Overnight Sensations: Gregor Mendel

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INTRODUCTION

"Overnight Sensations" is a series of short units that are to be used as elements introducing different content areas presented throughout the year. These units address aspects of science education that are generally given insufficient attention, the historical and social contexts in which influential scientists work. The unit covered in this paper introduces Gregor Mendel and his work.

Motivation

In teaching science we tend to present students with scientific theories as currently accepted. The student sees the end product, or even some intermediate advances. The student rarely gets an introduction to the environment within which the concepts and theories were articulated. We do not discuss the ways in which the introduction some theories radically change the way science proceeds from that point forward, what new questions can be asked, and what new avenues of research become available.

This current approach fails to meet one of the basic premises purported to be an element of curriculum development in science. In an introductory discussion of educational philosophy, curriculum documents often specify goals related to the nature of science. Students are expected to understand the development of scientific thought and the effect of the social and political context in which that development occurs. For example, the state of Texas includes an historical component in its science curriculum for each secondary school grade level. The following is from an online version of the sixth grade science TEKS (1)

112.22. Science, Sixth Grade

3) Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to:

   (D) evaluate the impact of research on scientific thought, society, and the environment; and

   (E) connect Grade 6 science concepts with the history of science and contributions of scientists.

An Internet article, "How *Not* to Teach History in Science," for the Minnesota Center for the Philosophy of Science, University of Minnesota, by Douglas Allchin states:

> Understanding historical context is important for appreciating how scientific concepts change and, in some cases, for understanding fully those concepts themselves. This involves some skill. In researching the history of science, historians frequently encounter ideas from the past that strike us today as strange, "wrong," or even incomprehensible. Yet historians endeavor to make sense of apparent absurdities: like scientists, to find underlying order amidst apparent chaos. They examine historical context--available theories, previous ideas, personal perspectives, styles of reasoning, records of observations, etc.--and then apply their imagination in reconstructing what the historical character was likely thinking, how the strange or outlandish (to us) may seem obvious

> and natural given the right context. Historians call this interpretive tool 'the historical imagination.'

Educational standards suggest that the presentation of scientific progress is to be, in effect, humanized.

Yet there is little material provided to support teachers in these areas. Beyond explanations of the theories ultimately developed, textbooks, for example, provide little information other than the nationality and profession of the scientist, and the year in which the scientist presented the theory. Three textbooks were examined to determine the extent to which this is true. The textbooks examined were some of the books considered for adoption by Houston ISD for sixth grade science. The texts will be referred to as Text A, Text B and Text C.

The procedure by which the books were examined is as follows. The indices of the textbooks were searched for scientists and the pages on which they were noted. Then each entry was read for any mention of the scientist outside of a description of the theory or work attributed to that scientist. Information sought included biographical information, mention of other scientists working at the time, and descriptions of the social, political or economic conditions of the time. A word count was done for any entry of such information. The word count was divided by the number of scientist to give an average number of words in qualifying entries. Each text had entries on people who were not considered in the count. These were entries on or interviews with people currently involved in careers requiring a background in the sciences. They were disregarded as they did not apply to scientists credited with theories covered in the books.

The results demonstrate that there is almost no information on the background of the scientists. Text A had entries on forty-six scientists with an average of 3.4 qualifying words per scientist. Text B mentions only nineteen scientists and provides 1.4 words per scientist. Text C includes entries on sixty-five scientists with an average of 8.0 words per scientist. This text included an excellent and extensive discussion of Charles Darwin and his work. With the Darwin entry excluded, Text C dedicated 3.3 words per scientist. In none of the texts was there any information on the social, economic, or political conditions. There was almost no mention of the relevant theories generally accepted at the time of the scientists' work. However, each text provided one or two short timelines on a specific set of developments. Overall the texts provided little more that the nationality and profession of each scientist. For further information a teacher will have to look elsewhere.

For further information the teacher can search the internet. There are several websites that provide biographical information about scientists. However, to find information about historical and cultural events of the times requires much more work. This paper is intended to provide such information about Gregor Mendel and thereby provide a model of the kind of background material one might gather.

Unit Implementation

Each "Overnight Sensation" introduces a scientist associated with a significant change in scientific thought. Students learn about the world in which the scientist worked, the scientific thought of the time, and the evidence available to the scientist. They examine the new thinking proposed by that scientist and look at the arguments for and against the new ideas. In choosing the scientist to include in these units, I used the premise of Thomas Kuhn's *The Structure of Scientific Revolutions*. Kuhn argues that the development of scientific thought does not always proceed as a steady accretion of facts and concepts. What he calls "normal science" does proceed in such a fashion. However, such progress is instead punctuated by paradigm shifts, episodes in which the perception of a field of science changes radically. The change in perception allows researchers to develop new approaches and to frame new questions that were not relevant under the old paradigm. These pivot points in science history are usually associated with specific scientists. This and future lessons will focus on these scientists.

The lessons in this work are intended for middle school "Integrated Sciences" and, therefore, involve scientists working in various fields of science. The unit herein introduces Mendel and his model of genetic inheritance. Later work will cover Mendeleyev and the Periodic Table, Darwin and the concept of natural selection, Dalton and Atomic Theory, Bohr and his model of the atom, Newton and his Laws of Motion, Schrödinger and the currently accepted atomic model, and Wegener and Continental Drift.

The units associated with the scientists are not intended to be taught as a group. Each scientist would be introduced where appropriate to the content of the curriculum. Incidentally, the term "paradigm shift" will not be introduced but the students are expected to develop an appreciation of the concept.

The units on the chosen scientists share a common structure. In the first activity the students are provided with information on the background of the scientist and on the scientific thought of his time. Using the information, the students create three parallel timelines, one for historical and economic developments, one for arts and society, and one for advances in science. There will then be an activity through which the student would mimic some aspect of the development or consequences of the concept. Some of these activities will be fairly common activities applied in a different context. Ideally the activity will allow the students to build parts of the concept for themselves.

Each of the lessons presented herein serves as an introduction to a unit exploring genetic inheritance. Activities for the remainder of each of the units are not developed as part of this project. However, supporting information is provided. Further activities for each unit should elaborate on the concept under consideration. Discussion could cover opposition to the new concept, its support, and the problems it solved. The development and acceptance of a significant concept make possible new avenues of scientific exploration. Also, advances in science often have effects that extend beyond science and technology. Such consequences of the scientists' work should be examined as part of the units. Students would produce assessment products such as a résumé for the scientist or a debate between the scientist and proponents of the older paradigm.

BACKGROUND MATERIALS

One of the purposes of this paper is to provide background material on one scientist, Gregor Mendel. It is important that the teacher have the information with which to provide a discussion of the conditions under which the scientist works as well as a sense of what was happening in the world at the time. This enables the teacher to provide a context that allows the students to better appreciate the work of the scientist, in this case Gregor Mendel. The information presented includes biographical data as well as information about the world in which the scientist lived and worked. The history, culture, economics, and politics of the times provide a context for the scientists' activities. Such information will allow students to link their knowledge of science with what they learn in other classes. There is also a section on the basics of the relevant theory. In each section the material is for the teacher, and it is not intended that all of the information be provided to the students.

The information is organized as follows. It begins with a general world view. This section comprises information on the history of the appropriate era, on economic and political concerns, on the arts of the time, and on the era's advances in science and technology. Next is biographical information on Mendel. Lastly is a section Mendel's work. That section covers precursors to his work, an abbreviated discussion of the work and its impact.

Johan Gregor Mendel's work was the beginning of the science of genetics. In 1866 he published a report on the results of eight years of breeding peas. Although the work was largely ignored for thirty years, Mendel is now credited with the development of the basic laws of heredity.

Mendel spent most of his life in parts of Austria that became Czechoslovakia. He lived in a time when the western world was beginning to look at the relationship between a society and its poor. The agricultural and industrial revolutions had reinvented the world. It was the time of the Reform Acts in Great Britain and the Civil War in the United States.

Born Johann Mendel on July 22, 1822 in Heinzdorf, Mendel was recognized as an excellent student and brilliant man but was plagued by debilitating reactions to stress throughout his life. He had a variety of interests and while he in known for his work in genetics he was also a meteorologist. Some of his earliest published papers covered sunspot activity and storms.

Mendel pursued most of his work and studies under the auspices of the monastery at Brno. He was well aware of the use of selective breeding in agriculture and sought to understand the underlying principles of the relatively "hit or miss" technique. During eight years of breeding pea plants in the experimental gardens of the monastery, Mendel developed his principles of genetics including his Principle of Segregation and Principle of Independent Assortment. He reported findings at Brno in 1865 and published in 1866. The work was mostly ignored despite Mendel's efforts to disseminate the results. Mendel was disappointed but often alleged that his time would come. He was vindicated in 1900 when three researchers independently came up with the same results. Each said that he had read Mendel's work.

Mendel's work was published about the same time as that of Charles Darwin. It was considered to be incompatible with Darwin's idea of gradual evolution, but the two lines of thought were eventually reconciled. Mendel's principles are considered to explain part of the mechanism of Darwin's theory of Natural Selection. Mendel's work also had an impact beyond the field of genetics. His approach introduced the use of statistical manipulation to the biologic al sciences.

In Mendel's Time

No scientist works in a vacuum. The social economic and political climates often affect work the scientist can do and how well it is accepted. Another factor is the reputation of the scientist, as well as that of the other scientists and the institutes with which he is associated. So what was the western civilization like during Mendel's lifetime?

Political and Economic forces

Brno itself was part of the Austro-Hungarian Empire of the Hapsburgs. By the time of Mendel's birth, the Hapsburg Empire had been much reduced by losses in the Napoleonic war. On three occasions Austria was forced to give up territories and make other political and economic concessions. In 1796 Napoleon led campaigns against Austrian forces in what is now northern Italy. Within a year he defeated the Austrian army. In February of 1801, Austria gave up the left bank of the Rhine River to France, and recognized a number of territories as independent nations. In 1805 Emperor Ferdinand III of Austria began another war over a territory called Bavaria. Napoleon defeated the Austrians and captured Vienna. Russia supported Austria but again Napoleon won and in December of 1805 Austria gave up more territory. Mendel's father fought for Austria during the Napoleonic Wars.

Like the rest of Europe in the early nineteenth century, the Hapsburg Empire was enjoying the fruits of the last stages of the Agricultural revolution. Great advances had been made in the process of food production. The benefits included the growth of a society that could afford to support centers of learning and research. As an aside, by the end of the Agricultural Revolution, the practice of selective breeding had become widespread. Mendel's work represented an effort to understand the workings of these practices. He had the practical aim of improving the efficiency of the practices.

The Industrial Revolution was also causing major changes in Europe and the United States. Wealth increased, and so did interest the development in instruments and machinery. Consequently branches of scientific research were gaining credibility. The community of scientists was growing, forming associations, and gaining credibility. However, off in the monastery in Brno, Mendel did not enjoy the exposure and interaction that was available to contemporaries such as Darwin and Newton. As members of The Royal Academy of Sciences, these scientists could reach a much broader audience. The lesser exposure contributed to a thirty-year period during which Mendel's work was "lost" to the scientific community.

The Agricultural and Industrial Revolutions also led to great political, economic and social change. Wealth increased, but populations grew rapidly and the ranks of the poor swelled. What was society's responsibility to the poor and disenfranchised? This became a major issue throughout the nineteenth century, especially in Great Britain and the United States. The effects were mixed. In some cases the poor were further oppressed. One philosophy for dealing with the poor was presented in 1798 in Malthus's *Essay on the Principle of Population*. The idea was that the number of the poor was best controlled by disease and malnutrition. In Great Britain laws providing support for the poor existed since 1600. The availability of this support was greatly restricted by the 1834 Poor Law Amendment Act. It created a Poor Law Commission to manage the poor law centrally. Local authorities were encouraged to refuse welfare payments to the poor unless they left their homes to live in workhouses. In other cases the upper classes in England were forced to share power with the middle classes by a series of acts called the Reform Acts that allowed a greater portion of the population to vote. The Reform Act of 1832 gave representation to urban areas. The Reform Act of 1867 changed voting requirements allowing still more people to vote. The Ballot Act of 1872 introduced the secret ballot. Across the ocean, the United States was engaged in its Civil War from 1861 to 1865. One of the many reasons for the war was the conflict over slavery. People could not be owned.

In many forums the structure of society was being criticized. In 1849 Henry David Thoreau, in *On the Duty of Civil Disobedience*, posited that the individual had the right to attempt to change a law by breaking it and accepting the consequences in a very public fashion. About that time (1848) Karl Marx and Friedrich Engels wrote the *Communist Manifesto* discussing the class struggle between the lower and middle classes. Later he published the first volume of *Das Kapital* in 1867 examining the relationship between politics and economy. In 1869 John Stuart Mill wrote *The Subjugation of Women*.

Some of the events Texas middle school (and high school) students might include in a timeline are:

- 1812 to 1814 – War of 1812
- 1815 – Napoleon surrenders at Waterloo
- 1836 – Texas Declaration of Independence
- 1844 – Texas becomes a state.
- 1846 to 1850 – The Irish Famine causes waves of immigration to America.
- 1854 – Commodore Perry establishes trade with Japan.
- 1861 to 1865 – American Civil War
- 1867 – Seward's Folly: the purchase of Alaska
- 1870 to 1871 – Franco-Prussian War

Mendel presented his work in Brno in 1865.

Arts and Society

During Mendel's lifetime was a period rich in literature. During the Victorian Era in England, writers were prolific. Tennyson, Browning, the Brontë sisters, Charles Dickens and others were writing poetry and novels. France, Russia and the United States also had a number of noted authors writing. Following is a list of some of the works produced from the time that Mendel joined the monastery until the time he published his findings on heredity in pea plants. Only a few of these selections will be familiar to middle school students. The information is presented primarily for the teacher who, however, may select for the students some entries such as *A Christmas Carol, Moby Dick,* and *Alice in Wonderland.*

- 1843 – Charles Dickens: *A Christmas Carol*
- 1845 – Edgar Allen Poe: *Tales of Mystery and Imagination*
- 1847 – Emily Brontë: *Wuthering Heights*
- 1847 – Charlotte Brontë: *Jane Eyre*
- 1850 – Nathaniel Hawthorne: *The Scarlet Letter*
- 1851 – Herman Melville: *Moby Dick*
- 1854 – Charles Dickens: *Hard Times*
- 1855 – Walt Whitman: *Leaves of Grass*
- 1855 – Henry Wadsworth Longfellow: *Hiawatha*
- 1857 – Charles Dickens: *Little Dorrit*
- 1857 – Gustav Flaubert: *Madame Bovary*
- 1858 – Alfred Lord: Tennyson *Idylls of the King*
- 1861 – Hans Christian Andersen: *Fairy Tales*
- 1861 – Charles Dickens: *Great Expectations*
- 1865 – Lewis Carroll: *Alice in Wonderland*
- 1865 – Leo Tolstoy: *War and Peace*
- 1866 – Fyodor Dostoyevski: *Crime and Punishment*

Music abounded. Listz was writing symphonic poems, Wagner was working on the ring trilogy and the Steinway family started making pianos. Bizet, Berlioz, Gounot, and Verdi were writing operas. The New York Symphony Orchestra gave its first performance. Mendelssohn, Offenbach and Schumann were composing. Following is a short list of music composed during Mendel's time at the monastery. This again is information for the teacher. Middle school students will not be familiar with the music unless the teacher presents short samples of the music.

- 1843 – Gaetano Donnizetti: "Don Pasquale," opera
- 1844 – Friedrich Mendelssohn: Violin Concerto in E minor, Opus 64
- 1845 – Richard Wagner: "Tannhauser"
- 1846 – Hector Berlioz: "Damnation de Faust"
- 1850 – Jenny Lind, the "Swedish Nightingale" tours America with P.T. Barnum
- 1851 – Guiseppi Verdi: "Rigoletto"
- 1853 – Henry Steinway begins the New York firm of piano manufacturers.
- 1853 – Guiseppi Verdi: "Il Trovatore," and "La Traviata"
- 1854 – Franz Liszt: "Les Preludes"
- 1855 – Hector Berloiz: "Te Deum"
- 1858 - New York Symphony Orchestra's its first public concert
- 1859 – Charles Gounod: "Faust"

- 1865 – Richard Wagner: "Tristan and Isolde"
- 1866 – Bedrich Smetana: "The Bartered Bride"
- 1867 – Johann Strauss II: "The Blue Danube"

Art history in the nineteenth century comprises Romanticism, the Pre-Raphaelite Movement, Realism and Impressionism. Claude Monet's "Impression: Sunrise" gave Impressionism its name. The first of the Impressionist Exhibitions was held in 1874. The beginning of Impressionism coincides with the end of Mendel's career as a scientist. Among the painters who were working while Mendel was experimenting with his peas are:

- Edouard Manet
- Edgar Degas
- Claude Monet
- Paul Cezánne
- James Abbott Whistler
- Dante Gabriel Rossetti
- J.M.W. Turner

Mendel lived in a century during which many basic advances were made in the sciences and in technology. The steamboat and telegraph changed transportation and communication. Pasteur and Lister brought advances to the field of medicine making it more effective and safer for the patients. ?ersted, Faraday, Ohm, Ampere, and Maxwell increased the understanding of electricity. John Dalton and Charles Darwin triggered paradigm shifts in the fields, respectively, of chemistry and biology. Listed below are some of the advances made in the early and middle nineteenth century.

- 1807 – Robert Fulton ushered in the era of self-propelled ships with his construction of a commercially viable paddle-wheel steamboat.
- 1808 – Dalton created modern chemical atomic theory.
- 1811 – Amedeo Avogadro developed the idea of the mole.
- 1811 – Jons Jacob Berzelius simplified chemistry by creating chemical symbols and formulas.
- 1816 – Augustin Jean Fresnel showed that diffraction and interference can be explained in terms of the wave theory of light.
- 1820 – Hans Christian Ørsted initiated the study of electromagnetism.
- 1827 – Georg Simon Ohm discovered the resistance of a conductor is the ratio between voltage and amperage.
- 1828 – Friedrich Wöhler synthesized an organic compound, urea, from inorganic material.
- 1831 – Michael Faraday discovered the means of producing electricity from magnetism.
- 1833 – Carl Friedrich Gauss invented the electric telegraph.
- 1838 – Mattias Jakob Schleiden discovered that plant tissues are composed of cells.
- 1846 – William Morton demonstrated the effective use of ether as an anesthesia.
- 1850 – Jean Bernard Léon Foucault, determined the speed of light in the air.
- 1859 – Charles Darwin, in *On the Origin of Species,* proposed that the origin of species was evolution by natural selection.
- 1864 – Louis Pasteur developed the process of pasteurization, the sterilization of liquid foods.
- 1867 – Joseph Lister published an article on the practice of using antiseptics during surgery.
- 1869 – Dmitri Ivanovich Mendeléev developed the Periodic Table.

- 1871 – Charles Darwin, in *The Descent of Man* suggested that human evolution was similar to that of animals.

Biographical Information

Mendel was born in 1822, the second of three children. He had two sisters. It seems as if even Mendel's ancestry and early schooling set Mendel on the path to his research in plant heredity. His father was a peasant who served in the Napoleonic Wars. Returning from service, he brought back ideas to improve farming, ideas he had picked up in his travels. Mendel's mother was the daughter of the village gardener. Many of her ancestors were professional gardeners.

Mendel's primary school teacher included the natural sciences in the curriculum and encouraged students to propagate fruit trees. Young Johann excelled at school and was sent to secondary school for one year and then Gymnasium for six years. Gymnasium in Austria provides secondary schooling in preparation for university work.

Mendel's psychological reaction to stress began to interfere with his academic life. At Gymnasium, when his father got sick, Johann had to begin private tutoring to finance his education. The stress of tutoring while keeping up his studies proved to be too much for the young man. The stress caused him to postpone his studies. Mendel finished at Gymnasium, and started at University of Olmütz, but stress caused him to return home and postpone studies there. The reaction to stress was a life-long problem. In May of 1856, well after Mendel had become a monk, he broke down during his second try at the examination for teachers of natural science. He became ill and never again attempted the examination.

Using his sister's dowry, Mendel returned to Olmütz and took philosophy courses to prepare for a university education. He again proved to be an exceptional student. His physics professor recommended him to the monastery in Brno. The Brno monastery was a center of learning and scientific work. It was the monastery that provided him the opportunity to continue his education and conduct his research.

Johann Mendel entered the monastery October 9, 1843, and took the name Gregor. He did not find himself to be very interested in the holy order but relished freedom from financial concerns. He had found the best conditions for his studies. He undertook his theological studies from1844 to 1848. The abbot at Brno wanted monks to teach and learn at the Philosophical Institute at Olmütz. During his theological studies, Mendel studied agriculture, breeding sheep, and artificial pollination hybridization of fruit trees. Also during his theological studies he worked in the monastery's experimental garden investigating variation, hybridization and evolution. He was eventually put in charge of the gardens.

At the end of his theological studies, Mendel was assigned service as hospital chaplain, but the stress of working with the ill was difficult for him. He got depressed. The abbot relieved him of hospital duty and sent him away to serve as a substitute teacher. Mendel proved to be an excellent teacher and was well liked. It was recommended that he take the examination to qualify as a full-time teacher of the natural sciences. He did not qualify and his failure was attributed to his lack of a university education. In1850 the monastery sent him to University of Vienna to study the natural sciences.

Mendel's time at the university did much to shape his future research. It was here that he studied the combinatorial analysis, which was the basis of his mathematical treatment of his later work. Incidentally, he studied Physics under Christian Doppler who characterized what is now known as the Doppler shift. In addition, Mendel did a great deal of work on studies in heredity. His instructor in plant physiology, Franz Unger, figured strongly in the development of Mendel's theories.

In 1854, after graduation from the University, Mendel returned to Brno. There he was appointed as a substitute teacher in physics and natural history at the Brno Technical School and was greatly appreciated in that role. At the monastery he started experimentation with peas in 1856. At the same he was preparing for his second try at the examination for teachers of natural science. In May of 1856, as mentioned above, Mendel broke down during the exam. He became ill and never again attempted the examination.

From 1856 to 1863 Mendel worked with 28,000 pea plants. In 1865 he presented his work at February and March meetings of the Natural Sciences Society of Brno, and in 1866 the results were published in their journal. The journal was sent to 134 scientific institutions throughout the Europe and the United States. Mendel, himself, sent out forty reprints. There was almost no response. The work was largely ignored. Mendel was disappointed but continued his work and believed that at some point he would be vindicated. He later tried his experiments many other plants and some animals

Mendel was particularly discouraged by extended correspondence with Carl Nageli at the University of Munich, an acknowledged authority on hybridization. Nageli did not agree with Mendel's theory that heredity was particulate, that parents passed unchanging elements of inheritance to their hybrid offspring. (A description of Mendel's experiments with peas can be found below in a separate section.)

In 1868 Mendel was appointed abbot of the monastery and became involved in local politics. He supported the Liberal party. Once they were elected to power, he had to fight their efforts to tax the monastery again subjecting himself to stress that he was ill-equipped to handle.

On January 6, 1884, Mendel died of kidney and heart problems.

Mendel's work was vindicated in 1900 when three researchers independently came up with the same results. Each said that he had read Mendel's reports

Mendel's Work

Accepted Theory of Inheritance in the Early Nineteenth Century

Selective breeding was hardly a new idea when Johann Gregor Mendel began his work. It preceded the agricultural revolution but the mechanism was not understood. Mendel grew up in a family of farmers and gardeners. He was certainly exposed to the practice of selective breeding in his youth and again in the experimental garden at the monastery in Brno.

Selective breeding was also a subject of scientific study. In 1809, Jean-Baptiste Monet de Lamarck stated, in *Philosphy Zoologique*, that inheritance of acquired characteristics could be achieved by selective breeding.

In Mendel's time the accepted theory of inheritance involved a blending of traits, not a transfer of discrete units of inheritance. The blending theory was supported by Charles Darwin among others. This approach was justified by common observation. A pair of parents, one short and one tall, might produce children of medium height. The children show traits between those of the parents. The traits were blended. Blending, however, did not explain the appearance of traits distinctly different from those expressed in the parents. The laws of inheritance that Mendel eventually proposed did not allow for blending.

Mendel's Approach to His Experiments

Mendel's work clearly had its roots in his studies at the University of Vienna. One of Mendel's instructors in Vienna and a major influence on the young monk was Franz Unger, a physiologist. In 1852, Unger stated his theory of the common descent of plants. Unger posited that evolution of plant forms developed from combination of "simplest elements" and considered sexual generation to be the basis of the great variety found in cultured plants. Mendel's work clearly incorporates the notion of "simplest elements" and just as clearly addresses the issue of variety. While at the university Mendel studied publications on K. F. von Gaertner's ten thousand experiments on heredity in over seven hundred different types of plants. Mendel also studied combinatorial analysis and acquired skills that allowed him to substantiate conclusions drawn from his work on thousands of plants.

Mendel's approach to his work was careful and methodical. It was also the first recorded work in biological research where statistical calculations were applied in order to examine work involving a large number of tests. He worked with 28000 plants between 1856 and 1863. The statistical approach was something he learned in his physical sciences and combinatorial analysis classes at the University of Vienna.

Some aspects of his approach suggest that he may have started with a preconceived notion of the results he expected and chose his experimental system to support his expectations. He needed a system that clearly showed the expression of recessive traits without the appearance of blending. It also had to be a system in which the generations were short enough for him to conduct a large number of tests involving several crosses. He needed to take pure-bred strains of plants and cross-pollinate them to produce hybrids. After characterizing them he had to interbreed the hybrids and characterize their offspring. He planned to do this with thousands of plants.

An explanation of dominant and recessive traits would be appropriate at this point. In individuals, characteristics are expressed differently, as differing traits. Use the characteristic of eye color as an example. One parent may have, as a trait, blue eyes. In the other the trait might be brown eyes. When parents produce offspring each parent contributes to the determination of the eye color of the new individual. The blue eye trait may not show at all. It may be completely hidden by the brown eye trait. In that case the blue eye trait would be the "recessive" trait. The brown eye trait would be the "dominant" trait. This concept of dominance is essential to Mendel's work.

Peas turned out to be an ideal system. In the years immediately following Mendel's birth, between 1822 and 1824, three researchers, John Goss, T. A. Knight, and Alexander Seton, working independently, studied inheritance of traits in peas. They recorded observations of the appearance of recessive traits in peas bred from hybrid plants in which that trait is not expressed. None of them kept records of work with subsequent generations. Nonetheless it was known that peas produced offspring that occasionally showed traits that were not present in either parent.

In peas Mendel was able to identify seven characteristics for which there were clearly recessive and dominant traits. The characteristics were flower color, flower position, stem length, seed shape, pod shape, seed color, and pod color. Some other characteristics did not breed as clearly; they showed more than two forms of the trait when the strains were interbred. Mendel did not use those traits; he selected only those seven traits that would give results consistent with what appears to be a preconceived idea. In addition, he used purebred strains that had been cultivated for many generations showing no variation in their traits. Using just the seven characteristics, Mendel was able to limit his variables. Most of his experiments involved plants that differed by only one trait. The limitation of variables was another approach taken from his studies in the physical sciences.

Mendel's Results

In retrospect Mendel's plan was very precise but ultimately simple. Starting with two strains of plants differing by only one trait, he cross-pollinated plants from the two strains and characterized the resultant hybrids in the second generation. The hybrids exhibited only one form of the trait. For example when Mendel cross-pollinated a purple flowered plant with a white flowered plant, all of the offspring had purple flowers. He then interbred the second-generation hybrid plants and characterized their offspring, the plants in the third generation. What he observed in the third generation was that both forms of the trait appeared. One quarter of the plants exhibited the trait that disappeared in the second generation of plants. Continuing with our example, Mendel cross-pollinated the purple-flowered hybrid plants. One quarter of their offspring had white flowers; the rest had purple flowers. Throughout the experiment the flowers were either white or purple like those of the original purebred plants. There were no other or intermediate forms, no plants with light purple flowers.

From these experiments Mendel came up with several conclusions. He decided that traits were passed from parent to offspring in units of inheritance. We now call these units "genes." For each trait the offspring inherits one unit (gene) from each parent. Traits that are not expressed (seen) in either parent may still be passed on to the offspring. The units for some traits are dominant and will mask the presence of recessive units.

These conclusions lead to Mendel's principle of segregation. According to the principle of segregation, each parent has two units of inheritance (genes) for any particular trait. During reproduction units of each parent separate and each parent passes only one unit to an offspring. Which of a parent's units is inherited is a matter of chance.

The second set of experiments was more complicated. Mendel started with plants that differed by more than one trait. For example one of the purebred strains might be tall plants with purple flowers. The other might be short plants with white flowers. The results were the same as in the first set of experiments. All of the hybrids in the second generation of plants were identical. In our example they would be tall plants with purple flowers. In the third generation all of the traits once again appeared, but not all of the plants were identical to one of the original pure-bred plants. In our example most of the offspring would be tall purple-flowered plants but there would also be some short plants with purple flowers and some tall plants with white flowers. (Also there were again no intermediate forms, no light purple flowers and no medium-tall plants.)

This set of experiments gave rise to Mendel's principle of independent assortment. According to the principle of independent assortment, the units of inheritance for different traits are passed to offspring independently of each other. The inheritance of one trait does not make the inheritance of another trait any more or less likely.

Aside from providing the basis for the science of genetics, Mendel made another important contribution to biological science. He was essentially the world's first "biostatistician." Mendel did thousands of individual cross-pollinations. He worked with over 28,000 plants. He kept meticulous records. He facilitated record keeping by using single letter notations for each of the traits. To the results of the thousands of tests, Mendel applied the statistical methods he learned in Vienna in order to substantiate his conclusions.

LESSON PLANS

Lesson One – Timeline Activity

Each "Overnight Sensation" unit contains a timeline activity that provides a context for the efforts of the scientist under discussion. The preparation and procedures for the activity are the same in each lesson. Therefore, the basic activity is described here. As each lesson refers to the activity and provides the list of events to be used in that instance of the activity. To begin the lesson, the teacher, using the information provided in the narrative, talks about Mendel. The students learn about Mendel's life and his fascination with the way traits are handed down through the generations. They learn about the history, about the political and social issues, and about the art, music, and literature of the time. The teacher will select a list of the events and issues for the students to pick from as they create their timelines. There will be three timelines. One will be biographical, one will cover advances in science, and the last will cover other historical and cultural events. The students then perform the following activity using that list of events. For the History and Arts timeline I stick with the major historical events and three pieces of literature that would be familiar to middle school students. For history I include the events relating to Texas. The music and art of Mendel's time will not be familiar to the students. To use the music the teacher will need to play part of the selected piece for the class. To use the art the class will need to look at an image. My choices for the history and arts timeline include:

- 1843 – Charles Dickens: *A Christmas Carol*
- 1851 – Herman Melville: *Moby Dick*
- 1861 – Hans Christian Andersen: *Fairy Tales*
- 1865 – Lewis Carroll: *Alice in Wonderland*
- 1815 – Napoleon surrenders at Waterloo
- 1836 – Texas Declaration of Independence
- 1844 – Texas becomes a state.
- 1854 – Commodore Perry establishes trade with Japan
- 1861 to 1865 – American Civil War
- 1867 – Seward's Folly: the purchase of Alaska

Purpose

To provide a context for the work of the specified scientist

Materials

The teacher will provide one set of the following materials to each student team:

- Paper - approximately 30 inches by 48 inches. Poster paper, butcher paper, newsprint, and bulletin board background paper work well.
- A set of colored markers (water washable)
- A meter stick
- Index cards (3 inches by 5 inches) If possible provide four different colors. Plan to use about twenty five cards for each student team..
- Glue, gluesticks or tape.
- The list of events that the students should use in the timeline.

Procedure:

1. Explain to the students that they will be creating timelines. There will be three of them, one listing the events in the scientist's life, one for advances in science, and one for the arts, literature, and historic events.
2. Students examine the list of events and classify them. They decide on which timeline each event belongs and mark the event accordingly. They might use highlighters or markers as color indicators. They might have written designations.
3. After classifying the events, the students pick five or more items for each of the three timeline.
4. Students choose a different color index card for each timeline, and write the events (including the date) on the appropriate colored card. For example, if the arts and literature timeline has pink cards, all arts and literature events are written on pink cards.
5. The students then prepare the structure of the timelines. The timelines will cover one century and will end with the decade following the death of the scientist. The students draw three horizontal parallel lines, one across the center of the page, one ten inches

above the centerline and one ten inches below the centerline. The beginnings of the lines should be directly above or below each other.

6. The students then mark the decades on each timeline. The marks on the three timelines should be vertically aligned and should be about five inches apart. There will be eleven marks on each timeline; the timeline should extend at least one full decade past the death of the scientist.
7. The students will then affix the index cards at the appropriate date on the appropriate timeline.

Lesson Two – Punnett Squares

Prior to the hands-on activity the students will complete a worksheet introducing Gregor Mendel, dominant and recessive traits, and Punnett squares. The Punnett Square exercise (see Appendix One) is self-explanatory. Although the students should be able to complete it independently, it is best done as a classroom activity. In the classroom setting, we start out by looking at different traits among the students. The students offer reasons why those different traits exist. Some will provide DNA or genes as an answer. The discussion about traits expands to include traits within the students' families. The students discuss ways the members of their families look familiar and how they look different. The teacher is looking for traits that show up in offspring but are not present in the parents. Of special interest are traits that have skipped a generation. Essentially you are looking for comments such as, "My parents have brown eyes, but my sister has green eyes like my grandmother." The teacher then discusses dominant and recessive genes as a possible reason for the variations in the traits that the students have described. This leads into the portion of the Punnett square exercise. After the class has completed the exercise, the teacher will check for understanding by working more examples on the board. Following that there should be a quick quiz in which the students check their understanding independently. The students will then use Punnett squares in the next exercise.

Lesson Three – DNA Doggies

Purpose

The hands-on activity is called DNA Doggies. The exercise provides students with a physical application of the information covered in the Punnett square exercise. The students work with a fictional animal called a DNA Doggie. The teacher shows the class the genotypes of two parent DNA Doggies and displays models of the animals. These are made of marshmallows, tacks and pipe cleaners. The students, in pairs, receive cards representing the chromosomes of each parent. Using these cards the students determine the genotype of one possible offspring. They then generate the phenotype of offspring. Finally, they get to build their offspring.

The following provides a brief description of the flow of the exercise. The student handout, with explicit instructions and the templates for "chromosome cards," are found in the appendix.

During this activity students will have the opportunity to observe many offspring produced by one set of DNA Dog parents. They will model inheritance of parental characteristics. The class will be provided with the parental genotypes. They will select one characteristic, snout color, and then predict the number of new individuals exhibiting the yellow phenotype. Other offspring will have orange snouts. It might be worthwhile to also predict the number of puppies with straight tails or curly tails. The class will make the prediction using the parental genotypes, a Punnett square, and the number of puppies to be created by the class.

Next, the students model the sorting of parent (Mom and Dad DNA Dog) chromosomes. The students work in pairs. One student in each pair receives an envelope with chromosome cards representing the mother's genes; the other receives the father's chromosome cards. The "mothers" randomly select one gene (chromosome card) for each trait to form the ovum. The "father" does the same to form the sperm. After forming gametes, the students combine the male and female gametes to create a new individual, the baby DNA Doggie. From the resultant genotype the students determine the phenotype of the puppy. Lastly, the class will compare their initial predictions with the number of new individuals exhibiting the selected characteristic(s). Collecting and combining the results of many classes will show the students that a larger sample size will provide a better match between the observed and predicted expression of a trait in a population. The students will be observing sorting, fertilization and expression of a genotype …all in just one class.

Materials

- Large white marshmallows (body)
- Tiny multicolored marshmallows (snouts)
- Toothpicks (to join body segments)
- Pipe cleaners – Purple and Red (tails)
- Top Hat Push pins (legs) - Blue and White
- Map pins (eyes) Blue and Red
- Card stock (for Chromosome cards and ears)
- Small envelops

Preparation

- Cut pipe cleaners into segments of approximately ten centimeters.
- Create ears by cutting thin strips of cardstock into two centimeter and four centimeter lengths.
- Creating the chromosome cards is a little more complex. On the heaviest cardstock your copier will handle copy the chromosome card masters from the appendix. The copies must be double sided with the name of the trait matched with the letter symbol for that trait. The pairings are as follows: Ears and A, Snout and Q, Curl and T, Tail and R, Eyes and A, Legs and L, Body and D. Cutting the cards out is labor intensive. Delegate the task. The masters for the cards are found in Appendix Three.
- Label envelops for the mothers and the fathers. Then put the appropriate chromosome cards in each envelop. Genotypes are provided in the section below.

Teacher Note: Parental Phenotype and Genotype.

Phenotypes:

Both parent DNA Dogs have long ears, orange snouts, blue eyes, long bodies, and blue legs. The mother has a straight purple tail and the father has a curly red one.

Traits:

Characteristic	Dominance	Gene
Long ears	Dominant	A
Short ears	Recessive	a
Orange snout (nose)	Dominant	Q
Yellow snout (nose)	Recessive	q
Curly tail	Dominant	T
Straight tail	Recessive	t
Purple tail	Dominant	R
Red Tail	Recessive	r
Blue eyes	Dominant	E
Red eyes	Recessive	e
White Legs	Dominant	L
Blue legs	Recessive	l
Long body	Dominant	D
Short body	Recessive	d

Parental Genotypes:

Genotype -Mother	Genotype - Father
AA	AA
Qq	Qq
Ee	Ee
Dd	Dd
tt	Tt
Rr	rr
LL	Ll

Procedure

The student procedures are explained in the student activity sheet found in Appendix Two.

Assessment

- Teacher Observation
- Punnett Square worksheet
- Answers to questions on the DNA Doggie worksheet.

CONCLUSION

These activities introduce the work of Gregor Mendel. The second and third activities cover the scientific principles related to his accomplishments. The students enjoy the hands on work mimicking the effects of hybridization as it produces great variety in a population. In covering the scientific principles these lessons accomplish what is important and necessary as students develop scientific competence. However, without the first lesson they miss an important component in science education. The first lesson educates the student in one aspect of the nature of science, how the world of the scientist provides the environment that affects that scientist's work. Most teachers do not address that aspect of science education because they are not provided with the necessary information. A similar approach, using the timeline as an introduction should be employed when teaching about other scientists. Often, because many scientists were working at the same time, it will be possible to revisit a time line and simply add a biographical strand for the new scientist. Using timelines in conjunction with instruction about scientific principles will put the development of those principles into a fuller context.

APPENDIX ONE

In this appendix is the student handout that comprises the main teaching element of the second lesson, Punnett Squares. The students will each need to complete their own copies.

PUNNETT SQUARES

The Father of Genetics

We look the way we do partly because of the genes we have. We inherit many of our traits from our parents, such as the color of our eyes, our height, curly or straight hair. Some of the traits we inherit are things that we cannot see, like our blood type. Our genes do not determine everything about us, but they control a lot.

Some scientists study the way we inherit our traits. The work they do is called genetics. One of the first people to study the inheritance of traits was an Austrian monk named Johann Gregor Mendel. (You will need to remember his name.) From 1856 to 1863, about the time of our Civil War, he studied many generations of peas. He found some of the basic rules about the way traits are passed one generation to the next. Because of his work, Mendel is now known of the "Father of Genetics."

Mendel collected a lot of data, a lot of information. He made some inferences from that data. These inferences include Mendel's rules of inheritance. One of the rules states that each of our traits is controlled by two separate genes, one from each of our parents. Together, the two genes are called a gene pair. Another rule tells us that one of the genes in a gene pair is "stronger" than the other. This is the dominant trait, or dominant gene. The "weaker" one is the recessive gene.

Dominant and Recessive Traits

So what do we mean by "dominant"? Let's take an example from Mendel's work. Mendel decided that the color of the peas was determined by one gene pair. One gene could make the peas green or yellow. The gene that makes peas yellow is the dominant, stronger, gene. The gene for green peas is the recessive gene. When a gene pair has two of the genes for yellow peas, the peas are yellow. When the pair has two genes for green peas the peas are green. What happens when a gene pair contains one gene for yellow peas and one for green peas? The pea is yellow. The pea will be green only if both of the genes in a pair are genes for green peas. Whenever the pair contains a gene for yellow peas, the pea will be yellow. This means that yellow is the dominant trait.

In Punnett squares we use single letter to label genes. For a dominant gene we use one uppercase letter. The recessive gene would be labeled with the lowercase form of the same letter. For example if we use "Y" to label the gene for yellow peas, we would use "y" for the gene for green peas.

Practice

In the table below there are genotype labels in the left hand column. For each gene pair, determine the phenotype and write its label in the right hand column. The first three examples are done for you.

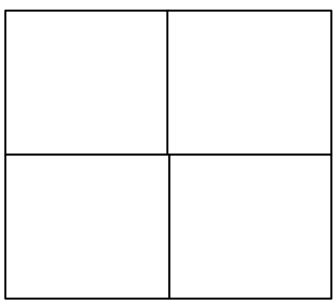
(Remember: Uppercase letters for dominant genes – lowercase letters for recessive genes.)

Genotype	Phenotype
TT	T
Tt	T
tt	t
EE	
ee	
AA	
aa	
Aa	
Gg	
GG	
gg	

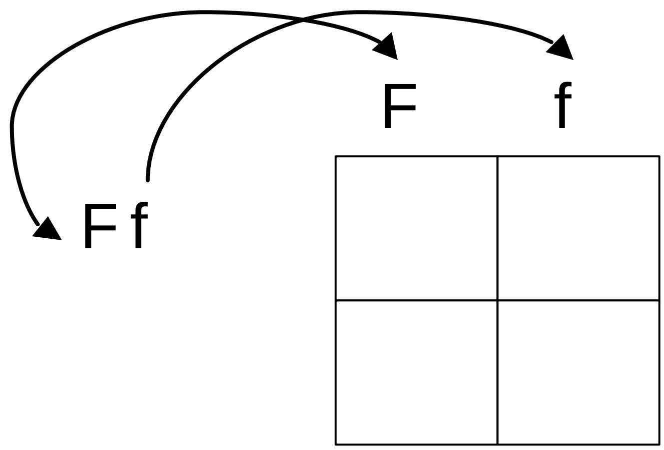
Punnett Squares

We can use Mendel's rules of inheritance to predict what fraction of a population will exhibit a certain trait. If we know the genotype of the parents, we can predict the genotype and phenotype of the offspring (for humans, offspring means children). Punnett squares help us make those predictions. Using Punnett Squares is easy. We will use Mendel's peas as an example. Mendel found that purple was the dominant trait for color and that white was the recessive trait. For this example, we will use "F" for purple flowers, and "f" for white flowers. Suppose that both parent plants have the genotype "Ff". The dominant purple trait will make the flowers purple. Will the flowers of the offspring be purple? Let's set up a Punnett square and find out.

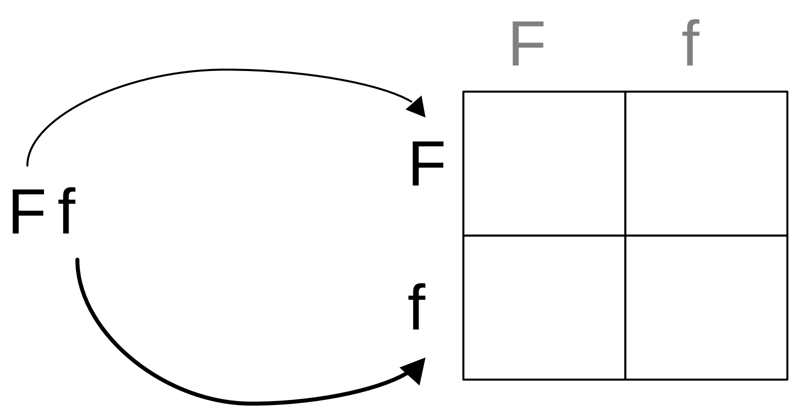
First draw a square split into four quadrants.



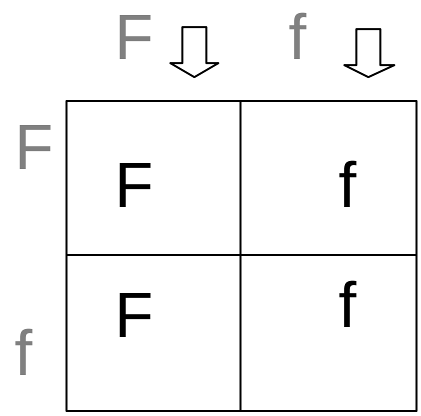
Then write down the genotype for one of the parents over the Punnett square. Put one letter over each column.



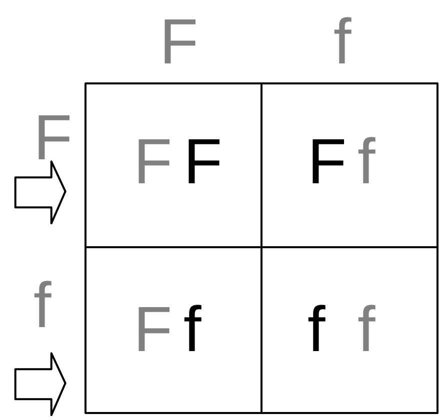
Next write the genotype of the second parent at the left of the Punnett square. Write one letter by each row.



You are done setting up the Punnett square. Now it is time to fill it in. Start with the letters at the top. Take the letter at the top of a column and copy it into the boxes below it



Next you will work with the genes from the second parent (the letters to left of the Punnett Square. Take the letter at the left of a column and copy it into the boxes to the right.



Now you know that ¼ of the offspring will have the genotype “FF” (phenotype – purple flower). One fourth of the offspring will have the genotype “ff” (phenotype – white flower). One half of the offspring will have the genotype “Ff” (phenotype – purple flower). Remember purple is the dominant trait for flower color. So ¾ of the new plants will have purple flowers. Now try some on your own.

Pea Color: Yellow Peas or Green Peas

- **Yellow** “G” **is the dominant trait for pea color.**
- **Green** “g” **is the recessive trait.**
- **One parent has the genotype** “GG” **(phenotype - a yellow pea) and the second parent has the genotype** “gg” **(phenotype - a green pea).**
- **What fraction of the offspring has yellow peas?**

Answer: ___________

	Q___	q___
q___		
q___		

Plant Height: Tall Plants or Short Plants

- **Tall** “H” **is the dominant trait for plant height.**
- **Short** “h” **is the recessive trait.**
- **One parent has the genotype** “Hh” **(phenotype - a tall plant) and the second parent has the genotype** “hh” **(phenotype - a short plant)**
- **What fraction of the offspring will be tall?**

Answer: ___________

	____	____
____		
____		

Pea Shape: Wrinkled Peas or Smooth Peas

- **Smooth** “Q” **is the dominant trait for pea shape.**
- **Wrinkled** “q” **is the recessive trait.**
- **One parent has the genotype “**Qq**” (phenotype - a smooth pea) and the second parent has the genotype “**qq**” (phenotype - a wrinkled pea).**
- **What fraction of the offspring has wrinkled peas?**

Answer: ___________

	____	____
____		
____		

APPENDIX TWO

This appendix contains the student instruction sheet for the DNA Doggies exercise. Each student should get his own copy, although they can work with one copy per student pair.

DNA DOGGIES

Procedure

1. You and you partner will receive two packets, each with the chromosome cards for one of the DNA Dog Parents. One student will work with the DNA Daddy Dog chromosomes. The other student will work with the DNA Momma Dog's chromosomes.
2. Each chromosome contains a gene represented by a letter on one side of the card. The other side of the card has a label that tells you what trait is controlled by that gene. Each parent has a chromosome pair for each trait. That means that before meiosis Mom's and Dad's cells are diploid. Mom and Dad should each have six chromosome pairs.
3. Take the chromosomes card out of the packets. Keep the mother's chromosomes separate from the father's chromosomes. Turn each card so that you can read the label that identifies the trait. The side with the letter should be face down.
4. Sort chromosome cards by trait. (So the tail chromosomes should be together, the ear chromosomes should be together and so on.)
5. Now you are going to simulate the random way in which the chromosomes from the parents form gametes. During meiosis, the chromosome pairs randomly form groups of unpaired chromosomes. These are the gametes. The gametes are haploid; they contain only one chromosome for each trait.
   - To form the female gamete, Mom takes one chromosome for each trait. Randomly select one chromosome card from each pair. Place these cards in a pile on the space for the egg (on the place mat). This forms the egg, the gamete from the female. It contains the genes that come from the mother.
   - To form the male gamete, Dad takes one chromosome for each trait. Randomly select one chromosome card from each pair. Place these cards in a pile on the space for the sperm (on the place mat). This forms the sperm, the gamete from the male. It contains the genes that come from the father.
6. Next, the sperm and the egg combine to form the beginnings of a new individual, the puppy.
   - Combine the chromosome cards from the sperm and the egg. Place the cards on the space for the fertilized egg.
   - Separate these cards into pairs. Each pair should be labeled for the same trait. You have just formed the chromosome pairs for the new individual.
   - Record the two letters from each chromosome pair the puppy inherited from its parents. Record them in Table 1 of the lab report.
   - Continue until all of the baby's chromosomes are recorded.
7. Refer to the key below to complete table #1 on the lab report. Remember dominance effects the way gene pairs express a trait.
   - Two dominant genes, XX, will express the dominant trait.
   - Two recessive genes, xx, will express the recessive trait.
   - One dominant gene paired with a recessive gene, Xx, will express the dominant trait.

Characteristic	Dominance	Gene
Long ears	Dominant	A
Short ears	Recessive	a
Orange snout (nose)	Dominant	Q
Yellow snout (nose)	Recessive	q
Curly tail	Dominant	T
Straight tail	Recessive	t
Purple tail	Dominant	R
Red	Recessive	r
Blue eyes	Dominant	E
Red eyes	Recessive	e
White Legs	Dominant	L
Blue legs	Recessive	l
Long body	Dominant	D
Short body	Recessive	d

8. Go to the materials table and gather your supplies to construct your baby DNA Doggie based on the effects of the gene pairs (genotype) which determines appearance (phenotype). You will need to cut out ears. Long ones should be two centimeters long. Short ears should be one half centimeter long.
9. Now construct your puppy. (Long bodies have 3 marshmallows. Short bodies have 2 marshmallows.)
10. Answer questions 2-8 on your lab report.

VOCABULARY

- Haploid: has only one of each type of chromosome
- Diploid: has two of each type of chromosome. The chromosomes exist in pairs
- Gamete: a haploid cell that carries chromosomes for sexual reproduction
- Meiosis: the process in which one diploid cell produces four haploid gametes
- Genotype: the genes on the chromosome pairs of an individual
- Phenotype: the way a trait is expressed in an individual
- Dominant Trait: a trait that is expressed any time an individual inherits a copy of the gene for that trait
- Recessive Trait: a trait that is expressed only when an individual inherits two copies of the gene for that trait

Name ____ **Date** ___________________

DNA DOGGIES LAB REPORT

1. **List your DNA puppy's "letters" (**genotype**) and describe the "appearance" (phenotype) for each trait listed in the table below.**

Table 1

Trait	Letters (genotype)	Appearance (phenotype)
Length of The Ears		
Snout Color		
Tail – Curly Or Straight		
Tail - Color		
Eye Color		
Leg Color		
Body – Long Or Short		

2. **How many total chromosomes did your DNA puppy have?** ___________________
3. **How many chromosomes did the "father" contribute?** _______________________
4. **How many chromosomes did the "mother" contribute?** ______________________
5. **How did you decide which genes the DNA puppy would get?** _________________

____

____

6. **Did anyone else in the class create a DNA puppy with the identical combination of traits that you did?** ______________________________

   Why or Why Not? ______________________________

   ____

   ____

7. **How many different types of DNA puppies did the class create?** __________

8. **If you and your partner created another DNA puppy using the same procedure, would the puppy turn out to have the exact same genotype? Explain your answer.**

   ____

   ____

   ____

   ____

9. **How does this lab help explain why no two people (unless they are identical twins) are alike?**

   ____

   ____

   ____

   ____

APPENDIX THREE

Creating the chromosome cards is a little complex. On the heaviest cardstock your copier will handle copy the chromosome card masters in this appendix. The copies must be double sided with the name of the trait matched with the letter symbol for that trait. Use a different color cardstock for each of the traits. The pairings are as follows: Ears and A, Snout and Q, Curl and T, Tail and R, Eyes and A, Legs and L, Body and D. Cutting the cards out is labor intensive. Delegate the task.

Body

D	D	D
D	D	D
D	D	D
D	D	D
D	D	D
D	D	D
d	d	d
d	d	d
d	d	d
d	d	d
d	d	d
d	d	d

Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body
Body	Body	Body

Ears

A	A	A
A	A	A
A	A	A
A	A	A
A	A	A
A	A	A
A	A	A
A	A	A
A	A	A
a	a	a
a	a	a
a	a	a

Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears
Ears	Ears	Ears

Eyes

E	E	E
E	E	E
E	E	E
E	E	E
E	E	E
E	E	E
e	e	e
e	e	e
e	e	e
e	e	e
e	e	e
e	e	e

Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes
Eyes	Eyes	Eyes

Legs

L	L	L
L	L	L
L	L	L
L	L	L
L	L	L
L	L	L
L	L	L
L	L	L
L	L	L
l	l	l
l	l	l
l	l	l

Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs
Legs	Legs	Legs

Snout

Q	Q	Q
Q	Q	Q
Q	Q	Q
Q	Q	Q
Q	Q	Q
Q	Q	Q
q	q	q
q	q	q
q	q	q
q	q	q
q	q	q
q	q	q

Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout
Snout	Snout	Snout

Tail

T	T	T
T	T	T
T	T	T
t	t	t
t	t	t
t	t	t
t	t	t
t	t	t
t	t	t
t	t	t
t	t	t
t	t	t

Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail
Tail	Tail	Tail

Curl

R	R	R
R	R	R
R	R	R
r	r	r
r	r	r
r	r	r
r	r	r
r	r	r
r	r	r
r	r	r
r	r	r
r	r	r

Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl
Curl	Curl	Curl

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