Representational congruence in a genetics game

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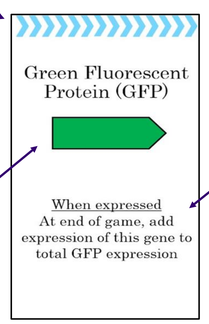
Background

- Biology students often struggle with concepts of **gene regulation,** *the process by which every cell in your body uses the same set of genetic blueprints to adapt diverse morphologies, perform separate functions, and respond to different environmental cues.*
- Without widely accessible ways to interact with the processes of gene regulation, learning is limited to rote memorization rather than functional understanding of how modular aspects of genetics work.
- We seek/sought to overcome this deficit with a game that directly co-opts cell mechanics as game mechanics, thus maintaining **representational congruence**, *where strategy of gameplay directly relies on the material the game is intended to teach*
- By learning to play the game, students will learn the basics of gene regulation

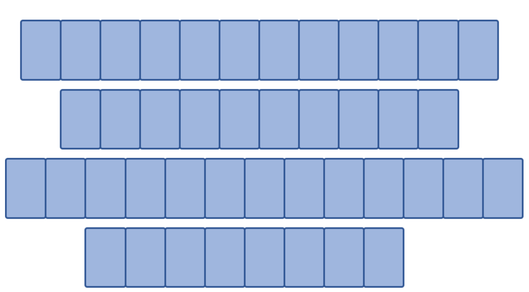
The design language

Chevrons represent the direction a sequence is read in. Cards can be played with chevrons up or down.



Rules are simple, written on each card, and accurate to the real biology.

Genes are shown as arrows. This symbol is used throughout genetics research

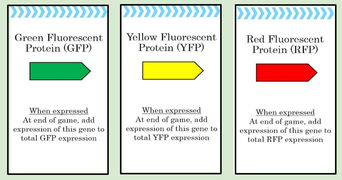


The board is made of rows of plastic rectangles. Each row represents a chromosome. Some cards modify nearby cards on the same chromosome (*cis* elements); others modify cards on any chromosome (*trans* elements). Our board is made of recycled lab supplies!

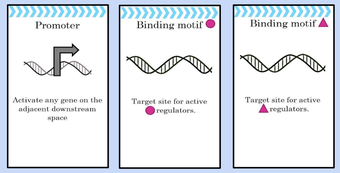
The Game

Card Types

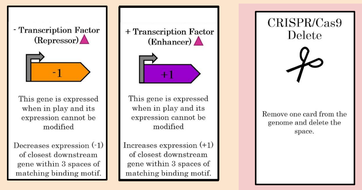
Target genes: Each player has a unique goal to achieve a specific level/amount of expression from one or more of these genes.



Regulatory Sequences directly impact nearby genes. They only act on genes that are on the same strand and in the same direction, indicated by blue chevrons.



Transcription Factors change expression of *Target genes* near matching *Binding motifs* (LO4). These have built-in promoters and are always on.



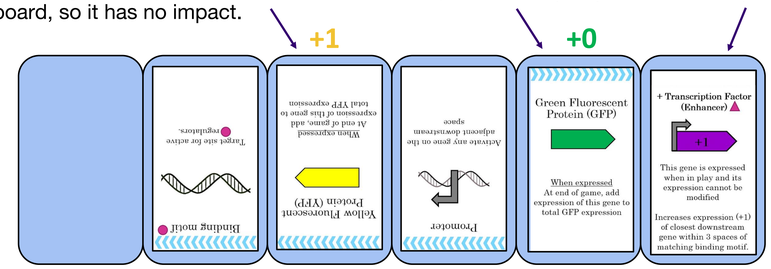
Action cards allow players to modify the playspace. These can have a global impact late in the game (LO8).

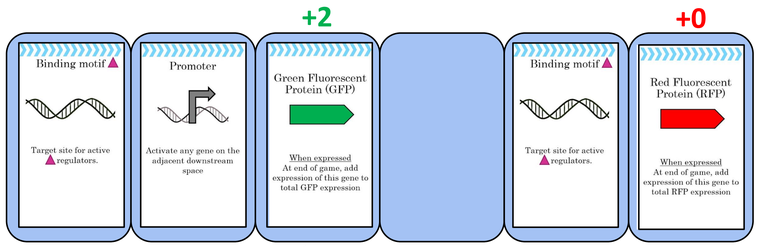
The Board (in action)

This *gene* has an active *promoter*. The nearby *binding motif* is in the proper orientation, but there's no matching transcription factor on the board, so it has no impact.

This *gene* does not have an adjacent *promoter* in the same direction, so it is off. (LO3)

This *transcription factor* matches two *binding motifs* on the board. (LO4,LO5)





The *promoter* turns the *gene* on (+1; LO1), while the nearby *binding motif* allows the the matching *transcription factor* to increase expression (+1; LO6) for a total expression of 2. (LO7)

This *gene* has no adjacent/active *promoter,* so its expression will remain 0, regardless of the other cards around it (LO1,LO2).

Goal

- Players have unique goals of which genes to turn on and how much (e.g. GFP > 2 & YFP < 4).
- They must place elements across the board to achieve their goals without inadvertently helping opponents accomplish theirs.
- True to biology, the elements available to players can interact in complex ways. Winning requires an ability to see the big picture.

Learning Objectives

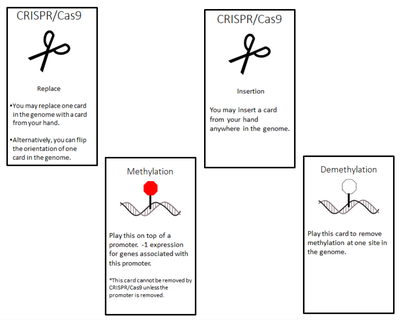
1. A 'gene' by itself is not enough; all genes require promoters in order to be expressed
2. There are other sequence elements outside of genes that contribute to the effect of a gene
3. *Cis* elements: DNA is double stranded; some elements must be nearby on the same strand in order to interact.
4. *Trans* elements: Some elements can impact the expression of genes far away, or on entirely separate pieces of DNA. Genes can impact the expression of other genes
5. Some *trans* elements work in multiple places, others are more specific.
6. Expression is tunable, not binary.
7. Multiple elements can impact a single gene
8. Small changes, particularly to trans factors, can have global impacts on expression.

Key Terms

Gene: a stretch of DNA sequence that serves as a blueprint for a **protein**, a molecular machine that performs a function within a cell.
Promoter: a regulatory sequence that tells gene expression machinery to read a nearby gene and make the protein it specifies.
Expression: When a gene is read to make a protein, we say it is 'expressed' or 'on'.
Directionality: DNA has 2 strands that are read in opposite directions. Both strands can code for genes or regulatory sequences.

Playtest-inspired future directions

- Create decks where genes are specific to certain cell types (e.g. neurons or muscle cells) to give game greater context and more opportunities to be used in classrooms.
- Include action cards that represent environmental changes that change the way genes and regulatory sequences function.
- Add expansion packs that include more gene editing options such as insertion or replacement.
- Add expansion packs that include *epigenetic* cards as an additional way of tuning gene expression.
- Add expansion packs with rules specific to particular domains of life.



Acknowledgements

We thank the playtesters, biologists, and students who have helped us to refine this idea.

We welcome all feedback! Contact us with ideas, critique, or requests for playtests.