

# **Supplementary Material for Multiple Choice Question Generation Utilizing An Ontology**

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**Question**

What contrasts with quantitative trait, includes type tongue curling ability, and includes type brown, black, or red hair? (Mendelian trait)

What is a type of state of matter, has molecules move freely, and is a site of diffusion? (liquid)

What converts CO<sub>2</sub> - sugar, has part leaf, and can be grass? (plant)

What eats mice, eats voles, and contrasts with eagle? (owl)

What is a part of kidney bean plant, is eaten by quails, and is eaten by skunks? (fruit)

What is driven by electrical field, has example aromatic molecules in air, and is defined as from higher concentration? (diffusion)

What eats voles, is a type of prey, and eats Insects? (skunk)

What is a component of ice, has cohesion, and has 0 degrees C.? (water)

What can be coffee, can be sugar water, and is a result of dissolving? (solution)

What occurs at site living cells, is a principle illustrated in egg in vinegar experiment, and is defined as permeable membrane from hi? (osmosis)

What eats quails, eats Insects, and eats spiders? (skunk)

What dissolves in water, can be monosaccharide, and is a type of nutrients in intestine? (sugar)

What has organelle rough ER, has organelle nucleus, and has subcellular structure cytoskeleton? (eukaryotic cell)

What can be lysine, is provided by beans, and can be phenylalanine? (amino acid)

What contrasts with oil, is an input to precipitation, and dissolves solute? (water)

What eats frogs and toads, is eaten by shrews, and eats leaf-feeding birds? (snake)

What is a type of prey, is eaten by raccoons, and eats carrions? (earthworm)

What can be snake, can be woodpecker, and can be lizard? (prey)

What is eaten by raccoons, is a type of prey, and eats fruit? (shrew)

What involves movement of molecules to lower concentration, is defined as movement of molecules, and occurs at site living cells? (diffusion)

Table 1: Questions evaluated in Study 1.

**Two Matching Relationships**

What is eaten by spiders, is eaten by Insects, and is eaten by quails? (centipede) [praying insect, insect, skunk]

What is eaten by woodpeckers, is a type of prey, and eats millipedes? (spider) [vole, owl, squirrel]

What has subcellular structure cytoskeleton, has subcellular structure spindle fibers, and has subcellular structure cilia? (protist cell) [plant cell, fungal cell, animal cell]

What is eaten by owls, is eaten by turtles, and eats fruit? (insect) [shrew, squirrel, rabbit]

What eats shrews, eats skunks, and eats twig-feeding birds? (owl) [bobcat, insect, centipede]

What develops from enlarged ovary wall, is eaten by raccoons, and is eaten by shrews? (fruit) [vole, earthworm, mouse]

What is a type of prey, eats mice, and eats earthworms? (raccoon) [vole, owl, herb]

What is composed of phosphorus atoms, is a class of compounds in living things, and is a type of organic molecule? (nucleic acids) [carbohydrates, proteins, lipids]

What eats bark, eats leaves, and is eaten by turtles? (insect) [porcupine, earthworm, squirrel]

What is a type of prey, has characteristic strong stomach muscles, and eats quails? (hawk) [owl, earthworm, squirrel]

Table 2: Distractors generated via Two Matching Relationship method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **One Matching, One New Relationship**

What is eaten by voles, is eaten by frogs and toads, and is a type of decomposer? (earthworm) [shrew, spider, insect]

What is a type of prey, is eaten by squirrels, and is eaten by hawks? (woodpecker) [shrew, bobcat, fox]

What is eaten by bobcats, eats twig-feeding birds, and has characteristic strong digestive juices? (hawk) [owl, insect, opossum]

What eats voles, eats fruit, and eats earthworms? (raccoon) [turtle, herb, insect]

What eats herbs, eats leaves, and eats bark? (porcupine) [deer, earthworm, rabbit]

What is a type of prey, eats skunks, and is weak digestive juices? (owl) [vole, turtle, fox]

What is eaten by woodpeckers, is eaten by deer, and is eaten by squirrels? (nut) [owl, leaf, herb]

What is eaten by shrews, has dormancy, and is eaten by voles? (seed) [owl, earthworm, herb]

What has subcellular structure spindle fibers, has organelle cell membrane, and is animal- or plant-like? (protist cell) [plant cell, fungal cell, animal cell]

What is eaten by hawks, is eaten by owls, and is a type of predator? (leaf-feeding bird) [vole, squirrel, insect]

Table 3: Distractors generated via One Matching, One Different Relationship Method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **Two Different Relationships**

What is eaten by woodpeckers, has part embryo, and has part cotyledons? (seed) [owl, squirrel, nut]

What has part leaf, produces cellulose, and has part style? (plant) [carpel, flower, tree]

What eats buds and twigs, is eaten by bobcats, and eats bark? (porcupine) [shrew, owl, skunk]

What has diffusion, has molecules move freely, and is a type of state of matter? (liquid) [solute, solid, movement of molecules]

What contains sugars, has function attracts animals, and is eaten by raccoons? (fruit) [vole, turtle, earthworm]

What is an output of freezing, is a type of solid, and has component water? (ice) [state of matter, hydrogen, oxygen]

What changes state via condensation, is polar, and is an input to evaporation? (water) [salt, table sugar, sugar]

What has stage anaphase I, has stage interphase I, and process in eukaryotic cell? (meiosis) [S stage, cell growth and development, G stage]

What is required in dissolving, can be table sugar, and dissolves in water? (solute) [polar substance, polar molecule, polar dye]

What produces pollen, has part nut, and produces cellulose? (plant) [tree, shrub, anther]

Table 4: Distractors generated via Two Different Relationship method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **One Matching Relationship**

What is an input to freezing, changes state via melting, and has adhesion? (water) [solid, 0 degrees C, state change process]

What has part stigma, has part ovary, and is located in inner ring of flower structure? (pistil) [style, female part, carpel]

What has example salt, dissolves in water, and is required in dissolving? (solute) [polar substance, solvent, polar molecule]

What can be rabbit, can be porcupine, and can be squirrel? (prey) [owl, nut, leaf]

What can be lizard, can be centipede, and can be raccoon? (predator) [vole, shrew, mountain lion]

What is defined as found in living things, can be protein, and has part CHNOPS? (organic molecule) [carbon, hydrogen, oxygen]

What can be protist cell, is a part of eukaryote, and can be animal cell? (eukaryotic cell) [Golgi body, chloroplast, smooth ER]

What can be fox, can be mouse, and can be owl? (prey) [squirrel, fruit, snake]

What is an organelle of eukaryotic cell, is an organelle of animal cell, and is an organelle of fungal cell? (Golgi body) [cell wall, chloroplast, central vacuole]

What is defined as cell division, is followed by prophase, and has stage S stage? (interphase) [G2 stage, replicated chromosome, G stage]

Table 5: Distractors generated via One Matching Relationship method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **Node Structure**

What eats mice, eats skunks, and eats shrews? (bobcat) [woodpecker, twig-feeding bird, squirrel]

What eats seeds, eats Insects, and eats earthworms? (quail) [owl, hawk, millipede]

What eats mice, eats deer, and is a type of predator? (mountain lion) [vole, raccoon, rabbit]

What is eaten by foxes, is eaten by leaf-feeding birds, and is eaten by shrews? (Insect) [lizard, twig-feeding bird, millipede]

What eats centipedes, eats earthworms, and eats herbs? (shrew) [vole, owl, hawk]

What eats opossums, eats raccoons, and is a type of predator? (bobcat) [woodpecker, twig-feeding bird, squirrel]

What eats Insects, is a type of predator, and is eaten by bobcats? (quail) [owl, hawk, millipede]

What is eaten by hawks, is eaten by mice, and is eaten by frogs and toads? (Insect) [lizard, twig-feeding bird, millipede]

What is a type of predator, eats bark, and eats seeds? (squirrel) [owl, fox, leaf-feeding bird]

What is eaten by raccoons, eats nuts, and is eaten by bobcats? (shrew) [vole, owl, hawk]

Table 6: Distractors generated via Node Structure method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **Correct Answer Embeddings**

What contains chromosome, is an organelle of eukaryotic cell, and is a type of organelle? (nucleus)  
[new genetic recombinations, protein synthesis, cell membrane]

What is autotrophic, converts CO<sub>2</sub> - sugar, and produces cellulose? (plant) [coevolution, carbohydrates, carbohydrate synthesis]

What has component oxygen, changes state via melting, and is a part of living things? (water)  
[glycolysis, saturated, food coloring]

What has organelle cell membrane, has subcellular structure cytoskeleton, and has subcellular structure chromosome? (eukaryotic cell) [important in membranes, RNA nucleotide, new genetic recombinations]

What has subcellular structure centriole, has subcellular structure cytoskeleton, and has organelle lysosome? (animal cell) [eagle pellet, RNA nucleotide, inorganic molecule]

What has chloroplast, has organelle central vacuole, and has organelle smooth ER? (plant cell)  
[lipid synthesis, adenine, mitotic spindle disassembles]

What occurs at site cytoplasm, is defined as of that molecule, and is driven by electrical field?  
(diffusion) [Golgi apparatus, atoms, holds electron weakly]

What is a component of ice, is a type of solvent, and dissolves solute? (water) [hydrogen atom, dissolving, nucleic acid]

What has consequence H<sub>2</sub>O moves out of celery, causes permeable membrane, and causes H<sub>2</sub>O to move across semi-? (food in saturated salt HO) [disaccharide, organic molecule, water vapor]

What eats seed, eats leaf, and eats fruit? (squirrel) [fertilization, takes on shape of container, insects]

Table 7: Distractors generated via the Correct Answer Embedding method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

### **Question Embeddings**

What is a type of state change process, has opposite condensation, and has output gas? (evaporation) [oxygen 17, oxygen 15, oxygen 18]

What is an important part of living things, is capillary action, and has solvent? (water) [conc. to low conc. of H<sub>2</sub>O, nitrogen, phosphorus]

What can be ice, is defined as molecules vibrate in place, and has function solute? (solid) [long arm, typically liquid, nitrogenous base]

What is eaten by earthworm, contains chlorophyll, and is a part of plant? (leaf) [takes on shape of container, angiosperm, germination]

What can be freezing, is a characteristic of matter, and produces change of state? (state change process) [usually involves H<sub>2</sub>O moving, molecules retain positions, human population of world]

What has part -N-C-C- backbone, can be tyrosine, and is a subunit of protein? (amino acid) [valine, NaCl, ribose]

What is eaten by shrew, is eaten by woodpecker, and is eaten by skunk? (spider) [fungi, owl population, rabbit population]

What produces water climbing paper, is a characteristic of water wood, and is produced by hydrogen bonding? (adhesion) [nonpolar substance, thymidine triphosphate, protein synthesis]

What takes shape of container, contrasts with solid, and can be solution? (liquid) [aspartic acid, glutamic acid, hydrophilic molecules]

What has organelle Golgi body, has subcellular structure chromosome, and has organelle cytoplasm? (protist cell) [two rounds of cell division, usually many per cell, regulate flow into/out of cell]

Table 8: Distractors generated via the Question Component Embedding method, with accompanying questions evaluated in Study 1. Correct answers are in parentheses while distractors are in square brackets.

What is a stage of S stage, has a process including DNA synthesis, and is a stage of meiosis? (interphase I)

What includes glucose, includes deoxyribose, and is a type of sugar? (monosaccharide)

What is a type of solute, is polar, and is a type of polar substance? (salt)

What can be RNA, has carbon, and has oxygen? (nucleic acid)

What is composed of bonds, has state change process, and can be a polar substance? (matter)

What has leaves, has a trunk, and has roots? (tree)

What is polar, has an oxygen atom, and has a hydrogen atom? (water molecule)

What includes salt water, includes sugar water, and is the site of evaporation? (evaporating solution)

What is a stage in which one would find unreplicated chromosome, follows metaphase II, and is a stage of meiosis? (anaphase II)

What is eaten by foxes, is eaten by mountain lions, and is eaten by hawks? (rabbit)

What is eaten by spiders, is eaten by voles, and is eaten by mice? (millipede)

What is supported by the style, is a part of flower, and collects pollen? (stigma)

What is eaten by earthworms, is eaten by millipedes, and is eaten by rabbits? (grass)

What is eaten by voles, is eaten by woodpeckers, and is eaten by mice? (praying insect)

What is connected to leaves, is a part of smaller flowering plant, and is a part of kidney bean plant? (stem)

What has solid, contains solute, and is a function of oil? (solvent)

What is supported by the filament, is a part of flower, and yields pollen? (anther)

What is produced by cohesion, is produced by hydrogen bonding, and is a characteristic of adhesion? (capillary action)

What is followed by telophase, is a stage in which one would find unreplicated chromosomes, and follows metaphase? (anaphase)

What is composed of hydrogen atoms, is composed of nitrogen atoms, and is composed of carbon atoms? (nucleic acids)

What is an organelle of the plant cell, is an organelle of the fungal cell, and is a type of organelle? (Golgi body)

What acts on ice, is a type of state change process, and is the opposite of freezing? (melting)

What is eaten by bobcats, is eaten by owls, and is a raptor? (hawk)

What is a part of tree, is a part of smaller flowering plant, and releases water vapor? (leaves)

What includes food in pure water, occurs at the cell membrane, and is driven by the concentration gradient? (osmosis)

What is a characteristic of mammals, occurs at the cytoplasm, and interacts with systemic respiration? (cellular respiration)

What is eaten by bobcats, is eaten by foxes, and is eaten by owls? (squirrel)

What is composed of atoms, is described by the periodic table, and includes oxygen? (element)

What is a stage in which one would find unreplicated chromosomes, can be pollen, and can be an egg? (gamete)

What is a type of primary consumer, is eaten by snakes, and is eaten by opossums? (leaf-feeding bird)

What is followed by interphase, follows telophase, and follows mitosis? (cytokinesis)

What is a stage in which one would find replicated chromosome, follows interphase, and is followed by prometaphase? (prophase)

What is interrupted by amphipathic molecule, is produced by hydrogen bonding, and is produced by cohesion? (surface tension)

What is a component in living things, is composed of atoms, and can be a polar substance? (matter)

What is eaten by shrews, is eaten by skunks, and is eaten by raccoons? (mouse)

What is a part of kidney bean, yields seedling, and is created from fertilization of egg? (embryo)

What can be a deer, can be a centipede, and can be a hawk? (prey)

What has variant allele, is a part of chromosomes, and is composed of DNA? (gene)  
 What includes carbon, is a part of organic molecule, and includes oxygen? (CHNOPS)  
 What is composed of atoms, includes carbon, and includes oxygen? (element)  
 What can be sublimation, can be freezing, and can be condensation? (state change process)  
 What includes organisms in role primary consumer, includes organisms in role producer, and includes organisms in role decomposer? (chaparral community)  
 What is followed by fertilization, is aided by pollinators, and is produced by pollinators? (pollination)  
 What has metabolism, has cellular respiration, and has digestion? (mammals)  
 What is eaten by voles, is eaten by woodpeckers, and is eaten by mice? (spider)

Table 9: Three-relationship questions generated for Study 2.

What has the subcellular structure cell wall and lacks chloroplast? (fungal cell)  
 What is eaten by squirrels and is eaten by lizards? (herb)  
 What is less dense than ice and is yielded by sublimation? (water vapor)  
 What is a subcellular structure of fungal cells and occurs at the cytoplasm? (ribosome)  
 What eats frogs and toads and eats coyotes? (mountain lion)  
 What has a process called fertilization and has a process called germination? (flowering plant)  
 What has the stage interphase II and has the stage metaphase I? (meiosis)  
 What has a nucleus and contrasts with fungal cell? (animal cell)  
 What can be a millipede and can be a snake? (prey)  
 What has an ovary and has diploid? (flower)  
 What has a filament and is a part of tree? (flower)  
 What is eaten by praying insects and is a type of predator? (centipede)  
 What can be a porcupine and can be a mouse? (prey)  
 What has the stage early prophase I and is the process of division of some cell? (meiosis)  
 What has a deoxyribose and occurs at the mitochondria? (DNA)  
 What influences saturation point and includes solids? (solute)  
 What has a flower and has a nut? (tree)  
 What contrasts with plant cell and has an organelle called rough ER? (animal cell)  
 What can be a nucleus and can be a mitochondria? (organelle)  
 What freezes to form ice and is formed by condensation of water vapor? (liquid water)  
 What can be a coyote and can be a millipede? (decomposer)  
 What is a subcellular structure of protist cells and occurs at the cytoplasm? (ribosome)  
 What has a mitochondria and lacks central vacuole? (animal cell)  
 What has life stage diploid and has a process called germination? (flowering plant)  
 What combines with deoxyribose and can be a cytosine? (nitrogenous base)  
 What follows prophase and is a stage in which one would find replicated chromosome? (prometaphase)  
 What has the stage telophase and has the stage metaphase? (mitosis)  
 What has sublimation and is included in solute? (solid)  
 What is eaten by coyotes and eats buds and twigs? (rabbit)  
 What is an example of catabolism and interacts with systemic respiration? (cellular respiration)  
 "What is a characteristic of solvents and can be ice? (solid) "  
 What yields water vapor and is the opposite of condensation? (evaporation)  
 What is formed by evaporation of liquid water and is formed by evaporation of sugar water? (water vapor)  
 What has chloroplast and has an organelle called central vacuole? (plant cell)  
 What is produced by an ovary and via fertilization creates an embryo? (egg)

What is a subcellular structure of plant cells and is a characteristic of fungal cells? (cell wall)  
What yields RNA and is contained in chromosome? (gene)  
What is formed by evaporation of sugar water and is formed by evaporation of liquid water? (water vapor)  
What is a type of prey and eats porcupines? (fox)  
What describes elements and provides information such as atomic weight? (periodic table)  
What eats leaves and is a type of decomposer? (earthworm)  
What is produced by DNA synthesis and occurs in the stage interphase II? (replicated chromosome)  
What yields an egg and has the stage late prophase I? (meiosis)  
What contrasts with tree and has leaves? (smaller flowering plant)  
What is a function of oil and has solid? (solvent)

Table 10: Two-relationship questions generated for Study 2.