**SUPPLEMENTAL MATERIALS**

**Supplemental Materials 1.** Conceptual model instructions and scoring rubric.

**DIAGRAM INSTRUCTIONS**

**Purpose**

These diagrams are a reflection of what you know about how components are related within a biological system. These diagrams can be useful for you and the instructor to identify what you know and what may need additional study. There can be multiple possible and correct diagrams.



**How to create a diagram**

These diagrams will have **components** connected by **labeled arrows**.

Your diagram needs to follow these rules (see examples below):

1. Connect individual components that are related to other components with an arrow.
2. **Label every arrow** with a word or phrase that describes the direct relationship between each two components.
3. Include arrow heads to give direction to the description.
4. Each should make sense alone and not depend on outside parts to make sense.

**Example diagram on surfing**



**Recitation #6:**

Gene Regulation Diagram

**Activity**

* Build a diagram to show how the components interact to affect transcription
* Use the component bank listed below to construct a diagram
* Use as many components as you can to show how transcription is regulated
* All provided components are relevant to gene regulation
* You may add your own components that are not already in the bank
* Connect two components that directly interact with an arrow AND label the arrow with a description of the relationship between each two components.
* **No textbooks, no internet, no neighbors, no lab packets.**
* When finished with the diagram, hand it into the TA

**Component Bank**

Use as many as you can and add your own components where you see appropriate

* Activator
* Co-activator
* Co-repressor
* DNA
* Inducer
* Operator
* Promoter
* Repressor
* RNA polymerase

**Correctness Rubric**

From Structure

To Structure

Relationship

Proposition:

* Structures are categorized into general structures and structures specific to the lac and trp operon systems.
* All relationships were generated by students.
* Relationships were categorized by coders using their expert knowledge, textbooks, and received feedback from a researcher external to the group that is familiar student thinking about the regulation of gene expression.
* Only propositions that included relationships in categories 2 (Plausible but lacking technical clarity) or 3 (Scientifically accurate) are presented here.
* Empty cells indicate that no student described a relationship that fit that category.
* Individual relationships are separated with commas.

|  |  |
| --- | --- |
| **COMPONENTS** | **RELATIONSHIPS** |
| **From component** | **To component** | **1. Inaccurate** | **2. Plausible but lacking technical clarity** | **3. Scientifically accurate** |
| *General Structures* |
| Activator | Co-activator | and, can make a, activates, assists, is, made up of | activates with, works with, are aided by, helped by, use, pairs with | regulated by, activated by, binds |
| Activator | DNA |  |  | binds |
| Activator | Operator | needs, starts, begins, comes before, part of, co-activator, uses  | turns on, activates, found on | attaches, binds  |
| Activator | Operon |  |  | turns on, activates, binds |
| Activator | Promoter | needs, starts, begins, initiates, comes before, part of, co-activator | activates, regulates, located on, found on | attaches, binds, turns on |
| Activator | RNA polymerase | produce, ex, begin synthesis of, starts, induces, binds to | activates, allows to bind, controls | recruits |
| Co-activator | Activator | is another form, part of, requires, similar to, starts | helps, assists, works with, aids, cooperates with, goes with | activates, binds to, joins with, attaches to |
| Co-activator | mRNA |  | begin transcription of |  |
| Co-activator | operator | leading to, bind to | activates, turns on, |  |
| Co-activator | operon |  | turns on |  |
| Co-activator | promoter | leading to, bind to | activates |  |
| Co-activator | RNA polymerase | begins synthesis of, binds, induces | helps activate |  |
| Co-repressor | Operator | are types of, binds, activate | turns off, stops |  |
| Co-repressor | Operon | binds to, example, helps with transcription | turns off |  |
| Co-repressor | Repressor | is another form, part of, requires, produces, needed for, inactivates, type, similar to, starts | helps, assists, works with, aids, cooperates with, goes with, pairs with | activates, binds to, joins with, attaches to |
| Co-repressor | RNA polymerase | example, stops synthesis of, helps translation of, | helps inhibit |  |
| DNA | Activator | has, contains, needs, requires, regulates, replication is started by an, signals | uses, transcription happens by | binds, produces |
| DNA | gene |  |  | is made of, contains |
| DNA | mRNA | translates | transcription, transcribes for | transcribes to |
| DNA | Operator | makes, uses, expressed by, expresses, becomes, codes for, goes after promoter, made up of, stretch of DNA, binds with, bound to, starts with, needs, synthesized by, exposes, located at the | composed of, has subsections | contains, part of, has |
| DNA | Operon | uses, segment of, collection of | has, included in |  |
| DNA | Promoter | makes, uses, expressed by, expresses, becomes, codes for, goes after promoter, made up of, stretch of DNA, binds with, bound to, starts with, needs, synthesized by, exposes, located at the | composed of, has subsections | contains, part of, has |
| DNA | Repressor | has, contains, encompasses, is, turns off, | is influenced by | produces |
| DNA | RNA polymerase | replicated by, broken down by, type of, copied by, converted to, by, consists of, translates to, involved for, initiates, activate, is made from, initiator, initiation, makes up, replicating by, and | transcribed, forms, uses, transcribed by, copied by, provides, info for | binds, is read by, is transcribed by, produces, split by |
| Gene | Activator | either, can be | activated by |  |
| Gene | DNA |  |  | consist of, make up |
| Gene | mRNA |  |  | transcribed into |
| Gene | Operator | are expressed as | begins with, starts with |  |
| Gene | Operon |  | are expressed through |  |
| Gene | Promoter |  | begins with, starts with |  |
| Gene | Repressor | can be | stopped by |  |
| Gene | RNA polymerase |  |  | transcribed by |
| Inducer | DNA | goes into the, starts | activates, turns on, |  |
| Inducer | Operator | binds, fuels, starts, kick starts, triggers, leads to | turns on, influences |  |
| Inducer | Operon | turns on, influence, for transcription in the | turns on |  |
| Inducer | Promoter | binds, fuels, starts, part of, leads to | turns on |  |
| Inducer | Repressor | turned off by, reuses, are controlled by, opposite of, starts |  | binds, inactivates, deactivates, inhibits, turns off, stops, |
| mRNA | DNA | copies |  | is made from |
| Operator | Activator | turns on/off, activates, can be a, contains |  | controlled by, activated by |
| Operator | DNA | binds to, attaches to, begins, transcribes, make | located on, influence the, turns on/off, on, is in, goes with | contains, part of, segment of, composed of |
| Operator | Operon | made of, consists of, active | located on, turns on/off | made up of, part of, is in the |
| Operator | Promoter | contains, needs, uses, triggers, opens, is a, inclusive, expresses genes using | located by the, makes up, made of, comes after, turn on, works with, run by | part of, segment of, is in |
| Operator | Repressor | turns on/off, follows after, have a, consists of, build up | on, uses, contains | controlled by, inhibited by, binds, attaches |
| Operator | RNA polymerase | produces proteins from, made up of, produces, starts, performs, is an | starting point for, binds to, uses, turns on, aids, signals, connects | allows or stops |
| Operon | DNA | works to transcribe, attached to, connected to, switch segment of | located on, is within the | consists of, is made of, include, segment of  |
| Operon | Gene | activator, is based on | express | consist of, contain |
| Operon | mRNA | broken down, develops | transcribed, transcribes, makes |  |
| Operon | Operator | part of, is a  |  | contains, includes, has an, comprised of, consists of |
| Operon | Promoter | part of, parts, all within, initiates | composed, uses | contains, includes, has an, comprised of, consists of |
| Operon | Repressor | influences | consists of, contains | turned off by |
| Operon | RNA polymerase | helps produce, part of | uses |  |
| Promoter | Activator | is an, contain, consists, activate, kick starts, promotes, induces, signals | activate transcription, contain sites for | binds, attaches, turned on by |
| Promoter | Co-repressor | contains, starts, unblocked by the | binds, connect |  |
| Promoter | DNA | binds to, attaches to, connected to, begins, transcribes, make, creates, starts, | located on, found on, influence the, turns on/off, on, is in, goes with | contains, part of, segment of, composes of, is |
| Promoter | Operator | binds, attaches, starts, stops, activates, are types of, runs | next to, work together, part of, precedes | contains, made up of, |
| Promoter | Operon | induces, promotes protein production | located on | part of, determines the on/off state of the |
| Promoter | Repressor | activates, and, using |  | bind, blocked by, turned off by |
| Promoter | RNA polymerase | made of, allows, utilize, starts, activate, are in, promotes, | contains, recruits | binds |
| Repressor | Co-repressor | and, can make a, activates, assists, is, made up of | activates with, works with, are aided by, helped by, use, needs, has a, pairs with | regulated by, binds with, turned on by |
| Repressor | DNA | inhibits, stops, contain, turns off |  | stop transcription of |
| Repressor | Inducer | inhibits, inactivates, turn off, block, consists of, signals |  | is inactivated by, binds to |
| Repressor | Operator | are types of, activates, consists of, acts as, induces | stops, deactivates, turns off, shuts off/down, inhibits, represses, uses | binds to, connects, found on, attaches, |
| Repressor | Operon |  | influence, counter acts | turns off, inhibits, stops, shuts off, represses |
| Repressor | Promoter | are types of, activates, consists of, acts as, induces | stops, deactivates, turns off, inhibits, represses, uses, shuts off/down | binds to, connects, found on, attaches, |
| Repressor | RNA polymerase | results in, makes, transcription, restarts, stops synthesis of | stops, inhibits, turns off | blocks |
| Repressor | Transcription |  |  | stops |
| RNA polymerase | Activator | makes up, uses, contains, accelerated by | requires, aided by, activated by |  |
| RNA polymerase | Co-repressor | contains | is stopped by |  |
| RNA polymerase | DNA | breaks down, transforms into, translates, creates, produces, results in, synthesizes, makes, facilitates, found in | copies, activates, performs with, comes from | binds, attaches, combines, transcribes, splits, unzips, reads |
| RNA polymerase | Gene | codes |  | transcribes |
| RNA polymerase | mRNA | made of |  | aids in synthesis of, creates, synthesizes |
| RNA polymerase | Operator | binds, attaches to, behind, type of, is an, part of, contains, makes, activates, turns on, requires | works with, runs along, goes along |  |
| RNA polymerase | Operon |  | starts | attaches, binds, joins, transcribes |
| RNA polymerase | Promoter | part of, creates, contains, begins the, activates | begins at, uses | binds, attaches, starts at, requires |
| RNA polymerase | Repressor | type of, contains, starts with, slowed down by | inactivated by, stopped by | blocked |
| *System-specific structures* |
| Allolactose | (lac) repressor | activates, induces  | negative | binds, turns off, inhibits, represses, inactivates, deactivates, releases |
| Allolactose | Inducer |  |  | is an |
| cAMP | CAP | makes, represses, produces, turns into | positive, co-activates | activates, binds to, induces |
| cAMP | Co-activator |  |  | which is a, example of |
| cAMP | Glucose |  | inhibited by | produced when no |
| cAMP | Lactose |  | promotes |  |
| CAP | Activator | binds to |  | which is an, example of, also called, |
| CAP | cAMP | promotes |  | activated by |
| CAP | (lac) operon | activated by | positive | activates, turns on, binds to, induces |
| CAP | Operator | turns off | activates | binds to |
| CAP | Promoter |  | activates | binds to |
| CAP | RNA polymerase | binds to | assists |  |
| CAP | Transcription |  | activates |  |
| Glucose | Allolactose |  | inhibits |  |
| Glucose | cAMP | forms, converted to, binds to, activates, induces | represses, negatively regulates, inhibits, signals low levels | lack of makes |
| Glucose | (lac) operon |  |  | inhibits |
| Lactose | Allolactose  | triggered by excess, inhibits | positive,activates, makes, converts, creates, induces | makes, promotes presence of,converts to, forms, turns into, becomes |
| Enzymes | Lactose |  |  | breakdown |
| lac operon | Activator | classified as, has an | requires an | activated by |
| lac operon | CAP | involves, uses | activator | activated by |
| lac operon | DNA | codes for |  | composed of |
| lac operon | Enzymes |  | produces,leads to, creates | codes for |
| lac operon | mRNA | transcribes, binds, positive, uses, activates | goes to, creates |  |
| lac operon | Repressor | always repressing |  | inhibited by,controlled by, inactivated by |
| lac operon | Promoter | controls |  | includes |
| lac operon | Lactose | monitors levels of, integrates between | needs | codes for enzymes to break down |

**Supplemental Materials 2.** Local Environment Post-Conceptual Model Comparison.

Summary of significant differences in the local environment (presence, average number of relationships, and average correctness) of each structure in students’ post conceptual models between treatments, build (B) and investigate (I). Structures shown in bold were provided in the instructions on both the pre and post conceptual model assessments.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Structure | Treatment | Presence | Relationships | Correctness |
| **Activator** | B | 80.0% | 2.06 | 1.94 |
| I | 82.4% | 2.12 | 1.85 |
| Allolactose | B | 25.2% | 2.07 | 2.08 |
| I | 19.8% | 1.91 | 2.29 |
| cAMP | B | 31.3% | 1.97 | 2.11 |
| I | 21.2% | 1.85 | 2.10 |
| CAP | B | 33.9% | 1.95 | 2.20 |
| I | 21.6% | 2.1 | 1.95 |
| **Coactivator** | B | 55.7% | 1.31 | 2.09 |
| I | 55.0% | 1.26 | 1.98 |
| **Corepressor** | B | 54.8% | 1.3 | 2.06 |
| I | 57.7% | 1.25 | 1.93 |
| **DNA** | B | 78.3% | 1.91 | 2.11 |
| I | 79.7% | 1.77 | 2.05 |
| Gene | B | 6.1% | 2.57 | 1.82 |
| I | 8.1% | 2.56 | 2.06 |
| Glucose | B | 19.1% | 1.45 | 2.31 |
| I | 18.9% | 1.40 | 1.68 |
| Inducer | B | 55.7% | 1.55 | 1.70 |
| I | 55.9% | 1.47 | 1.70 |
| *Lac* Operon | B | 22.6% | 3.00 | 2.00 |
| I | 19.4% | 2.98 | 2.05 |
| Lactose | B | 26.1% | 1.57 | 1.60 |
| I | 23.0% | 1.45 | 1.96 |
| mRNA | B | 17.4% | 1.90 | 1.70\* |
| I | 7.7% | 1.94 | 1.97\* |
| **Operator** | B | 69.6% | 2.33 | 1.89 |
| I | 74.8% | 2.40 | 1.87 |
| **Operon** | B | 19.1% | 3.50 | 2.08 |
| I | 25.7% | 2.91 | 2.13 |
| **Promoter** | B | 57.4% | 1.89 | 2.02 |
| I | 66.7% | 2.05 | 1.90 |
| **Repressor** | B | 74.8% | 2.15 | 2.05 |
| I | 78.8% | 2.23 | 2.05 |
| **RNA polymerase** | B | 81.7% | 2.04 | 2.05 |
| I | 87.8% | 1.87 | 1.87 |
| + p < 0.1; \* p < 0.05; \*\* p < 0.001 |