How Can Genomics Inform Education?

Elena L. Grigorenko[1]

ABSTRACT—This article offers some thoughts on possible connections between genomics and education. Genomics is already revolutionizing the way medical care is delivered and distributed; it will inevitably affect children's developmental trajectories by introducing more pharmacological and behavioral therapies. Educators should be prepared to understand the effect of these changes on children in the classroom, where children around the world spend a large portion of their formative years. Educators should also be prepared to understand the current advances in genomics and be able to discuss them with the parents and health care providers of their students.

The completion of the Human Genome Project in 2003 (http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml) and subsequent genetic research have resulted in the discoveries of genes and gene variants associated with typical and atypical human development. In addition, sequencing the genomes of humans and approximately 180 other organisms has provided, to some extent, the detailed characterization of specific genes and their expression patterns (i.e., the translation of particular DNA sequences into specific proteins). These developments have led to one of the main doctrines of modern genetics: that DNA is both inherited and sensitive to environments. That is, phenotype—the physical and behavioral characteristics that collectively define a person—is determined both by the presence of certain genes (one's genotype) and by the environment, not one over the other.

The idea that behavioral variation is an outcome of genes and environments coacting and interacting is not new in the world of biologists. However, the complexity and volume of the research in this area often results in misconceptions and misunderstandings of the latest genomic findings (Rutter, 2006; Rutter & Plomin, 1997). DNA exists and exerts its influence in the increasingly distal environments of the nucleus, cell, organ, organism, family, society, and culture. In turn, all these environments influence how DNA is regulated, transcribed, and transmitted from generation to generation. These interactions are necessarily multifaceted and therefore difficult to study and track. In addition, research on DNA is ongoing and producing burgeoning volumes of new genetic information, crystallizing the field of genomics—the study of the complex interactions of multiple genes (the genome) with different environments. It is difficult to stay on top of findings from these studies, even for someone directly involved in the field. The rapid flow of new information is often overwhelming for those outside the fields of biology and medicine. Hence, it is not surprising that, despite multiple attempts at resolution (Sternberg & Grigorenko, 1997), the nature–nurture controversy has not been put to rest, at least when it comes to education.

Much of the public, understandably, is reluctant to view DNA as a significant source of variance in academic achievement, school success, and the development of competencies. People often feel more comfortable attributing school failures to bad teachers, poor motivation, or concepts of "skill." Many educators and psychologists are also leery of accepting DNA as a basis for the individual differences observed in school settings; concerns with overstating the role of biology in general, and of genes in particular, in schooling are quite prevalent in the educational literature (Miller, 2000). This attitude has its roots in a general lack of knowledge of genetics in the public, naïve associations of DNA with concepts of biological determinism and eugenics, and the mistaken concept that what is genetic is fixed and unmodifiable. These misconceptions must be overcome to make the best use of the latest findings in genomics to the benefit of education. Here I will share some brief comments to show why understanding and incorporating concepts and recent findings from genomics are both important and informative for the future of education.

Because schooling is one of the major cultural inventions of humankind, the school environment has always been and will always be a major player in modifying children's gene

[1]Yale University; Moscow State University

Address correspondence to Elena L. Grigorenko, Child Study Center, Yale University, 230 South Frontage Road, New Haven, CT 06519-1124; e-mail: elena.grigorenko@yale.edu.

expression. What used to be viewed as the "black box" of children's individual differences will gradually be replaced by a summary of the roughly 24,500 genes carried by these children and their differential patterns of expression in different environments (Pennisi, 2003). Genomics is on its way to characterizing every individual in terms of his or her genetic "script," but it is environments—especially the school environment—that will determine the realization of this script into "the performance of a lifetime" (Lewis, 1999, p. 1), where every individual "plays out" his or her genetic script in a unique way. Similar to the way the Human Genome Project has broadened and increased the importance of genetics and genomics in health care (Epstein, 2005, 2006; Guttmacher, Jenkins, & Uhlmann, 2001; Khoury, 2003; Weston & Hood, 2004; Willard, Angrist, & Ginsburg, 2005), recent advancements in our understanding of the genetic bases of academic abilities and disabilities (for specifics, see Plomin, Kovas, & Haworth, this issue) will magnify the role of genetics and genomics in education.

Genomics is already revolutionizing the way medical care is delivered and distributed; it will inevitably affect children's developmental trajectories by, if nothing else, introducing more pharmacological and behavioral therapies. Because the genome substantially contributes to individual differences in abilities and disabilities, and school is one of the major environments in which almost all children are immersed for many years, many hours per day, it is important to understand the role of schooling in general, and different school environments in particular, in the manifestation of different genetic predispositions, then translate these findings into informed pedagogical tactics and strategies. In anticipation of this, I suggest that it would be wise for educators (i.e., broadly defined, professionals concerned with education) to start preparing for the infusion of genomic knowledge into their everyday practice. They need to be in the vanguard of the dissemination and popularization of this knowledge, or they will find themselves in the rearguard of it. In sum, I argue that educators should pay close attention to developments in genomics to (a) enhance their understanding of the dynamics and complexities of human development, (b) discover bases for strengthening their attempts to individualize education by capitalizing on every child's strengths and minimizing his/her weaknesses, and (c) prepare themselves for new paradigms of child rearing and schooling.

This, of course, is not to say that genomics should be added to the already long list of "what a teacher needs to know." No single teacher working in a classroom every day can know everything. The quantity of knowledge in modern society is constantly increasing across multiple domains of our culture. As a result, there is a greater demand for the practicality of team-based approaches. In school, team-based approaches are chiefly targeted at increasing the individualization of education, especially in special education. Bridging genomics and education might in these cases mean including genomics experts in teams of specialists who are shaping children's education. In other words, a teacher would not be expected to master a new field of knowledge or attempt to be an expert in it. What would be expected is that a teacher realize the importance of including this knowledge when making decisions regarding individualized education and make proper referrals to "educogeneticists" (or educational geneticists)—professionals whose knowledge of both education and genetics allows them to make informed recommendations to both schools and families.

To address the larger question of how genomics and education can form a viable and useful partnership, I will now discuss three main areas where the two fields intersect. First, there are several widely accepted genetic phenomena that are relevant to education if we understand school as a specific environment that can affect gene expression. Second, I will present genomic developments in the field of medicine, specifically in the context of the emerging field referred to as genomic medicine (Epstein, 2006), which could serve as a model for a genomics–education relationship. Third, I will hypothesize how knowledge of genomics may affect schooling in the not-too-distant future. Because the field of medicine is more rich with relevant examples than either psychology or education, I will use medical examples to illustrate various points where illustrations from psychology and education are not (yet) available.

GENETIC FINDINGS THAT ESTABLISH A GENOMICS–EDUCATION RELATIONSHIP

Research in the field of genetics and genomics, broadly defined, provides some important realizations that are of significant relevance to education as a specific environment. First, genetic or heritable influences do not determine specific phenotypic outcomes; in the overwhelming majority of cases, they predispose for a number of phenotypes, each of which might or might not manifest in particular environments.

Second, even the most deterministic genetic variants that are associated with rare, single mutations and lead to severe genetic disorders (e.g., a type of mental retardation called phenylketonuria [PKU] caused by a single mutation in the gene called *PAH*) have a statistic of penetrance associated with them, indicating that, when a predisposition is inherited, it often requires specific triggers in the environment to effect the manifestation of this predisposition. In other words, even when a harmful mutation is inherited, environmental influence might interfere with the genetic influences by both changing the probability of the manifestation of a particular disorder and moderating the severity of its manifestation.

Third, specific genetic influences are strong for the rare severe conditions that are typically caused by deleterious

mutations in a single gene, such as for PKU, but they are milder and probabilistic for common traits and conditions such as high blood pressure or learning disabilities. These common conditions are assumed to be caused by many genes acting simultaneously (i.e., by a polygenetic mechanism), whose impact is altered by environmental conditions. In other words, these common conditions are assumed to be multifactorial in nature or to be influenced by both genes and environments. Assuming that two given individuals differ from each other, on average, by about 6 million DNA variants (or polymorphisms), there are many possible combinations of common polymorphisms that result in differing combinations of common diseases or conditions (Weston & Hood, 2004). In addition, we cannot even imagine the number of environmental factors that might differ for any two given individuals. If one considers the possible combinations of genetic and environmental risk factors, the number approaches infinity.

Fourth, although the common conditions mentioned above appear to be influenced by many genes coacting with many environments, these common conditions are characterized by substantial heritability coefficients and call for the usage of methodologies associated with genomics, the study of the whole genome rather than single isolated genes.

Fifth, most, if not all, traits and skills tested so far that are associated with learning and school achievement demonstrate substantial heritabilities, indicating the importance of genetic influences for their manifestations (for a detailed discussion, see Plomin, Kovas, & Haworth, this issue). These influences, however, are emergent and attributable to the impact of many genes working together in specific settings. All these realizations concerning gene expression and environment collectively form an important basis for understanding the role of genetic factors in human development and for grasping the forward-thinking ideas linking genomics and education.

WHAT EDUCATORS CAN LEARN FROM MEDICAL PRACTITIONERS

Although genomic science has been slow, so far, in entering the consciousness of practitioners in educational circles, it has already had a substantial influence in the spheres of medicine, public health, and public consciousness (Epstein, 2005, 2006). One indication of this is that biotechnology companies are beginning to market genetic tests directly to the public (Jacobellis et al., 2003). As more data linking the human genome to human conditions and behaviors are accumulated, scientists face a very important challenge of the genomics era—the translation of genomic knowledge into public benefits. In medicine, this challenge is specifically apparent in the prevention and treatment of common conditions—such as hypertension, diabetes, and cardiovascular disorders—so that individuals at genetic risk for these heritable conditions may benefit from various forms of health prevention and intervention (Khoury, 2003; Khoury, Burke, & Thomson, 2000). These prevention measures and interventions include pharmacological prevention and treatment options, behavioral modifications conditioned on genetic risk, and lifestyle monitoring.

Many frameworks have been developed to bridge genomics and medicine. Here I will briefly discuss only one, developed by the Centers for Disease Control (CDC) (Kardia & Wang, 2005). In this framework, the translation of genomic knowledge into public benefit can occur at various points where science and the general public intersect. This intersection can be visualized as the meeting of two axes: one which represents the continuum in medicine from research to practice and the other which represents the range of possible recipients of medical care, from individuals (in the case of clinical medicine) to society at large (as in the case of public health). The four resulting quadrants (see Table 1) organize the interface between genomics and medical practice by linking

1. *individualized medicine* and *scientific research* through risk communication, informed consent, formulation of health-based decisions, and the enhancement of the providers' knowledge of research;
2. *individualized medicine* and *practice* through a patients' genetic education and counseling, behavior modification and patient adherence, medical decisions, and the applied training of providers;
3. *population health* and *research* through the enhancement of the genetic literacy of the general public, tracking and studying public responses to direct-to-consumer marketing, the assessment of genetic service needs, and investigating and mapping patterns of family dynamics and communication when facing the presence and transmission of genetic risk; and
4. *population health* and *practice* through mass media approaches to health education, public health advocacy, increased awareness of family history as a tool for public health prevention, and the development and installation of social support interventions.

This framework was rapidly developed with the intention of quickly penetrating the networks of major public and private health providers. At the end of 2005, some 500 genetic tests were publicly available, and more tests are being planned, tested, and commercialized every day. In this atmosphere, it is crucial to ensure that this knowledge and these techniques are used to improve people's lives. Of special importance are applications of these newly developed approaches to children. Given these current events in medicine and, correspondingly, in pediatric and developmental sciences, the importance of

Table 1
Framework Relating Genomics and Medicine

	Continuum	
Range of effect	*Research*	*Practice*
Individual	Individualized medicine and research	Individualized medicine and practice
Society	Population health and research	Population health and practice

educators' participation in the genomics era is clear for at least a few reasons.

First, educators have intimate knowledge of how individual differences between children manifest themselves in classrooms. They can contribute to the understanding of the genetic bases of both disabilities and abilities by providing information on how abilities and disabilities, whether in reading, mathematics, or some other academic domain, manifest themselves in classrooms, to what extent they are modifiable, and, if they are, with what educational techniques. In fact, educators' input is crucial to understanding phenotypes (observable characteristics), capturing individual differences, and explaining their sources, whether genetic or environmental. They can also speak knowledgeably and authoritatively about the needs of children and are in a position to mediate the interface of these needs with genomic and educational practices.

Second, the participation of educators in the translation of genomics will benefit education as well as genomics. Educators have always been interested in understanding the sources of individual differences among children in their classrooms. New and exciting findings linking individual differences in reading and mathematics to genetic variation will, no doubt, be of interest and use to educators. In addition, deepening our understanding of the etiologies of individual differences has resulted in many changes in the educational profession, broadly defined. Thus, at the beginning of this century, the introduction of abilities testing resulted in an understanding of the sources of individual differences between students and the rise of new professions, such as school psychologist. Similarly, the introduction of genetic testing into the everyday life of children will enhance our understanding of why children differ and will also lead to the appearance of new career trajectories in education.

Third, in many instances, at least in those related to policy issues with regard to special education, parents have triggered and promoted major changes in the educational system in the United States. When parents, informed by genetic findings, come to educators asking for advice and accommodations for their children, educators need to be ready to respond.

Tables 1 and 2 present the analogous relationships between genomics and medicine, and genomics and education.

HOW A MERGER BETWEEN GENOMICS AND EDUCATION MIGHT WORK

The main point of introducing genomics into the field of education is to find ways to effectively and efficiently use genetic information to the greatest benefit. It is clear even now that genomic knowledge will be particularly relevant to special education, especially with regard to finding the best possible pedagogical interventions for children with special needs and reducing the burden that developmental disorders place on society. In other words, the field's steady progress in understanding the genetic etiologies of atypical development (for a review, see Rutter, 2006) will result in the development of more effective interventions, which will likely combine pharmacological and behavioral approaches, initially for special education and, possibly, later for general education. Along with expanding our knowledge of genomics, researchers are extending our knowledge of normal variation; intriguingly, behavioral indicators of learning-related processes appear to be under substantial genetic influence (Plomin, 2005). Hence, it is conceivable that soon we will understand, at least partially, some of the genetic bases of memory and academic skills such as language, reading, mathematics, and writing. Identifying genetic pathways involved in the development of these psychological processes will most likely lead to experimental manipulations of these pathways and the identification of pharmacological and environmental interventions that may enhance them. This will in turn create a variety of new challenges for educators, ranging from parental demands for specific, individualized educational approaches for their children based on their pattern of genetic variants, to the introduction of pharmacological enhancer tests prior to

Table 2
Framework Relating Genomics and Education

	Continuum	
Range of effect	*Research*	*Practice*
Individual	Sources of and approaches to individual differences in the classroom: research	Sources of and approaches to individual differences in the classroom: practice
Society	Relationships between sources of individual differences and pedagogical approaches: research	Relationships between sources of individual differences and pedagogical approaches: practice

examinations or achievement testing, similar to those administered in sports for steroids. How can we prepare for these new challenges?

First and foremost, education can examine and learn from the field of public health. The World Health Organization, the CDC, and the National Institutes of Health have launched major initiatives aimed at designing and redesigning major approaches to public health. Launching comparable initiatives suitable for the needs of schooling in the United States might be an important step forward. Another important step might be adapting or redesigning the medical framework discussed above to fit the needs of education. The field of education need not borrow from medicine to incorporate genomics into schooling, but it might consider observing what is going on there and developing corresponding translational models that will enhance the main premises of the educational system in developed countries.

A second strategy for meeting the challenges of a genomics–education merger is the use of partnership models that can be developed so that pediatricians/primary care physicians can work with mental health providers and educators and have access to regional teams of professionals equipped with the necessary expertise in behavioral medicine, genetic counseling, and genomics. This team-based approach to an individual child, especially a child who has difficulties in school and might have a variety of the somatic and mental health issues associated with these difficulties, is crucially important. These teams of professionals should have access to real-time databases that merge and systematize online the Health Insurance Portability and Accountability Act–protected information generated by all the practitioners working with a child, as well as the child's education records. The availability and use of this information should lead to improved individual learning outcomes and the maximization of the learning potential for every child. Many U.S. schools use a team-based approach for making determinations regarding issues related to special educations; few of these teams, however, include medical professionals. Initial models for an exchange of information between medical clinicians, schools, parents, and other care professionals are being developed in the private sector (e.g., by Raging Knowledge, an educational service in Westport, CT). Of course, it is important to consider the variety of ethical implications of bringing genetic data to school and the possible misuses of these data. One hope for this article is that it will trigger a debate regarding these relevant issues. Such a discussion will hopefully receive attention at both national and international policy levels, as well as in academic circles. In fact, the National Institutes of Health's Task Force on Genetic Testing and the Department of Health and Human Services' Secretary Advisory Committee on Genetic Testing are two government bodies currently developing relevant recommendations. Although none of these recommendations have yet been implemented, this is a crucial moment (Javitt, Stanley, & Hudson, 2004) and it might be important for the U.S. Department of Education to join these discussions.

A third aspect of a genomics–education merger might be, with the further development of applied technologies, the development of preventive developmental and educational tools within genomics. Because, broadly speaking, genetic information as it is captured in DNA polymorphisms does not change across the life span, genotyping young children for genetic variants associated with developmental disabilities (assuming that they can be identified reliably and validly!) might be important. In this context, the following steps might be considered: (a) predict who is at risk for developmental disabilities and comorbid conditions, (b) identify risk factors and intervene to prevent the behavioral manifestation of developmental disabilities in persons at risk, (c) identify those children who are only in the early stage of a developmental disability and intervene and remediate to prevent later complications, and (d) individualize complex treatment and remediation approaches to improve outcomes. Globally speaking, these prevention and early identification techniques would be aimed at minimizing the trial-and-error approach and maximizing individual differentiation. If bringing one's gene chip,[1] with its exhaustive information about genetic polymorphisms, to one's doctor to optimize one's diet, vitamin supplementation, or medication no longer sounds like a futuristic idea—that is in fact expected to be in place by the near future (Epstein, 2006)—why cannot we start thinking about the possibility of using individual genetic information to help children in school settings? It is possible that such anticipatory guidance, based on genetic information, will not only result in more effective pedagogical approaches and beneficial outcomes but also enable the system to avoid the manifestation of various developmental disorders (e.g., learning disabilities).

And finally, a fourth and most important consideration in the genomics–education merger is the education of educators on the relevant genetic issues. Most practicing educators have had little, if any, training in genetics and genomics. Plomin and Walker (2003), for example, reviewed the major educational psychology textbooks and found that these textbooks did not include any material on genetics, mentioned genetics only while discussing specific developmental or learning disorders (e.g., Attention Deficit and Hyperactivity Disorder), or included only a maximum of three pages on genetics. Recent advances in the field and an explosion of scientific and popular reports on genes discovered for "this and that" make it very difficult to keep up. Nevertheless, educators have always been the first point of reference for concerned parents. If children are having learning difficulties, it is important that their teachers know what kinds of referrals to make and to whom they should be made. Of special value here is the teacher's

attention to reports provided by the child's family members, both in terms of making inquiries into family history and making referrals to professionals equipped to design family-based prevention. Thus, to be ready to embrace the genomic era in schools, educators need to be informed.

At this point, I will reemphasize that there is no expectation that front-line classroom teachers become experts in genetics and genomics. On the contrary, what is suggested here is (a) an increased awareness of the relevance of genomic findings to both development and education and their use as a further source of guidance in maximizing educational outcomes for all students and (b) a realization that access to information should be moderated by an educogeneticist, an expert who can, in an informed, professional, and ethical manner, interpret the genetic and educational information available on an individual child and advise both family and teachers on how to maximize schooling and learning environments for that particular child and any siblings who might be at genetic risk for the same.

ETHICAL CONSIDERATIONS

Yet, no matter how optimistic some of these possibilities sound, it is well known that the genomic era has brought with it many concerns and ethical dilemmas. Here I will name only a few. First, as is true for any testing, the initiation of genetic testing without a full understanding of the prevention or intervention that should follow is ill-advised. For example, recent reports of genes related to the manifestation of reading disabilities resulted in a flurry of statements by the mass media about corresponding genetic testing. It is important to understand that, although these genetic discoveries are very promising and encouraging, they are far from accepted as repeatable findings among scientists and are very far from being turned into commercial genetic tests. Besides, given issues of penetrance (see above) and the impact of the environment on the manifestation of genetic risk factors, these genetic tests are meaningful only in conjunction with prescribed pedagogies and other relevant interventions.

Nevertheless, from the point of view of the public, as conveyed by the mass media multiple times, testing is the direction in which practices are going, at least with regard to the emerging reality of genomic medicine (Epstein, 2006). In this context, it is vital to reiterate the cautionary points made by a number of scientists and popularizers of science. The predictive power of genetic risks, especially for common conditions, is meaningful and substantial only when considering many genes and many environments (e.g., lifestyle, diet, and pedagogical strategies) simultaneously. And even then, the predictive power will not be absolute but will remain probabilistic based on likelihoods of specific outcomes. As Epstein (2006, p. 436) stated: "That risk assessment or profiling *can* be done does not mean that it actually *will*, or, indeed, *should* be done." Decisions about testing should be made by informed professionals (e.g., educogeneticists) who will take into consideration the child's or the family's needs; the predictive power of the specific test with regard to the improvement of educational practices; and issues related to privacy protection, parental permissions and student consent and who will secure the compliance of the educational system in delivering the needed pedagogical strategy. All these issues are new to educators and deserve careful consideration and an open discussion, the time for which is now, before parents start approaching the school system with results of genetic profiling, asking for feedback and changes in educational accommodations for their children.

A second ethical consideration concerns the challenge of molding research findings into viable and appropriate practices. This warning, of course, is relevant to any educational intervention, with or without a link to genomics. The field has to think deeply about establishing criteria for sufficient evidence to indicate the need or usefulness of any intervention, prior to putting this intervention into practice. Because genetic research is advancing into the field of academic abilities, producing many new and exciting findings (Fisher & Francks, 2006; Grigorenko, 2005; McGrath, Smith, & Pennington, 2006), it is only a matter of time before these findings are translated into applications that will become a new facet of schooling for children in the developed countries. Medical genetics (and genomics) is gradually transforming, as pointed out by the 1977 president of the American Society of Human Genetics, Dr. Arno Motulsky, in his Presidential Address, "…from a largely research-oriented science to a service-oriented specialty."

A third ethical concern is the various roles different educators, teachers, administrators, and educogeneticists might play in generating, interpreting, and making decisions about the results of such profiling. The discussion above touched on the importance of raising awareness among educators in general, and classroom teachers in particular, with regard to genetics and genomics. Although raising awareness is important, it is also important to realize the expert boundaries of such knowledge. Similar to interpreting results of psychological or psychoeducational testing, the interpretation of genetic testing, especially at the junction of testing and pedagogical practices, should be done by specially trained, and probably licensed, professionals. With the era of genomic medicine approaching and the initial emergence of genomics in education, I believe that new models of incorporating this knowledge and establishing bridges between genomic medicine and education are required. That is why this article stresses the importance of starting relevant discussions as soon as possible.

Fourth, given the discussion at the beginning of this article, it is ethically very important to be mindful of the complex

interactions of the genetic script with social variables such as socioeconomic status, ethnicity, and culture. The human genome is neither culture free nor fair; it has been deeply marked by human evolution, history, and geographic migrations, and all these factors should be taken into account. No doubt the merging of genomics and education will result in even more heated discussions of gender and ethnic differences in achievement and their etiologies.

Finally, with respect to ethical considerations—especially in light of the current fascination with accomplishments of genome-related research—it is crucial to avoid excessively reductionist strategies and to stay as far as possible from the geneticization of humanity. Some may remember the 1997 movie *Gattaca*, which presented a retro-futuristic eugenic society where genetic engineering and in vitro fertilization were used to generate children of predetermined gender, intelligence, life expectancy, physical characteristics, and health. This movie generated a number of discussions among specialists and lay people and raised many important questions that remain unresolved even now, almost 10 years later. The movie showed in a convincing way why deterministic interpretations of genes do not and cannot work. Although reductionism is important when trying to identify specific mechanisms contributing to complex dynamic processes, such as human development and schooling, it is important not to regress to what Dennett (1995, pp. 82–83) has called "greedy reductionism": "… In their zeal to explain too much, too fast, scientists and philosophers often underestimate the complexity, trying to skip whole layers or levels of theory in their rush to fasten everything securely to the foundation." Let us refrain from overzealousness!

In conclusion, a balance of research-based evidence for the possible benefits and harms, as well as an unquestionable consideration of individuals' fundamental rights, should guide decisions about the introduction of individualized genomics into the process of schooling. None of these considerations are ethically neutral and, therefore, all of them should be considered with great care. Nobody says that it is going to be easy. We must never forget the sad history of eugenics and its impact on society; many scientists are worried that the general public might see some parallels between that history and the modern achievements of genomics (Stehney, 2004). Thus, we should proceed with caution, but we should proceed.

Acknowledgments—This work received partial support from a grant under the Javits Act Program (Grant R206R00001) administered by the Institute for Educational Sciences, U.S. Department of Education, and from Grant R21 TW006764-02 administered by the U.S. National Institutes of Health. I express my gratitude to Robert J. Sternberg and my colleagues at PACE Center and EGLab for providing valuable feedback on the manuscript and to Ms. Mei Tan for her editorial assistance.

NOTE

1 Such chips are based on so-called microarray technologies and allow scientists to analyze the presence/absence of multiple (hundred of thousands) genetic polymorphisms or specific gene products. When considered together, due to the amount of information collected, these chips provide unique identification information for the DNA or RNA profile of a particular individual.

REFERENCES

Dennett, D. C. (1995). *Darwin's dangerous idea: Evolution and the meanings of life*. New York: Touchstone.

Epstein, C. J. (2005). Medical geneticists in the 21st century. *Genetics in Medicine*, **7**, 375–379.

Epstein, C. J. (2006). Medical genetics in the genomic medicine of the 21st century. *American Journal of Human Genetics*, *79*, 434–438.

Fisher, S. E., & Francks, C. (2006). Genes, cognition and dyslexia: Learning to read the genome. *Trends in Cognitive Sciences*, *10*, 250–257.

Grigorenko, E. L. (2005). A conservative meta-analysis of linkage and linkage-association studies of developmental dyslexia. *Scientific Studies of Reading*, *9*, 285–316.

Guttmacher, A. E., Jenkins, J., & Uhlmann, W. R. (2001). Genomic medicine: Who will practice it? A call to open arms. *American Journal of Medical Genetics*, *106*, 216–222.

Jacobellis, J., Martin, L., Engel, J., VanEenwyk, J., Bradley, L., Kassim, S., Jorgensen, C., & Litch, J. A. (2003). Genetic testing for breast and ovarian cancer susceptibility: Evaluating direct-to-consumer marketing—Atlanta, Denver, Raleigh-Durham, and Seattle. *Morbidity & Mortality Weekly Report*, *53*, 603–606.

Javitt, G. H., Stanley, E., & Hudson, K. (2004). Direct-to-consumer genetic tests, government oversight, and the First Amendment: What the government can (and can't) do to protect the public's health. *Oklahoma Law Review*, *57*, 251–302.

Kardia, S. L., & Wang, C. (2005). The role of health education and behavior in public health genetics. *Health Education & Behavior*, *32*, 583–588.

Khoury, M. J. (2003). Genetics and genomics in practice: The continuum from genetic disease to genetic information in health and disease. *Genetics in Medicine*, *5*, 261–268.

Khoury, M. J., Burke, W., & Thomson, E. J. (2000). *Genetics and public health in the 21st century* (Vol. 40). Oxford, UK: Oxford University Press.

Lewis, J. (1999). The performance of a lifetime: A metaphor for the phenotype. *Perspectives in Biology & Medicine*, *43*, 112–127.

McGrath, L. M., Smith, S. D., & Pennington, B. F. (2006). Breakthroughs in the search for dyslexia candidate genes. *Trends in Molecular Medicine*, *12*, 333–341.

Miller, R. (2000). Beyond reductionism: The emerging holistic paradigm in education. *Humanistic Psychologist*, *28*, 382–393.

Pennisi, E. (2003). Gene counters struggle to get the right answer. *Science*, *301*, 1040–1041.

Plomin, R. (2005). Finding genes in child psychology and psychiatry: When are we going to be there? *Journal of Child Psychology & Psychiatry & Allied Disciplines*, *46*, 1030–1038.

Plomin, R., & Walker, S. O. (2003). Genetics and educational psychology. *British Journal of Educational Psychology*, 73, 3–14.

Rutter, M. (2006). *Genes and behavior*. Malden, MA: Blackwell.

Rutter, M., & Plomin, R. (1997). Opportunities for psychiatry from genetic findings. *British Journal of Psychiatry*, *171*, 209–219.

Stehney, M. (2004). Legacy of the American eugenics movement: Implications for primary care. *Primary Care; Clinics in Office Practice*, *31*, 525–541.

Sternberg, R. J., & Grigorenko, E. L. (Eds.). (1997). *Intelligence, heredity, and environment*. New York: Cambridge University Press.

Weston, A. D., & Hood, L. (2004). Systems biology, proteomics, and the future of health care: Toward predictive, preventative, and personalized medicine. *Journal of Proteome Research*, *3*, 179–196.

Willard, H. F., Angrist, M., & Ginsburg, G. S. (2005). Genomic medicine: Genetic variation and its impact on the future of health care. *Philosophical Transactions of the Royal Society of London-Series B: Biological Sciences*, *360*, 1543–1550.