

# Supplemental Material

*CBE—Life Sciences Education*

Flowers *et al.*

## **SUPPLEMENTAL MATERIAL**

### *Provided Definitions*

**Gene Regulation:** The genome of a cell contains in its DNA sequence the information to make many thousands of different protein and RNA molecules. All of the steps involved in expressing a gene can in principle be regulated, and a cell typically expresses only a fraction of its genes at any one time. For example, cells can change the pattern of genes they express in response to changes in their environment, such as signals from other cells.

**Cell-Cell Communication:** Communication between cells is mediated mainly by extracellular signal molecules that are emitted and received. Reception of the signals results in the altering of one or more intracellular signaling pathways, which ultimately affects an intracellular target. The properties of these targets are altered in response to changes in the signaling pathway to implement the appropriate change of cell behavior.

**Relationship between Genotype and Phenotype:** The phenotype is the observable properties of a cell or an organism (including both physical characteristics and behavior) resulting from both the genotype (i.e. genetic code) and environmental factors, which can vary.

*Table S1. Student answers to how gene regulation occurs*

Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
Describes concepts or processes related to the regulation of gene expression	4	3	2	0
Factors external to the cell can affect gene regulation	3	2	1	0
Gene regulation is making sure genes are kept healthy/ good	2	1	0	1
Gene regulation governs cell division	2	2	0	1
Other statements	3	3	0	0
No answer	1	N/A	N/A	N/A

For the code “Describes concepts or processes related to the regulation of gene expression,” one student gave a *what* and a *how* response. For the code “Gene regulation governs cell division,” one student gave a *what* and *why* response.

*Table S2. Student answers to how cell-cell communication occurs*

Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
Describes concepts or processes related to cell-cell communication	8	6	5	0
Lists examples of cell-cell communication types, types of signaling molecules, or receptor types	4	4	0	0
Explanation has mechanistic features	2	0	2	0
Connects cell-cell communication to gene regulation	1	0	1	0
Other statements	1	1	0	0

For the code “Describes concepts or processes related to cell-cell communication,” three students gave a *what* and a *how* response.

*Table S3. Student answers to how phenotype is regulated*

Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
Phenotype is regulated/ informed by the genotype/ gene expression	7	7	0	0
Phenotype is regulated based on interactions with the internal or external environment	3	3	1	0
Phenotype is based on gene heredity	3	3	0	0
Phenotype is dependent on cell division mechanics	2	2	0	0
Provides definition or description of phenotype	5	5	0	0
Other statements	2	1	1	0

For the code “Phenotype is regulated based on interactions with the internal or external environment,” one student gave a *what* and a *how* response.

*Table S4. Student answers to why gene regulation occurs*

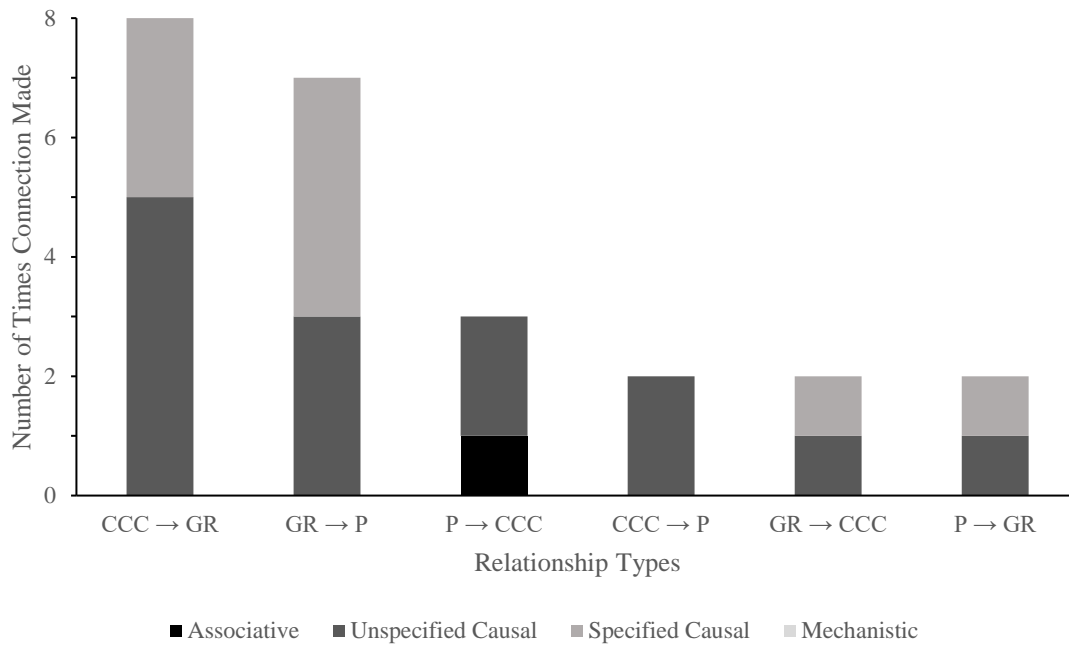
Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
Not all genes are expressed all the time	1	0	0	1
To respond to the environment	2	0	0	2
To efficiently use energy and/ or resources	1	0	0	1
To make sure proper/ correct cell division occurs	3	0	0	3
To make sure the body develops into/ stays a healthy organism	3	0	0	3
Other statements	2	0	0	2

*Table S5. Student answers to why cell-cell communication occurs*

Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
Allows for cells to monitor/ react to the environment	3	1	0	2
General statement about for the whole to function, to “get things done”, or they “need to communicate”	8	0	0	8
For health purposes	5	0	0	5
Other statements	3	3	0	0

*Table S6. Student answers to why it is important that genotype and phenotype are linked*

Content Code	# of Students (n = 9)	Type of Explanation (# of Students)		
		What	How	Why
We understand phenotype through its definitional link to genotype; would not be able to explain/ understand biology otherwise	5	4	0	1
We would not be able to deduce what genes correspond to what phenotypes or vice versa	3	2	0	1
The linkage makes it possible for favorable phenotypes to be selected for (from an evolutionary perspective)	1	0	0	1
No answer	1	N/A	N/A	N/A



**Figure S1. Nature of connection categories for each specific relationship.** This graph shows how many students in the sample ( $n = 9$ ) described a particular relationship type and how each student described the relationship. Key: GR = gene regulation, CCC = cell-cell communication, P = phenotypic expression.