this difference in the acquisition of fear is dependent on different genetic predispositions that are rooted in adaptive evolution. What percentage of fear acquisition is genetic and what percentage is environmental? The question is largely pointless. For monkeys to acquire a fear in these experiments, individuals must be both genetically predisposed and have the necessary experience. As is true for most complex traits, the acquisition of fear is not a simple weighted sum of genetic and environmental contributions. Statistically speaking, the genetic and environmental influences are not additive.

## Liberating or Limiting?

If students are to take full advantage of the genetic revolution, they will need to understand basic concepts such as a gene-environment interaction. Phenylketonuria (PKU) has been put forward as an example of how genetic information may prove liberating. Individuals with PKU do not produce the enzyme necessary to convert the amino acid phenylalanine to tyrosine. Prior to knowledge of the biochemical mechanism behind this condition, the resulting accumulation of phenylalanine led to retardation and often death. It could be said that the retardation which resulted from possession of a pair of PKU alleles was highly heritable and thus largely genetically determined (Vigue 1996). This sounds (and was) grim. But of course, estimates of genetic effects are valid only for the environment employed while deriving the estimate, a concept rarely taught at the introductory level or reported in the media. One hundred years ago, no one could have imagined the phenylalanine restricted diet that is employed today in an attempt to manage this condition. Thus, the prognosis for an individual with this genetic condition, although not universally favorable, is now determined in part by environment. The alleles responsible for PKU are still inherited; the associated retardation need not be.

The ability of humans to consciously create novel environments in response to genetic variation suggests that we look to genetics as an important contributor, not as fate. The treatment of congenital dwarfism with growth hormone demonstrates how we attempt to construct an environment appropriate to the genetic condition. Students can be introduced to the ability of technology to expand our traditional concept of environment by the use of rosette forms of Wisconsin Fast Plants™. This low-growing genetic variety is gibberellin-deficient and responds dramatically to the application of gibberellic acid. The wild-type variety of these *Brassica* plants shows little response. By analogy, students can learn two important lessons about human genetics: that technology has the potential to expand the notion of "environment" in the production of phenotype, and that environments, whether natural or technology-influenced, have a much greater impact on some genetic makeups than others (gene-environment interaction). Success in modifying environments will come first for traits affected by a single gene in which the physiological mechanism is well understood. It will be important not to hype the rapidity of progress for treatment of traits that have an underlying genetic basis, but for which we are ignorant about the number of genes involved, gene-environment interactions, or the biochemical manifestations of the genes.

The ongoing revolution in the care of children with Down syndrome is a result of imagination as much as of technology. Traditionally, parents of a child with Down syndrome were told that the child was unteachable and would never be able to provide basic care for him or herself. The fate of these children was predetermined by an extra copy of chromosome #21, and the best that could be done was institutionalization. As Michael Berubé (1996) has pointed out, it was the courage of parents who did not accept the inevitable that was instrumental in the change from institutional to home care. Continuing advances in medical technology and a deeper understanding of the biochemistry of this genetic condition will greatly aid parents who are providing environments that allow children with this syndrome to thrive.

To date, most of the progress in creating appropriate environments for individuals with Down syndrome or phenylketonuria has come from understanding of biochemistry, not genetics. Greater knowledge of genetic influences may allow us to create specific environments not imaginable to our ancestors. Instructors of introductory biology will have the primary task of keeping the general populace up-to-date on developments in gene therapy and our understanding of genetic effects on traits. Equally important, it will be necessary to go beyond the simpler principles of genetics and to find time for more complex concepts such as gene-environment interactions, gene-gene interactions, polygeny, and pleiotropy. Knowledge of these will be required to take full advantage of advances in genetic technology. I do not think we can rely on the objectivity of those motivated by profit, politics or presumption. While progress in genetics seems inevitable, the benefits from this knowledge are not. As with previous technological advances, benefits will accrue preponderantly to the educated and the wise.

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