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| **Unit 6: Gene Expression and Regulation** |

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| **Topic** | **Learning Objective(s)** |
| 6.1  DNA and RNA Structure | **IST-1.K** Describe the structures involved in passing hereditary information from one generation to the next. |
| **IST-1.L** Describe the characteristics of DNA that allow it to be used as the hereditary material |
| 6.2  Replication | **IST-1.M** Describe the mechanisms by which genetic information is copied for transmission between generations. |
| 6.3  Transcription and RNA Processing | **IST-1.N** Describe the mechanisms by which genetic information flows from DNA to RNA to protein. |
| 6.4  Translation | **IST-1.O** Explain how the phenotype of an organism is determined by its genotype |
| 6.5  Regulation of Gene Expression | **IST-2.A** Describe the types of interactions that regulate gene expression. |
| **IST-2.B** Explain how the location of regulatory sequences relates to their function. |
| 6.6  Gene Expression and Cell Specialization | **IST-2.C** Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism. |
| **IST-2.D** Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms. |
| 6.7  Mutations | **IST-2.E** Describe the various types of mutation |
| **IST-4.A** Explain how changes in genotype may result in changes in phenotype. |
| **IST-4.B** Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection. |
| 6.8  Biotechnology | **IST-1.P** Explain the use of genetic engineering techniques in analyzing or manipulating DNA. |

Free Response Practice

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| 2022 #6 |
| Researchers are studying the use of RNA vaccines to protect individuals against certain diseases. To develop the vaccines, particular cells are first removed from an individual. Then mRNAs coding for specific proteins from a pathogen are introduced into the cells. The altered cells are injected back into the individual, where the cells make the proteins encoded by the introduced mRNAs. The individual then produces an immune response to the proteins that will help to protect the individual from developing a disease if exposed to the pathogen in the future.  When introduced into cells, the mRNAs used for vaccines must be stable so that they are not degraded before the encoded proteins are produced. Researchers developed several modified caps that they hypothesized might make the introduced mRNAs more stable than mRNAs with the normal GTP cap. To test the effect of the modified caps, the researchers produced mRNAs that differed only in their cap structure (no cap, the normal cap, or modified caps I, II, or III). They introduced the same amount of each mRNA to different groups of cells and measured the amount of time required for half of the mRNAs to degrade (mRNA half-life) and the total amount of protein translated from the mRNAs (Table 1).  A picture containing text, screenshot, font, number  Description automatically generated  (a) Based on the data, **identify** which cap structure is most likely to protect the end of the mRNAs from degradation.  (b) Based on the data for the mRNAs with modified caps, **describe** the relationship between the mRNA half-life and the total amount of protein produced.  (c) After examining the data on mRNA half-lives and the amount of protein produced, the researchers hypothesized that each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap. **Evaluate** their hypothesis by comparing the data in Table 1.  (d) Introduction of mRNAs into cells allows the cells to produce foreign proteins that they might not normally produce. **Explain** why the production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells. |

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| 2021 #2 |
| Geneticists investigated the mode of inheritance of a rare disorder that alters glucose metabolism and first shows symptoms in adulthood. The geneticists studied a family in which some individuals of generations II and III are known to have the disorder. Based on the pedigree (Figure 1), the geneticists concluded that the disorder arose in individuals II-2 and was caused by a mutation in mitochondrial DNA.        (a) The disorder alters glucose metabolism. **Describe** the atoms AND types of bonds in a glucose molecule.  (b) Using the template in the space provided for your response, **construct** an appropriately labeled graph based on the data in Table 1. **Determine** one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV-1.  Chart  Description automatically generated with medium confidence  (c) Based on the pedigree, **identify** all individuals in generation IV who can pass on the mutation to their children.  (d) Based on the fact that individual II-2 is affected, a student claims that the disorder is inherited in an X-linked recessive pattern. Based on the student’s claim, **predict** which individuals of generation III will be affected by the disorder. Based on the pedigree, **justify** why the data do NOT support the student’s claim. |

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| 2021 #6 |
| The small invertebrate krill species *Thysanoessa inermis* is adapted to cold (4°C) seawater. Over the past ten years, there has been a gradual increase in the water temperature of the krill’s habitat. A sustained increase in water temperature may ultimately affect the ability of the krill to survive.  One effect of higher temperatures is protein misfolding within cells. Krill have several *hsp* genes that code for heat-shock proteins (HSPs). These proteins help prevent protein misfolding or help to refold proteins to their normal shapes.  Scientists conducted experiments on *T. inermis* to detect changes in the expression of *hsp* genes when the krill were exposed to temperatures above 4°C. An experimental group of krill was maintained in tanks with 4°C seawater and then placed into tanks with 10°C seawater for approximately three hours. The krill were then given a six-hour recovery period in the 4°C seawater tanks. A control group of krill was moved from a tank of 4°C seawater to another tank of 4°C seawater for approximately three hours and then returned to the original tank. The scientists analyzed *hsp* gene expression by measuring the concentrations of three mRNAs (I, II, III) transcribed from certain *hsp* genes in both the heat-shocked krill (Figure 1) and the control krill. For the control krill, no transcription of the *hsp* genes were detected throughout the test period (data not shown).    (a) **Identify** the *hsp* mRNA that has the slowest rate of concentration increase in response to heat-shock treatment.  (b) **Describe** the trend in the average concentration of mRNA I throughout the experiment.  (c) The scientists hypothesized that the heat-shock protein (HSP) translated from mRNA I plays a greater role in refolding proteins than does the HSP translated from mRNA II. Use the data to **support** the hypothesis.  (d) mRNAs I and II are transcribed from the same gene. **Explain** how a cell can produce two different mRNAs from the same gene. |

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| 2019 #6 |
| A picture containing text, screenshot, number, font  Description automatically generated  The yeast *Saccharomyces cerevisiae* is a single-celled organism. Amino acid synthesis in yeast cells occurs through metabolic pathways, and enzymes in the synthesis pathways are encoded by different genes. The synthesis of a particular amino acid can be prevented by mutation of a gene encoding an enzyme in the required pathway.  A researcher conducted an experiment to determine the ability of yeast to grow on media that differ in amino acid content. Yeast can grow as both haploid and diploid cells. The researcher tested two different haploid yeast strains (Mutant 1 and Mutant 2), each of which has a single recessive mutation, and a haploid wild-type strain. The resulting data are shown in Table 1.  (a) **Identify** the role of treatment I in the experiment.  (b) **Provide reasoning** to explain how Mutant 1 can grow on treatment I medium but cannot grow on treatment III medium.  (c) Yeast mate by fusing two haploid cells to make a diploid cell. In a second experiment, the researcher mates the Mutant 1 and Mutant 2 haploid strains to produce diploid cells. Using the table provided, **predict** whether the diploid cells will grow on each of the four media. Use a plus sign (+) to indicate growth and a minus sign (-) to indicate no growth.  A picture containing text, screenshot, font, number  Description automatically generated |

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| 2019 #7 |
| A researcher is studying patterns of gene expression in mice. The researcher collected samples from six different tissues in a healthy mouse and measured the amount of mRNA from six genes. The data are shown in Figure 1.  A picture containing text, screenshot, crossword puzzle, square  Description automatically generated  (a) Based on the data provided, **identify** the gene that is most likely to encode a protein that is an essential component of glycolysis. **Provide reasoning** to support your identification.  (b) The researcher observed that tissues with a high level of *gene H* mRNA did not always have gene H protein. **Provide reasoning** to explain how tissues with high *gene H* mRNA levels can have no gene H protein. |

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| 2018 #4 |
| The common bedbug (*Cimex lectularius*) is a species of insect that is becoming increasingly resistant to insecticides. Bedbugs possess several genes suspected of contributing to the resistance, including *P450, Abc8,* and *Cps*. To investigate the role of these genes in insecticide resistance, researchers deleted one or more of these genes in different strains of bedbugs, as indicated in Figure 1, and treated the strains with the insecticide beta-cyfluthrin. Each strain was genetically identical except for the deleted gene(s) and was equally fit in the absence of beta-cyfluthrin. The percent survival of each strain following beta-cyfluthrin treatment is shown in Figure 1.  A picture containing text, diagram, screenshot, technical drawing  Description automatically generated  (a) **Identify** the control strain in the experiment. Use the means and confidence intervals in Figure 1 to **justify** the claim that *Abc8* is effective at providing resistance to beta-cyfluthrin.  (b) *P450* encodes an enzyme that detoxifies insecticide. *Abc8* encodes a transporter protein that pumps insecticides out of cells. *Cps* encodes external structural protein located in the exoskeleton that reduces the absorption of insecticides. Based on this information and the data in Figure 1, **explain** how a deletion of both *P450* and *Abc8* results in lower survival in bedbugs compared with a deletion of *Cps* only*.* |

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| 2017 #3 |
| Gibberellin is the primary plant hormone that promotes stem elongation. GA 3-beta-hydrozylase (*GA3H*) is the enzyme that catalyzes the reaction that converts a precursor of gibberellin to the active form of gibberellin. A mutation in the *GA3H* gene results in a short plant phenotype. When a pure-breeding tall plant is crossed with a pure-breeding short plant, all offspring in the F1 generation are tall. When the F1 plants are crossed with each other, 75 percent of the plants in the F2 generation are tall and 25 percent of the plants are short.  A picture containing text, font, number, crossword puzzle  Description automatically generated  (a) The wild-type allele encodes a GA3H enzyme with alanine (Ala), a nonpolar amino acid, at position 229. The mutant allele encodes a GA3H enzyme with threonine (Thr), a polar amino acid, at position 229. **Describe** the effect of the mutation on the enzyme and **provide reasoning** to support how this mutation results in a short plant phenotype in homozygous recessive plants.  (b) Using the codon chart provided, **predict** the change in the codon sequence that resulted in the substitution of alanine for threonine at amino acid position 229.  (c) **Describe** how individuals with one (heterozygous) or two (homozygous) copies of the wild-type *GA3H* allele can have the same phenotype. |

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| 2017 #6 |
| A comet assay is a technique used to determine the amount of double-stranded breaks in DNA (DNA damage) in cells. The nucleus of an individual cell is placed on a microscope slide coated with an agarose gel. An electric current is applied to the gel that causes DNA to move (electrophoresis), and the DNA is stained with a fluorescent dye. When viewed using a microscope, undamaged DNA from the nucleus appears as a round shape (the head), and the fragments of damaged DNA extend out from the head (the tail). The length of the tail corresponds to the amount of the damage in the DNA (see Figure 1).  A picture containing text, diagram, line, font  Description automatically generated  (a) To explain the movement of DNA fragments in the comet assay, **identify** one property of DNA and **provide** **reasoning** to support how the property contributes to the movement during the comet assay technique.  (b) In a different experiment, cells are treated with a chemical mutagen that causes only nucleotide substitutions in DNA. **Predict** the likely results of a comet assay from this treatment. |

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| 2016 #4 |
| The figure represents the process of expression of gene X in a eukaryotic cell.  A diagram of a dna sequence  Description automatically generated with low confidence  (a) The primary transcript in the figure is 15 kilobases (kb) long, but the mature mRNA is 7kb in length. **Describe** the modification that most likely resulted in the 8 kb difference in length of the mature mRNA molecule. **Identify** in your response the location in the cell where the change occurs.  (b) **Predict** the length of the mature gene X mRNA if the full-length gene is introduced and expressed in prokaryotic cells. **Justify** your prediction. |

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| 2016 #6 |
| Living and dead organisms continuously shed DNA fragments, known as eDNA, into the environment. To detect eDNA fragments in the environment, the polymerase chain reaction (PCR) can be used to amplify specific eDNA fragments. eDNA fragments of different lengths persist in the environment for varying amounts of time before becoming undetectable (Figure 1).  A picture containing text, diagram, screenshot, map  Description automatically generated  To investigate whether silver carp, an invasive fish, have moved from a nearby river system into Lake Michigan, researchers tested water samples for the presence of eDNA specific to silver carp (Figure 2).  (a) **Justify** the use of eDNA sampling as an appropriate technique for detecting the presence of silver carp in an environment whether many different species of fish are found. **Propose** ONE advantage of identifying long eDNA fragments as opposed to short fragments for detecting silver carp.  (b) The researchers tested a large number of water samples from Lake Michigan and found eDNA specific to silver carp in a single sample in the lake, as indicated in Figure 2. The researchers concluded that the simple positive sample was a false positive and that no silver carp had entered Lake Michigan. **Provide reasoning** other than human error to support the researcher’s claim. |

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| 2015 #7 |
| Smell perception in mammals involves the interactions of airborne odorant molecules from the environment with receptor proteins on the olfactory neurons in the nasal cavity. The binding of odorant molecules to the receptor proteins triggers action potentials in the olfactory neurons and results in transmission of information to the brain. Mammalian genomes typically have approximately 1,000 functional odorant-receptor genes, each encoding a unique odorant receptor.  (a) **Describe** how the signal is transmitted across the synapse from an activated olfactory sensory neuron to the interneuron that transmits the information to the brain.  (b) **Explain** how the expression of a limited number of odorant receptor genes can lead to the perception of thousands of odors. Use the evidence about the number of odorant receptor genes to **support** your answer. |

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| 2013 #5 |
| The table below shows the amino acid sequence of the carboxyl-terminal segment of a conserved polypeptide from four different, but related, species. Each amino acid is represented by a three-letter abbreviation, and the amino acid residues in the polypeptide chains are numbered from the amino end to the carboxyl end. Empty cells indicate no amino acid is present.   |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | Relative Amino Acid Position | | | | | | | | | | | Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | I | Val | His | Leu | Val | Glu | Glu | His | Val | Glu | His | | II | Val | His | Leu | Lys | Glu | Glu | His | Val | Glu | His | | III | Val | His | Leu | Val | Glu | Glu | His | Val |  |  | | IV | Val | His | Leu | Val | Arg | Trp | Ala | Cys | Met | Asp |   (a) Assuming that species I is the ancestral species of the group, **explain** the most likely genetic change that produced the polypeptide in species II and the most likely genetic change that produced the polypeptide in species III.  (b) **Predict** the effects of the mutation on the structure and function of the resulting protein in species IV. **Justify** your prediction. |

Free Response Scoring Guidelines

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| 2022 #6 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A picture containing text, screenshot, font, document  Description automatically generated | 6.3 |
| (b) | A picture containing text, screenshot, font, document  Description automatically generated | 6.4 |
| (c) | A picture containing text, screenshot, font, document  Description automatically generated | 6.4 |
| (d) | A picture containing text, screenshot, font, information  Description automatically generated | 6.6 |

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| 2021 #2 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
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| 2021 #6 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) |  | 6.3 |
| (b) | Text  Description automatically generated | 6.3 |
| (c) | Graphical user interface, text  Description automatically generated | 6.6 |
| (d) | Text  Description automatically generated | 6.6 |

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| 2019 #6 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A black text on a white background  Description automatically generated with low confidence | 5.2 |
| (b) | A picture containing text, font, line, screenshot  Description automatically generated | 6.7 |
| (c) | A black text on a white background  Description automatically generated with low confidence | 5.2 |

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| 2019 #7 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A black text on a white background  Description automatically generated with low confidence | 3.6 |
| (b) | A picture containing text, font, screenshot, line  Description automatically generated | 6.4 |

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| 2018 #4 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
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| (b) | A picture containing text, screenshot, font, line  Description automatically generated | 6.7 |

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| 2017 #3 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
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| (b) | A black text on a white background  Description automatically generated with low confidence | 6.7 |
| (c) | A black text on a white background  Description automatically generated with medium confidence | 6.4 |

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| 2017 #6 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) |  | 6.8 |
| (b) | A black text on a white background  Description automatically generated with medium confidence | 6.8 |

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| 2016 #4 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A black text on a white background  Description automatically generated with low confidence | 6.3 |
| (b) | A white background with black text  Description automatically generated with low confidence | 6.3 |

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| 2016 #6 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
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| (b) |  | 6.8 |

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| 2015 #7 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A picture containing text, font, screenshot, line  Description automatically generated | 4.2 |
| (b) | A picture containing text, font, number, line  Description automatically generated  \*Note: The nervous system is no longer in scope\* | 6.3 |

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| 2013 #5 | | |
| **Part** | **Scoring Guidelines** | **Topic** |
| (a) | A picture containing text, font, line, number  Description automatically generated | 6.7 |
| (b) | A picture containing text, screenshot, font, number  Description automatically generated | 6.7 |