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| **3.1.U1** | **A gene is a heritable factor that consists of a length of DNA and influences a specific characteristic.**   * Define gene. |
| **3.1.U2** | **A gene occupies a specific position on a chromosome.**   * Define gene locus. |

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| **3.1.U3** | **The various specific forms of a gene are alleles.**   * Define allele. * List two examples of genes with multiple alleles. * State a similarity between alleles of the same gene. |
| **3.1.U4** | **Alleles differ from each other by one or only a few bases.**   * State the difference between alleles of the same gene. |

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| **3.1.U5** | **New alleles are formed by mutation.**   * State the source of new alleles of a gene. * Describe a base substitution mutation. |
| **3.1.U6** | **The genome is the whole of the genetic information of an organism.**   * Define genome. * State the size in base pairs of the human genome. |

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| **3.1.U7** | **The entire base sequence of human genes was sequenced in the Human Genome Project.**   * Define “sequence” in relation to genes and/or genomes. * State the aim of the Human Genome Project. * Outline two outcomes of the Human Genome Project. |
| **3.1.A1** | **The causes of sickle cell anemia, including a base substitution mutation, a change to the base sequence of mRNA transcribed from it and a change to the sequence of a polypeptide in hemoglobin.**   * State the cause of sickle cell anemia, including the name of differences in the Hb alleles. * State the difference in amino acid sequences in transcription of normal and mutated Hb mRNA.Outline the consequences of the Hb mutation on the impacted individual. |

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| **3.1.A2** | | **Comparison of the number of genes in humans with other species.**   * State the number of genes in the human genome. * Describe the relationship between the number of genes in a species and the species complexity in structure, physiology and behavior. |
| **3.1.S1** | **Use of a database to determine differences in the base sequence of a gene in two species.**   * Explain why cytochrome oxidase 1  is often used to assess the differences in the base sequences of a gene between two species. * Use NCBI to search for COX1 sequences for different species. * Use a computer software tool to create an alignment of the gene sequences between different species. * Outline information that can be determined given gene sequence alignment data. | |

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| **3.1.** **NOS** | **Developments in scientific research follow improvements in technology-gene sequencers are used for the sequencing of genes.**   * Outline the technological improvements that have sped the DNA sequencing process. * Determine a DNA sequence from an electropherogram. | |
| **3.2.U1** | | **Prokaryotes have one chromosome consisting of a circular DNA molecule.**   * Describe the arrangement of prokaryotic DNA (nucleoid and plasmid). * Define the term “naked” in relation to prokaryotic DNA. |
| **3.2.U2** | | **Some prokaryotes also have plasmids but eukaryotes do not.**   * Describe the structure and function of plasmid DNA. |

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| **3.2.U3** | **Eukaryote chromosomes are linear DNA molecules associated with histone proteins.**   * Describe the structure of eukaryotic DNA and associated histone proteins during interphase (chromatin). * Explain why chromatin DNA in interphase is said to look like “beads on a string.” |
| **3.2.U4** | **In a eukaryote species there are different chromosomes that carry different genes.**   * List three ways in which the types of chromosomes within a single cell are different. * State the number of nuclear chromosome types in a human cell. |

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| **3.2.U5** | **Homologous chromosomes carry the same sequence of genes but not necessarily the same alleles of those genes.**   * Define homologous chromosome. * State a similarity and a difference found between pairs of homologous chromosomes. |
| **3.2.U6** | **Diploid nuclei have pairs of homologous chromosomes.**   * Define diploid. * State the human cell diploid number. * Outline the formation of a diploid cell from two haploid gametes. * State an advantage of being diploid. |

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| **3.2.U7** | **Haploid nuclei have one chromosomes of each pair.**   * Define haploid. * State the human cell haploid number. * List example haploid cells. |
| **3.2.U8** | **The number of chromosomes is a characteristic feature of member of a species.**   * State that chromosome number and type is a distinguishing characteristic of a species. * List mechanisms by which a species chromosome number can change. |

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| **3.2.U9** | **A karyogram shows the chromosomes of an organism in homologous pairs of decreasing length.**   * Describe the process of creating a karyogram. * List the characteristics by which chromosomes are arranged on the karyogram. | |
| **3.2.U10** | | **Sex is determined by sex chromosomes and autosomes are chromosomes that do not determine sex.**   * Outline the structure and function of the two human sex chromosomes. * Outline gender determination by sex chromosomes. |

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| **3.2.A1** | **Cairns’ technique for measuring the length of DNA by autoradiography.**   * Describe Cairn’s technique for producing images of DNA molecules from E. coli. * Outline conclusions drawn from the images produced using Cairn’s autoradiography technique. |
| **3.2.A2** | **Comparison of genome size in T2 phage, *Escherichia coli, Drosophila melanogaster, Homo sapiens*, *Paris japonica.***   * Describe the relationship between the genome size of a species and the species complexity in structure, physiology and behavior. |

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| **3.2.A3** | **Comparison of diploid chromosome numbers of *Homo sapiens, Pan troglodytes, Canis familiaris, Oryza sativa, Parascarsis equorum.***   * State the minimum chromosome number in eukaryotes. * Explain why the typical number of chromosomes in a species is always an even number. * Explain why the chromosome number of a species does not indicate the number of genes in the species. * Explain the relationship between the number of human and chimpanzee chromosomes. |
| **3.2.A4** | **Use karyograms to deduce sex and diagnose Down Syndrome in humans.**   * Distinguish between a karyogram and a karyotype. * Deduce the sex of an individual given a karyogram. * Describe the use of a karyogram to diagnose Down syndrome. |

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| **3.2.S1** | | **Use of databases to identify the focus of a human gene and its polypeptide product.**   * Search NCBI or OMIM for a given gene. * Determine the gene locus, abbreviated gene name, and description of the gene. | |
| **3.2.** **NOS** | **Developments in research follow improvements in techniques- autoradiography was used to establish the length of DNA molecules in chromosomes.**   * Outline the advancement in knowledge gained from the development of autoradiography techniques. | | |
| **3.3.U1** | | | **One of diploid nucleus divides by meiosis to produce four haploid nuclei.**   * Compare divisions of meiosis I and meiosis II. |
| **3.3.U2** | | | **The halving of the chromosomes number allows a sexual life cycle with fusion of gametes.**   * Compare sexual and asexual life cycles. * Explain why meiosis must occur as part of a sexual life cycle. |

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| **3.3.U3** | **DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids.**   * State that DNA is replicated in interphase before meiosis. * Given a diploid number (for example 2n=4), outline the movement and structure of DNA through the stages of meiosis. |
| **3.3.U4** | **The early stages of meiosis involved pairing of homologous chromosomes and crossing over followed condensation.**   * List three events that occur in prophase 1 of meiosis. * Define bivalent and synapsis. * Outline the process and result of crossing over. |

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| **3.3.U5** | **Orientation of pairs of homologous chromosomes prior to separation is random.**   * Describe the attachment of spindle microtubules to chromosomes during meiosis I. * Describe random orientation of chromosomes during meiosis I. |
| **3.3.U6** | **Separation of pairs of homologous chromosomes in the first division of meiosis halves the chromosome number .**   * Explain why meiosis I is a reductive division. * State that cells are haploid at the end of meiosis I. |

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| **3.3.U7** | **Crossing over and random orientation promotes genetic variation.**   * Explain how meiosis leads to genetic variation in gametes. * State the the number of chromosome combinations possible due to random orientation is 2^n. |
| **3.3.U8** | **Fusion of gametes from different parents promotes genetic variation.**   * Outline the role of fertilization as a source of genetic variation. |

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| **3.3.A1** | **Non-disjunction can cause Down syndrome and other chromosome abnormalities.  Studies showing age of parents influences chances of non-disjunction.**   * Define non-disjunction. * State the result of nondisjunction. * Describe the cause and symptoms of Down syndrome. * Explain the relationship between parental age and chances of non-disjunction. |
| **3.3.A2** | **Description of methods used to obtain cells for karyotype analysis e.g. chorionic villus sampling and amniocentesis and the associated risks.**   * Describe the two procedures for obtaining fetal cells for production of a karyotype. |

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| **3.3.S1** | | **Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells.**   * Outline the events of prophase, metaphase, anaphase and telophase in meiosis I and meiosis II. * Draw diagrams of cells in prophase, metaphase, anaphase and telophase in meiosis I and meiosis II. | |
| **3.3.** **NOS** | **Making careful observations- meiosis was discovered by microscope examination of dividing germ-line cells.**   * Discuss difficulties in microscopic examination of dividing cells. * Describe the discovery of meiosis. | | |
| **3.4.U1** | | | **Mendel discovered the principles of inheritance with experiments in which large numbers of pea plants were crossed.**   * Describe Mendel’s pea plant experiments. |
| **3.4.U2** | | | **Gametes are haploid so contain only one allele of each gene.**   * Define gamete and zygote. * State two similarities and two differences between male and female gametes |

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| **3.4.U3** | **The alleles of each gene separate into different haploid daughter nuclei during meiosis.**   * State the outcome of allele segregation during meiosis. |
| **3.4.U4** | **Fusion of gametes results in diploid zygotes with two alleles of each gene that may be the same allele or different alleles.**   * Outline the possible combination of alleles in a diploid zygote for a gene with two alleles. * Outline the possible combination of alleles in a diploid zygote for a gene with three alleles. |

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| **3.4.U5** | **Dominant alleles mask the effect of recessive alleles but co-dominant alleles have joint effects.**   * Define dominant allele and recessive allele. * State an example of a dominant and recessive allele found in pea plants. * State the usual cause of one allele being dominant over another. * Define codominant alleles. * Using the correct notation, outline an example of codominant alleles. |
| **3.4.U6** | **Many genetic diseases in human are due to excessive alleles of autosomal genes.**   * Define “carrier” as related to genetic diseases. * Explain why genetic diseases usually appear unexpectedly in a population. |

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| **3.4.U7** | **Some genetic diseases are sex-linked and some are due to dominant or co-dominant alleles.**   * Describe why it is not possible to be a carrier of a disease caused by a dominant allele. * Outline inheritance patterns of genetic diseases caused by dominant alleles. * Explain sickle cell anemia as an example of a genetic disease caused by codominant alleles. * Define sex linkage. |
| **3.4.U8** | **The pattern of inheritance is different with sex-linked genes due to to their location on sex chromosomes.**   * Outline Thomas Morgan’s elucidation of sex linked genes with Drosophila. * Use correct notation for sex linked genes. * Describe the pattern of inheritance for sex linked genes. * Construct Punnett grids for sex linked crosses to predict the offspring genotype and phenotype ratios. |

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| **3.4.U9** | **Many genetic diseases have been identified in humans but most are very rare.**   * List five example genetic diseases. * Explain why most genetic diseases are rare in a population. | |
| **3.4.U10** | | **Radiation and mutagenic chemicals increase the mutation rate and can cause genetic diseases and cancer.**   * State two factors that can increase the mutation rate. * Outline the effects of gene mutations in body cells and gamete cells. |

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| **3.4.A1** | **Inheritance of ABO blood groups.**   * Describe ABO blood groups as an example of complete dominance and codominance. * Outline the differences in glycoproteins present in people with different blood types. |
| **3.4.A2** | **Red-green color blindness and hemophilia as examples of sex-linked inheritance.**   * Describe the cause and effect of red-green color blindness. * Explain inheritance patterns of red-green color blindness. * Describe the cause and effect of hemophilia. * Explain inheritance patterns of hemophilia. |

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| **3.4.A3** | **Inheritance of cystic fibrosis and Huntington’s disease.**   * Describe the relationship between the genetic cause of cystic fibrosis and the symptoms of the disease. * Outline the inheritance pattern of cystic fibrosis. * Outline the inheritance pattern of Huntington’s disease. * List effects of Huntington’s disease on an affected individual. |
| **3.4.A4** | **Consequences of radiation after nuclear bombing of Hiroshima and accident at Chernobyl.**   * Outline the effects of radiation exposure after nuclear exposure at Hiroshima and Chernobyl. |

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| **3.4.S1** | **Construction of Punnett grids for predicting the outcomes of monohybrid genetic crosses.**   * Define monohybrid, true breeding, hybrid, F1 and F2. * Determine possible alleles present in gametes given parent genotypes. * Construct Punnett grids for single gene crosses to predict the offspring genotype and phenotype ratios. |
| **3.4.S2** | **Comparison of predicted and actual outcomes of genetic crosses using real data.**   * Explain the reason why the outcomes of genetic crosses do not usually correspond exactly with the predicted outcomes. * Describe the role of statistical tests in deciding whether an actual result is a close fit to a predicted result. |

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| **3.4.S3** | | **Analysis of pedigree charts to deduce the pattern of inheritance of genetic diseases.**   * Outline the conventions for constructing pedigree charts. * Deduce inheritance patterns given a pedigree chart. | |
| **3.4.** **NOS** | **Making quantitative measurements with replicates to ensure reliability, Mendel’s genetic crosses with peas plants generated numerical data.**   * Outline why Mendel’s success is attributed to his use of pea plants. * Explain discoveries made by Thomas Andrew Knight in relation to current understanding of genetics. * List three biological research methods pioneered by Mendel. | | |
| **3.5.U1** | | | **Gel electrophoresis is used to separate proteins or fragments of DNA according to size.**   * Match restriction enzyme names to the bacteria in which they are naturally found. * Describe the role of restriction enzymes in nature and in biotechnology applications. * Contrast sticky vs. blunt ends. * Identify a restriction site as either leaving sticky or blunt ends. * Demonstrate accurate use of a micro-pipette. * Determine the number and size of DNA fragments after being exposed to restriction enzymes (both linear and plasmid DNA). * Explain the function and purpose of DNA electrophoresis. * Describe how and why DNA fragments separate during electrophoresis. * Outline the functions of the buffer, marker and loading dye in DNA electrophoresis. |
| **3.5.U2** | | | **PCR can be used to amplify small amounts of DNA.**   * State the function of the PCR. * Describe the selectivity of the PCR. |

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| **3.5.U3** | **DNA profiling involves comparison of DNA.**   * Outline the process of DNA profiling. |
| **3.5.U4** | **Genetic modification is carried out by gene transfer between species.**   * Outline how the universality of the genetic code allows for gene transfer between species. |

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| **3.5.U5** | **Clones are groups of genetically identical organisms, derived from a single original parent cell.**   * Contrast sexual and asexual reproduction. * Define clone and cloning. * Describe different ways in which natural clones can arise. | |
| **3.5.U6** | | **Many plants species and some animal species have natural methods of cloning.** |

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| **3.5.U7** | **Animals can be cloned at the embryo stage by breaking up the embryo into more than one group of cells.**   * Describe the process of reproductive cloning via embryo splitting. * Outline example of cloning animal embryos via natural and artificial embryo splitting. |
| **3.5.U8** | **Methods have been developed for cloning adult animals using differentiated cells.**   * Describe the process of reproductive cloning via somatic cell nuclear transfer. |

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| **3.5.A1** | **Use of DNA profiling in paternity and forensic investigations.**   * List example sources of DNA that can be used in DNA profiling. |
| **3.5.A2** | **Gene transfer in bacteria using plasmids makes use of restriction endonucleases and DNA ligases.**   * Describe a technique for genetic modification including plasmids, restriction enzymes, reverse transcriptase and ligase. * Outline why plasmids with genes coding for antibiotic resistance are chosen as vectors in gene transfer between species. |

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| **3.5.A3** | | **Assessment of potential risks and benefits associated with genetic modification of crops.**   * Outline potential environmental, health and agricultural benefits and risks associated with genetic modification of crops. * Assess the risks and benefits of an example of a genetically modified crop (i.e. golden rice). |
| **3.5.A4** | **Production of clones embryos produced by somatic-cell nuclear transfer.**   * Outline the production of Dolly the sheep using somatic cell nuclear transfer. | |

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| **3.5.S1** | **Design of an experiment to assess one factor affecting the rooting of stem-cuttings.** |
| **3.5.S2** | **Analysis of examples of DNA profiles.**   * Analyze a DNA profile to determine relatedness or forensic guilt. |

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| **3.5.S3** | | **Analysis of data on risks to monarch butterflies of Bt crops.**   * Outline the formation and use of Bt crops in agriculture. * Assess the impact of Bt corn on monarch butterflies. | |
| **3.4.** **NOS** | **Assessing risks associated with scientific research- scientists attempt to assess the risks associated with genetically modified crops or livestock.**   * State two ways in which the risk of scientific research can be assessed. | | |
| **10.1.U1** | | | **Chromosomes replicate in interphase before meiosis.**   * Identify tetrad, bivalent, sister chromatids and non-sister chromatids in diagrams of replicated chromosomes. |
| **10.1.U2** | | | **Crossing over is the exchange of DNA material between non-sister homologous chromatids.**   * State that crossing over occurs during prophase I. * Define chiasmata. |

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| **10.1.U3** | **Crossing over produces new combinations of alleles on the chromosomes of the haploid cells.**   * State two consequences of chiasmata formation between non-sister chromatids. |
| **10.1.U4** | **Chiasmata formation between non-sister chromatids can results in an exchange of alleles.**   * Draw a diagram to illustrate the formation of new allele combinations as a results of crossing over. * Explain how crossing over between linked genes can lead to genetic recombinants. |

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| **10.1.U5** | | **Homologous chromosomes spate in meiosis I.**   * Contrast meiosis I with meiosis II. |
| **10.1U6** | **Independent assortment of genes in due to random orientation of homologous chromosomes pairs in meiosis I.**   * Describe random orientation and independent assortment. * Given a parent cell genotype, determine the allele combinations that are possible in the gametes due to independent assortment and random orientation. | |

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| **10.1.U7** | | **Sister chromatids separate in meiosis II.**   * Compare meiosis II with mitosis. |
| **10.1.S1** | **Drawing diagrams to show chiasmata formed by crossing over.**   * Draw a diagram to illustrate the process and result of crossing over. | |

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| **10.1** **NOS** | **Making careful observations- careful observations and record keeping turned up anomalous data that Mendel’s law of independent assortment could not account for. Thomas Hunt Morgan developed the notion of linked genes to account for the anomalies.**   * Describe the experiment of Bateson and Punnett that lead to results that did not support Mendel’s law of independent assortment. * Describe the trends and discrepancies that led Morgan to propose the idea of linked genes. | |
| **10.2.U1** | | **Unlinked genes segregate independently as a result of meiosis.**   * State the difference between independent assortment of genes and segregation of alleles. * Describe segregation of alleles and independent assortment of unlinked genes in meiosis. |
| **10.2.U2** | | **Gene loci are said to be linked if on the same chromosome.**   * Define autosome and sex chromosome. * Describe what makes genes “linked.” |

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| **10.2.U3** | **Variations can be discrete or continuous.** |
| **10.2.U4** | **The phenotypes of polygenic characteristics tend to show continuous variation.**   * Explain polygenetic inheritance using an example of a two gene cross with codominant alleles. * Outline the use of Pascal’s triangle to determine phenotype frequencies that results from polygenic crosses. * State that a normal distribution of variation is often the result of polygenic inheritance. * State example human characteristics that are associated with polygenic inheritance. |

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| **10.2.U5** | **Chi-squared tests are used to determine whether the difference between an observed and expected frequency distribution is statistically significant.**   * State the two possible hypotheses of a statistical test. * Calculate the chi square value to determine the significance of differences between the observed and expected results of a genetic cross. * Determine the degrees of freedom and critical value for the chi-square test. * Draw a conclusion of significance by comparing the calculated and critical chi-square values. |
| **10.2.A1** | **Completion and analysis of Punnett squares for dihybrid traits.**   * Determine possible allele combinations in gametes for crosses involving two genes. * Use correct notation to depict a dihybrid cross between two unlinked genes. * Construct a Punnett square to show the possible genotype and phenotype outcomes in a dihybrid cross. |

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| **10.2.A2** | **Morgans’s discovery of non-Mendellian ratios in Drosophilia.**   * Describe how Morgan discovered relationship between eye color and sex in Drosophila. |
| **10.2.A3** | **Polygenic traits such as human height may be influenced by environmental factors.**   * Outline two example environmental factors that can influence phenotypes. * Compare continuous to discrete variation. |

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| **10.2.S1** | **Calculation of the predicted genotypic and phenotypic ratio of offspring of dihybrid crosses involving unlinked autosomal genes.**   * Determine the predicted genotype and phenotype ratios of F1 and F2 offspring of dihybrid crosses. |
| **10.2.S2** | **Identification of recombinants in crosses involving two linked genes.**   * Use correct notation to show alleles of linked genes. * Construct a Punnett square to show the possible genotype and phenotype outcomes in a dihybrid cross involving linked genes. * Explain how crossing over between linked genes can lead to genetic recombinants. |

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| **10.2.S3** | | **Use of chi-squared test on data from dihybrid crosses.**   * Calculate a chi-square value to compare observed and expected results of a dihybrid genetic cross. * Using the df and critical chi-square value, determine if there is a significant difference between observed and expected results of a dihybrid cross. | |
| **10.2.** **NOS** | **Looking for patterns, trends and discrepancies- Mendel used observations of the natural world to find and explain patterns and tends, Since then, scientists have looked for discrepancies and asked questions based on further observations to show exceptions to the rules. For example, Morgan discovered non-Mendellian ratios in his experiments with Drosophilia.**   * Describe the trends and discrepancies that led Morgan to propose the idea of linked genes. | | |
| **10.3.U1** | | | **A gene pool consists of all the genes, and their different alleles, present in an interbreeding population.** |
| **10.3.U2** | | | **Evolution required that allele frequencies change with time in populations.** |

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| **10.3.U3** | **Reproductive isolation of populations can be temporal, behavioral or geographic.** |
| **10.3.U4** | **Speciation due to divergence of isolated populations can be gradual.** |

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| **10.3.U5** | **Speciation can occur abruptly.** |
| **10.3.A1** | **Identifying examples of directional, stabilizing and disruptive selection.** |

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| **10.3.A2** | | **Speciation in the genus Allium by polyploidy.** |
| **10.3.S1** | **Comparison of allele frequencies of geographically isolated populations.** | |

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| **10.3** **NOS** | **Looking for patterns, trends and discrepancies- patterns of chromosome number in some genera can be explained by speciation due to polyploidy.** |