

Are We Moving Too Quickly? An Historical, Biological, and Philosophical Perspective of Human Genetics

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The Academic Setting

Freedom High School began in January 1970 as a federally funded pilot-program for students at risk of dropping out of traditional high schools in the Albuquerque Metro Area. In 1975 the program was accredited by North Central Accreditation, which allowed the granting of certified diplomas. Freedom High has an enrollment of approximately 230 students, and a faculty of eleven teachers, one counselor, a part time nurse, and a half-day resource teacher. The staff consists of two custodians, one teacher's aide, a registrar, and the principal's secretary.

Freedom High School is not a school for "undesirables" or "misfits." The school is designed to offer a nontraditional setting which promotes close teacher-student relationships with goals of encouraging a life-long interest in learning, responsibility, and graduating. The faculty stresses high academic standards, personal growth, creativity, and celebrates cultural diversity. This unit will be designed for eleventh and twelfth grade students in Biology and Chemistry.

Context and Background

Advances in science and technology have happened so quickly that the application of these discoveries have people feeling like helpless observers of their destinies. The feeling of helplessness is shared by many people who are not savvy in the latest computer applications or the latest biological advances. Since the population as a whole is poorly educated about computer and bio-technology, it is easy to understand the mistrust that continues to persist.

In the years that I worked in the field of cytogenetics, I witnessed many decisions made concerning prenatal healthcare. In my experience as a cytogenetic technologist, I felt as though I was standing on the cutting edge of discoveries made in human genetics. Many nights passed in the lab looking at various translocations, deletions and additions. However, I always knew in the back of my mind that I, a recent grad from a local university, was trained for a mere six weeks to interpret, analyze, and almost assign a diagnosis for people and their unborn children. Of course any decision made, after I released my information, was purely up to trained physicians and their patients. The information and training that I received was very new to me and to the scientific and medical world as well. The main thrust of my unit will be a thorough study of human genetics, an exploration of where we came from, where we are today and of course the question, "Where will it all lead?" In the article, "Human and Medical Genetics," by A.G. Motulsky, it is pointed out that many people working in this broad field of genetics are often disconnected and still in the infancy stage. He talks about the "mad scientist that is manipulating human genetics for elitist and racist possibilities." (Brothwell). These fears and concerns will be fully addressed in this unit.

It is important to start at the beginning. All living organisms are made of cells that grow and reproduce. The reproduction of a living organism requires the raw materials of each cell as well as a complete guide for cell division. The process of cell division is simple. The genetic information, or code (often referred to as the genome), exists as deoxyribonucleic acid (DNA) and is wound into a tightly condensed coil. In human genetics, we will study the eukaryotic chromosomes. These chromosomes are made of a

complex of DNA and protein, with 60% protein and 40% DNA. One chromosome contains millions of bits of information underlying the design of living organisms. The DNA of a chromosome is a very long double stranded fiber. A human chromosome can contain up to 300 million nucleotides in its DNA fiber. A nucleotide is a single unit of nucleic acid composed of a five carbon sugar, a phosphate, and a purine or pyrimidine base. Every cell in the human body contains 46 chromosomes, or 23 pairs of homologous chromosomes.

When the cell is about to divide, the two homologues replicate, which produce two identical copies called sister chromatids. At the beginning of cell division, there are a total of 46 replicated chromosomes composed of sister chromatids joined by one centromere. The process of cell division is broken down into stages called mitosis. During mitosis, the cell moves through five stages. interphase, prophase, metaphase, anaphase and telophase.

Sex cells and sexual reproduction involve the process called meiosis. The phases in meiosis are different than the phases in mitosis. The phases of meiosis include the following: interphase, prophase I, metaphase I, anaphase I, telophase I, prophase II, metaphase II, anaphase II, and telophase II. Meiotic recombination is the main factor that makes possible the evolution of eukaryotic organisms. The possible number of genetic combinations is virtually unlimited because of meiosis and crossing over. During crossing over, four chromatids exchange portions of DNA strands.

A diploid cell contains two versions of each chromosome, contributed by the egg from the mother and the sperm from the father. These homologues will pair with each other along their length and their chromatids (daughter strands of duplicated chromosomes) exchange genetic material. The sister chromatids are bound together by a single centromere. During crossing over, four sister chromatids are held together and exchange portions of DNA.

What led to the discovery of DNA was the question of heredity in plants. Two centuries ago, English gentleman farmers were trying to improve agricultural plants. They crossed different strains hoping to isolate the best qualities of each parent plant. The hybrids, however, often produced plants that were dissimilar to the original parent plant. Each hybrid plant had different combinations of the features of their parents.

In 1790, T.A. Knight crossed two true-breeding varieties of the garden pea, one that produced a white flower and one that produced a purple flower. All the progeny had purple flowers, and among the offspring of the hybrids some had purple flowers while a few had white flowers. A trait from one of the parents was hidden in one generation only to reappear in the subsequent generation. In these seemingly simple experiments were the makings of a scientific revolution.

Gregor Mendel, an Austrian monk, was the first to quantitatively study inheritance. Mendel experimented on plant heredity in his garden. Mendel, like his predecessors, used the garden pea in his experiments. Gregor Mendel chose peas because they had versatile features such as a short generation time, small plants, many can be grown in a relatively small space, and the crosses in peas had been studied earlier.

Mendel was the first to identify dominant and recessive traits. He learned four things about the nature of heredity:

"Mendel observed that alternative genetic traits were inherited intact and did not blend, that one of the alternatives was not expressed in the f1 generation, but reappeared in the f2 and subsequent generations; that the alternative traits segregated

among the progeny of a particular cross, and that pairs of alternative traits were expressed in the f₂ generation in the ratio of three-fourths dominant, one fourth recessive" (Raven).

In 1900, German geneticist Carl Correns first suggested the central role of the chromosome. In 1902, American geneticist Walter Sutton developed the chromosomal theory of inheritance. The proof that genes were located on chromosomes came in 1910 with the experiments performed on a small fly known as *Drosophila Melanogaster*. American geneticist Thomas Hunt Morgan set out to prove that Sutton was correct in his assumptions that the factors determining mendelian traits do reside on the chromosomes. In 1931, Curt Stern set up experiments and concluded that genetic exchanges of traits on a chromosome, such as eye color, involve the phenomenon known as crossing over, which simply means the physical exchange of chromosome arms.

The complete number of chromosomes found in humans would not be discovered for another century. Not until 1956 did we have the necessary technical support to accurately establish mammalian and human genetics. Since that time, however, the field of genetics has become a diverse and powerful friend to the fields of biology, medicine and chemistry.

The next major discovery in genetics would come as soon as 1957, when Heinz Fraenkel-Conrat isolated tobacco mosaic viruses from tobacco leaves. The payoff of his experiments was the discovery that most viruses use RNA and not DNA.

A subsequent development in the field was the understanding of the structure of DNA by American James Watson and Englishman Francis Crick. The "double helix" is shaped like a spiral staircase composed of two polypeptide chains of hydrogen bonded to each other and wrapped around a central axis. The Watson-Crick model was a great source of new experimentation and discovery. It clearly demonstrated how DNA and RNA are replicated.

The genetic information which exists as DNA and RNA molecules make copies of themselves early in the life of a cell. They do this in part by the process of transcription and translation. During transcription, one strand of DNA functions as a template on which nucleotide building blocks are assembled into RNA. During transcription, nucleotide-sequence information is translated into amino acid-sequence information.

In the latter part of the century, understanding gene expression would become an attainable goal. The process of transcription and translation would become clear. What began as a simple experiment to control crops led mankind to the brink of unlocking the mysteries of our own biological secrets. Cures for disease, improving and elongating life, are within the grasp of humans. The birth of gene technology and genetic engineering was now a major thrust of research and development.

In 1973, Herbert Boyer and Stanley Cohen inserted amphibian RNA into a bacterial plasmid. This was the beginning of genetic engineering. New fields would be born from this latest surge of knowledge. Some of these include cytogenetics, genetic counseling, DNA fingerprinting, and finally, the Human Genome Project. The Human Genome Project was begun in the early 1990's.

The goals of the Human Genome Project seem very clear and altruistic. The goal is stated simply in the foreword of the Human Genome Program Report:

Acquiring complete knowledge of the organization, structure, and function of the human genome ... The Human Genome Project ultimately will create scientific resources for the next wave of advances in biology and medicine. As the project is

completed, accomplishments will dwarf those that have occurred in the biological sciences since the advent of recombinant DNA technologies. By the same token, the ethical and social consequences of the uses of this new knowledge must be considered as the knowledge is acquired. (United States Department of Energy).

Cytogenetics is the study of genetics at the chromosomal level. It is this process that allows medical practitioners to evaluate the health of an unborn fetus, the blast phase of certain types of leukemia, and other genetic diseases like fragile x syndrome, Down's syndrome, Prader Willie syndrome, Klinefelter's syndrome and Turner's syndrome.

To work in a cytogenetics laboratory, a person is required to have a science degree and about six weeks training. A great deal of training occurs while on the job. It is in the field of cytogenetics that much information is gained concerning genetic disorders. However, the main drawback of cytogenetics is the level at which the laboratory or medical practitioner is receiving information. While trisomies can be easily detected and the validity accounted for, other syndromes, like Prader Willie, are not as easily detected this method.

In the article "Human and Medical Genetics," A.G Motulsky argues that while a clear cut delineation of medical genetics makes for slower institutional practice, the flexibility probably has some advantages. He feels that medical fields that have rigid, well defined boundaries can become top heavy with departments no longer relevant to the current state of science (Brothwell).

Dr. Motluskus points out six advances in the practical application of genetics. They are the detection of chromosomal and biochemical disorders in utero allowing for selective abortion, understanding of the mechanisms of Rh Hemolytic disease (which can be almost eliminated), development of histocompatibility testing that will allow organ graphs with less fear of tissue rejection, development of screening tests to detect individuals susceptible to drug reactions, and understanding of genetics and pathophysiology in a variety of diseases and genetic counseling.

The information explosion that is occurring with the recent developments of the human genome project raises some legal and ethical questions. In a hearing before the Subcommittee on Energy, regarding the Human Genome Project, issues of social, legal and ethical practices have been addressed. The committee has recommend that "vigorous protection be given to autonomy, privacy, confidentiality and equity(Committee on Science, Space and Technology). The two main concerns addressed are the genetic discrimination in health insurance, and genetic discrimination in employment opportunities. The committee recommends that insurance reform laws preclude the use of genetic information when establishing eligibility for health insurance. The committee feels that the legislation should adopt laws that will forbid employers from collecting genetic information on potential or current employees unless it is clearly job related.

Since the race began to map out the entire human genome, these concerns have been voiced. Ellen Wright Clayton, MD., JD states in her address to the committee in 1994:

Learning more about one's genetic makeup is not without cost. Even when the implications are properly understood, people may be made uncomfortable or anxious by having more knowledge about the risks of disease they or their family may face. Women, in particular, may be anguished by the implications of prenatal diagnosis. This anxiety may be heightened by the fact that oft times the person who receives it

is clinically in good health. In addition, most genetic information is probabilistic rather than certain--the fact that a person has a gene for colon cancer means that he is more likely to get cancer but no one knows when or if he actually will. In addition, people and their physicians may simply misunderstand the implications of genetic information"(Testimony Before the Subcommittee on Energy).

One real life situation related to these concerns happened while I was working as a cytogenetic technologist in the early 90's. The lab that I worked for was sent amniotic fluid from twin fetuses. After careful examination of the data, it was discovered that the twins were males and showed signs of genetic abnormalities. Both fetuses had Klinefelters syndrome and both showed an inversion of genetic material in the Y chromosome. The fathers blood was checked for any genetic anomalies and we found that the father had the same inversion of genetic material on his Y chromosome. This "anomaly" was considered a normal variant in the twins because the father carried the same defect. Klinefelters Syndrome occurs when there is an addition of an X chromosome. Therefore, each twin had a karyotype that revealed 47, XXY. At this point of understanding, the information that the medical practitioner would share with the parents was the fact that each boy would be sterile and show some secondary sexual characteristics of females upon puberty.

The parents were given this information on a Friday afternoon, and the genetic counselor stressed to these parents that the twins would not show any signs of mental retardation. They were also instructed not to go to the public library and look up the syndrome as much of the information available was five years out of date and would not give a clear picture of how this disorder would be expressed. By Monday morning it was learned that the parents had so much anxiety that they did look up information in the public library, finding inaccurate results. This information caused great stress in the parents, and the mother voluntarily aborted both twins before seeking more advice from the genetic counselor. I do not have all of the facts that went into the decision made by the parents, but the one thing that has always stuck out in my mind was the fact that we were giving people information that was not ready to be understood. The dangers of giving incomplete or poorly understood information to the general public can and will cause stress and resentment for this new technology.

Another concern that I have run across in my research is the idea that people can be discriminated against because of this information. Studies on genetic variance for cognitive abilities has been studied by Paul Lichtenstein and Nancy L. Pedersen. The aim of this study was to investigate the importance of genetic differences in cognitive abilities for individual differences. Their analysis of the data showed that genetic variations for cognitive abilities contributes significantly to genetic variation in the SES measures (Lichtenstein, No1,2).

In an early presidential address for the Behavior Genetics Association, Theodosius Dobzhansky asks the question, "Is genetic diversity compatible with human equality?" His conclusion states that "genetic diversity can be made compatible with equality of opportunity. The answer hinges on one's ethical standards and political ideals. This is a problem very largely of ethics, and only marginally of genetics and biology" (Dobzhansky).

It is this disconnect that worries me most about the future of human genetics. Can we really separate the ethics from the scientific knowledge? I personally think that there is an inherent danger in doing this. We must find a workable marriage between these issues before we blindly move toward the future. My goal with this unit will be a complete

instruction on human genetics and the practical ethical applications of these discoveries.

Implementation

Lesson #1: History of Genetics

Objective- Students will experience the history of the discovery of the structure and function of the genetic substance.

In pairs, students will be assigned the following categories: the discovery of DNA, role of the nucleus, discovery of nucleic acid, early theories of heredity, mechanism of gene expression, search for chemical structure of DNA and RNA, three-dimensional structure of DNA, and the genetic code. Each pair will research assigned topic and prepare a ten minute presentation with a two-page narrative essay. After the completion of the presentations, the students will work as a whole group and discuss other students' work and recreate a significant discovery (student choice), to be re-produced in our lab. The students will work with their partners on this lab. The students will be assessed on essays, presentations, participation in group discussions and recreation of discovery.

Lesson #2: Cell Division - Mitosis and Meiosis

Objective- Students will understand the process of cell division on the chemical, biological and physical level.

The teacher will direct the students in a simulation of mitosis and meiosis. Following the simulation, the teacher will lead a whole group discussion and reinforce vocabulary used in the simulation. Students will draw the entire cell cycle of the eukariotic cell using any artistic medium available at the time including paints, colored pencils or computer graphics. The drawing will include all stages of mitosis and meiosis. Each drawing should be graded for accuracy, proper use of labels and vocabulary, and complete cycle of the cell.

Lesson #3: Bio-Genetics - DNA ÷ RNA ÷ PROTEINS

Objective- Students will gain insights on Mendelian genetics with a complete knowledge of the chemistry behind DNA, RNA, proteins, and nucleic acids. The underlying processes of each will also be explored.

Each student will create models of the following molecules: DNA, RNA, normal hemoglobin beta chain, sickle-cell anemia hemoglobin beta chain, guanine, cytosine, thymine, adenine, and uricil. The students can use any material that is readily available to them to build their models. The students work in pairs for the DNA - RNA lab, the "Do Onions Have DNA?," and the protein synthesis simulation included at the back of the lesson plans. The teacher will assess the students models and participation in the labs.

Lesson #4: Classification Systems of Organisms

Objective- An emphasis on the five kingdoms of life on Earth will be explored. Each student will understand how these kingdoms developed and the symbiotic theory of the origin of the eukaryotic cells.

Students will be assigned one of the following kingdoms to research. The kingdoms are Fungi, Animalia, Plantae, Monera, and Protista. After the students have completed their research they will form a group with other students in the class who were assigned the same kingdom. The students will generate a list of ten items that help define their

kingdom. At this point students will form a group with students of different kingdoms. Each student will share the list of ten items with their new group members. Each group will build a web using the shared information of each member. The teacher will assess students individually on original research brought to the first group as well as the group web. This lesson should be followed up with a whole group discussion on how classification systems help humans organize life on Earth.

Lesson #5: Cytogenetics - Chromosomes

Objective- Students will learn to identify genetic disorders related to chromosomes. They will recognize basic differences in banding patterns and the morphology of chromosomes. They will gain insights into the field of cytogenetics and prepare a karyotype of an abnormal cell line.

It is best to begin this lesson with a whole group discussion about the field of cytogenetics. The discussion should include the purpose and goals of cytogenetic laboratories. The goal of cytogenetics is the understanding and diagnosis of several types of genetic disorders at the chromosome level. The morphology and characteristics of each chromosome should be addressed in this discussion. The students will receive an example of a normal karyotype to use for the abnormal karyotype that they will each create. The forms for this exercise are at the end of the lesson plans. The students will write a lab report on the sequence of steps used by cytogeneticists to find results using amniotic fluid as their cell type. This report will include cell culture technique, cell harvest, cell staining and microscopic analysis. The completed karyotype and lab report will serve as the assessment for this lesson.

Lesson #6: Electrophoresis - DNA Fingerprinting

Objective- Students will gain an understanding of the theory and mechanics behind DNA fingerprinting technology. Each student will be able to read and analyze a DNA gel to determine the correct suspect in a murder case.

The students will be put into pairs. Each pair will complete the lab "Whose DNA was left behind?" The complete directions for this lab can be found at the end of the lesson plans. At the end of the lab each pair will report on their findings in a mock trial. Different students will be assigned a role to play for the trial. Each student will be assessed on a final lab report as well as participation in the mock trial.

Lesson #7: To Clone or Not to Clone?

Objective- Students will begin thinking about how ethics plays a role in scientific discovery and application.

Each student will select a point of view on the ethics of human cloning. The students will research both sides of this highly controversial subject. Each student will prepare a ten minute presentation for the United States Senate committee supporting their views. The presentations need to include the biology behind the technique of cloning and the ethical viewpoint of the presenter. Each student will write a five paragraph essay that will be handed in to the teacher. The essay and the presentation will be used as the devices of assessment for this lesson. A whole group debriefing is recommended for the completion of this unit. Students should be encouraged to talk about the experience that they had during this lesson and the teacher should use this discussion to introduce the Human Genome Project at this time.

Lesson #8: Human Genome Project

Objective- Students will understand all aspects of the Human Genome Project. They will explore the bio-technology behind the Genome Project and the possible benefits and drawbacks that this knowledge will give to the scientific community and mankind. This lesson should begin with a whole group discussion about the history, technology and future of the Human Genome Project. The teacher should stress different aspects of this project. These aspects include highlights of research progress, program management infrastructure and DOE groups working on ethical, legal and social issues. Each student will be required to produce a multi-media campaign that the DOE could use to educate the general public about the project. The campaign can include video commercials, poster art, endorsements and computer models. The companies will be presented briefly to the whole class followed by a debriefing. The companies can be used to assess student work for this lesson.

Lesson #9: Genetic Counseling

Objective- Students will explore and understand the field of genetic counseling. They will experience case studies and gain insights in to the demands of this new and growing field.

Working in pairs, students will contact a local genetic counselor or medical program and conduct an interview. Students should collect the following information; job description, educational requirements, salary, and employment opportunities. This information will be shared in whole group discussions. Each group will be given a specific case study and they will write a formal recommendation. These recommendations will be turned in to the teacher for evaluation. Case studies should be created by the teacher. A list of possible options is included at the end of the lesson plans.

Lesson #10: Medical Ethics

Objective- Students will explore issues raised in medical ethics concerning recent discoveries made in the field of genetics. They will begin to form opinions based on knowledge gained from this lesson.

Students will create a list containing ethical concerns of genetic technology. These lists should include genetic labeling, parenting, disabilities and selective abortion, diagnostic labeling, inherited tendencies, manipulation of genes, genetic discrimination in the workplace, genetic discrimination in insurance, genetic privacy and civil liberties, and genetic privacy. Each student will be assigned one item from their lists to explore and comment on before the class. The students will select a book to read from the list of readings and will write a one page reaction paper on the book. The reaction paper and participation in group discussions will be used for assessment by the teacher. A comprehensive exam will follow this lesson to wrap up the entire unit. The exam should be written by the individual teachers who are teaching this unit. Every discussion will be unique to the class and teachers will need to decide what information should be covered on this exam.

New Mexico State Standards

This unit addresses the following state standards for students in grades 9-12.

Standard 1:

A. Appraise, compare, and contrast information about the complexity, organization, and

predictability of the universe.

Standard 2:

A. Interpret evidence to understand changes in natural and artificial systems; evaluate specific hypothesis, models, laws, theories, principles, and paradigms as explanatory tools; analyze models for limitations, strengths, and basic assumptions.

Standard 3:

A. Compare and contrast form and function as complimentary aspects of units of matter, objects, organisms, and systems.

Standard 4:

A. Discriminate between the effects of constancy and change as properties of objects and processes.

B. Quantify the transformation of energy and matter in a system.

D. Employ typical high school mathematics skills to explain a given problem or situation.

E. Evaluate the contribution of external and internal forces to change in the form and function of objects, organisms, natural systems.

Standard 5:

A. Apply the scientific method in daily life both within and outside the school environment.

B. Evaluate, design, and use the most appropriate equipment, tools, techniques, and information sources to improve scientific investigations and solutions to problems.

Standard 6:

B. Apply explanations to their data that abide by rules of evidence, can be questioned and modified, and are based on historical and current scientific knowledge.

C. Evaluate new knowledge and methods using professional standards and scientific criteria.

E. Apply scientific knowledge, technological, computer, problem-solving, and other skills to design investigations and to collect data.

F. Explain and interpret the results of investigations to teachers, peers, parents, and others.

H. Explain that scientific ideas depend on experimental and observational confirmation, and that theories and ideas are refined or discarded as new evidence becomes available.

Standard 7:

A. Compare and contrast elements and compounds based upon knowledge of the structure of matter as composed of atoms and the smaller particles that comprise atoms.

C. Predict and describe chemical reactions between elements and compounds based on knowledge of their characteristics.

Standard 10:

A. Cell structure and function.

C. The functions of DNA and RNA in genes and the process of heredity.

D. How almost all human cells contain two copies of 23 chromosomes.

E. How changes in DNA can result in the mutation of an organism.

Standard 11:

C. Predict an organism's behavioral responses to internal changes and to external stimuli as a function of inherited and acquired characteristics.

Standard 14:

A. Design and construct artificial or computer systems that simulate natural systems.

B. Evaluate the protection and restriction of technological knowledge through patents,

and through financial, national, and special interest groups.

C. Evaluate research conducted by scientists and engineers in terms of adherence to accepted ethical standards.

D. Assess the impact of computers and other technology tools on the advancement of scientific knowledge.

Standard 15:

A. Analyze the contribution of context to scientific and technological investigations.

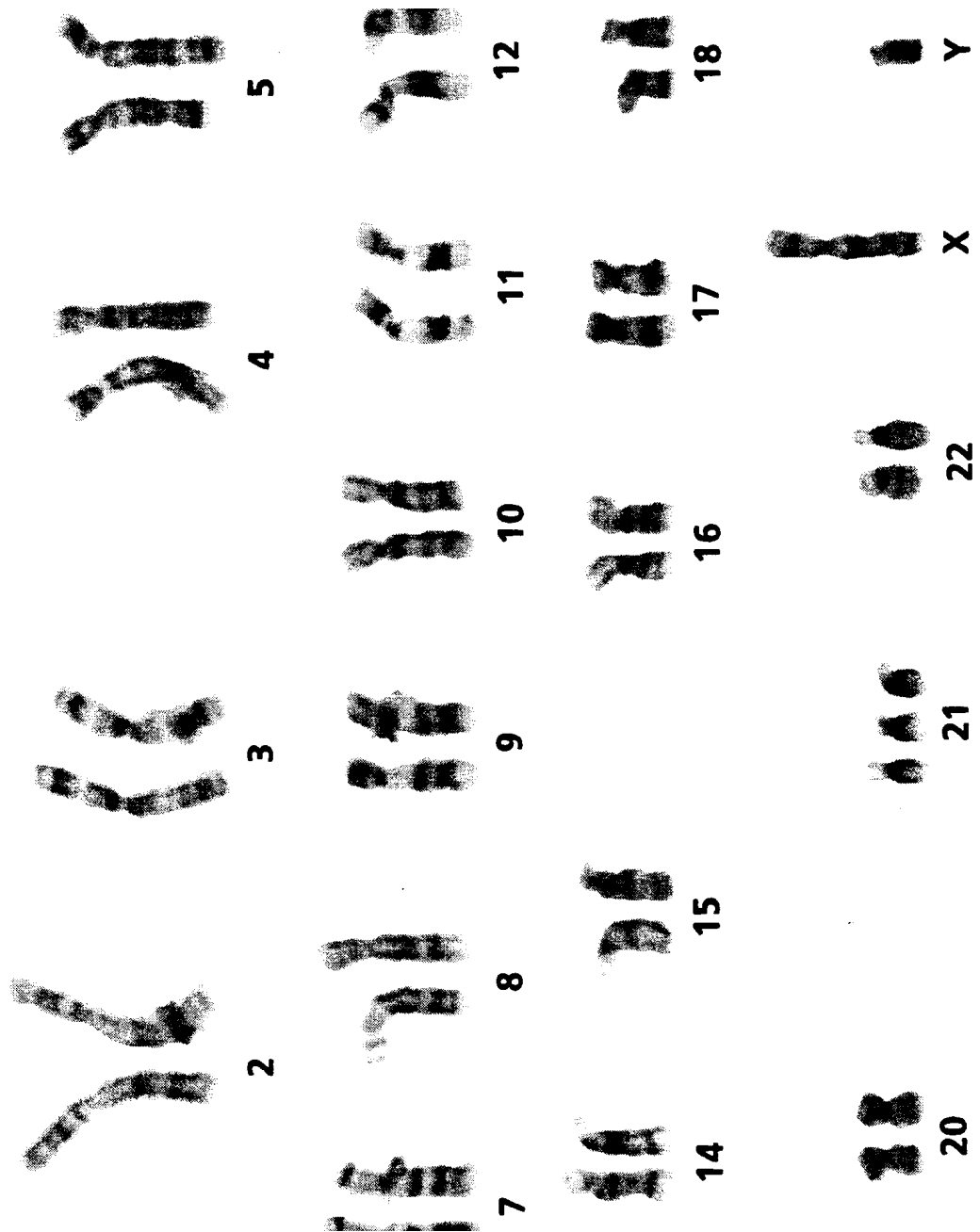
B. Evaluate the influence of science and technology on society.

C. Analyze the limitations of science and technology in the solution of human problems and social challenges.

D. Trace the changes in scientific perspectives over time based on earlier scientific discoveries and inventions.

E. Appraise the development of new areas of scientific inquiry based on previous research as it impacts an individual's choice of science as a career.

F. Evaluate the contribution of ethical standards to scientific inquiry.



Abnormal Karyotype



Documentation

See hand-outs.

Annotated Student Bibliography

Hubbard, Ruth and Elijah Wald. *Exploding The Gene Myth*. Boston, Massachusetts: Beacon Press, 1999.

Book on the misuse of genetics with a special section on cloning.

Newton, David E. *Science Ethics*. New York, New York: Franklin Watts, 1987.

A book of imaginary case studies that show some of the ways ethical questions arise in a scientist's life.

Appleyard, Bryan. *Brave New Worlds: Staying Human in the Genetic Future*. New York, New York: Viking Penguin, 1998.

An articulate plea to realign technological advances with human morals.

Levine, Joseph and David Suzuki. *The Secret Of Life: Redesigning the Living World*. Boston, MA: WGBH Educational Foundation, 1993.

This book is a guided tour of the ongoing scientific revolution in genetics and its impact on our daily lives.

Ruiz, Andres L. *The Life of a Cell*. New York, New York: Sterling Publishing Company, Inc., 1997.

Bold, colorful book on the life cycle of the eukariotic cell.

Marshall, Elizabeth L. *The Human Genome Project: Cracking The Code Within Us*. New York, New York: Franklin Watts 1996. Comprehensive view of the Human Genome Project.

Lanza, Robert p., et al. "Cloning Noah's Ark". *Scientific American* November 2000: 84 - 89.

Andersen, Jesper L., et al. "Muscle, Genes and Athletic Performance." *Scientific American* September 2000: 49 - 55.

Bill Nye The Science Guy: <http://www.nyelabs.com/core.html>

DNA Learning center. <http://vector.cshl.org/>

Teacher Bibliography

Brothwell, Don. *Biosocial Man*. London, England: The Eugenics Society, 1977.

A collection of papers showing the various ways in which biological aspects of man are linked with social man.

Ridley, Matt. *Genome: The Autobiography Of A Species In 23 Chapters*. New York, New York: Harpercollins Publishers 2000.

Nussbaum, Martha C. and Cass R. Sunstein. *Clones and Clones: Facts and Fantasies about Human Cloning*. New York, New York: W.W Norton & Company, 1999.

Portugal, Franklin H. and Jack S. Cohen *A Century of DNA*. Cambridge, Massachusetts: The MIT Press, 1979.

Raven, Peter H. and George B. Johnson. *Understanding Biology*. St. Louis, Missouri: Mosby Year Book, 1991.

United States Department Of Energy. *Human Genome Program Report 1991-1992*. Washington, DC: DOE 1992.

Lichtenstein, Paul and Nancy L Perderson. "Does Genetic Variance For Cognitive Abilities Account For Genetic Variance In Educational Achievement And Occupational Status?" *Social Biology* Spring - Summer, 1997. Vol. 44.

Dobzhansky, Theodosius. "Is Genetic Diversity Compatible With Human Equality?" *Behavior Genetics Association*, 1973. Vol. 46, No 3-4.

Hearing Before The Subcommittee On Science, Space, And Technology. "Department Of Energy's Human Genome Project Issues Arising From Research." October 4, 1994. No. 173.

Hearing Before The Committee On Labor And Human Resources. "Advances In Genetics Research And Technologies: Challenges For Public Policy." July 25, 1996.