

Supplemental Material

CBE—Life Sciences Education

Southard *et al.*

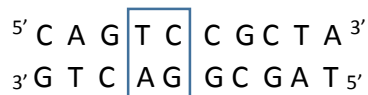
SUPPLEMENTARY MATERIALS

SM1: Concept Assessment: Central Dogma Content Knowledge Survey

Please answer the following questions to the best of your ability in the space provided for the short answer questions or by selecting the BEST answer for the multiple choice questions.

1. What are proteins? (Short Answer)
2. Fill in the blanks:
Translation is a process by which _____ is used as a template to make _____.
Replication is the mechanism by which _____ is copied.
Transcription is a process by which _____ is used as a template to make _____.
3. Select the molecules that are actively used in the process of replication, transcription and translation (there may be multiple answer choices):

Used in the process(es) of...	Replication	Transcription	Translation
Example: DNA	X	X	
Ribosomes			
DNA Polymerase			
Helicase			
tRNA			
RNA Polymerase			



4. The picture above shows a piece of double-stranded DNA. Which of the following statements about the structure of the molecule WITHIN THE BOX is true?
 - a) T is covalently bonded to C and to A.
 - b) T is non-covalently bonded to C and to A.
 - c) T is covalently bonded to C and non-covalently bonded to A.
 - d) T is non-covalently bonded to C and covalently bonded to A.
 - e) T is non-covalently bonded to A; C is non-covalently bonded to G; there is no bond between T and C or A and G.
5. What is a mutation and how does it cause disease? (Short Answer)
6. Proteins are mainly composed of:
 - a) Lipids

- b) Nucleic acids.
- c) Amino acids.
- d) Carbohydrates
- e) Genes

7. What do proteins do? List a couple types of proteins and their function.

Type of protein	General Function
1. <u>Transcription Factors</u>	<u>Help turn on genes</u>
2. _____	_____
3. _____	_____
4. _____	_____
5. _____	_____

SM2: Interview Protocol: Molecular Mechanistic Descriptions of the Processes of DNA Replication, Transcription, and Translation

DNA Replication

Interviewer: "Will you explain to me a little bit about what you know about the mechanism or process of DNA replication? For example what is physically happening, who are the players, and where does it happen."

Interviewer: "Now that we've looked at the specifics of replication, why does a cell undergo replication?"

Transcription

Interviewer: "Will you explain to me a little more about what you know about the mechanism of transcription? Again, what is happening, who are the players and where it happens."

Interviewer: "Again, now that we've talked about the specifics, why does a cell undergo transcription?"

Translation

Interviewer: "Take me through the same explanation process with translation, what do you know about the mechanism?"

Interviewer: "And why does a cell undergo translation?"

SM3: Coding Scheme: Student Descriptions of DNA Replication, Transcription and Translation

Sorting Entities into Appropriate Mental Categories

Coding Scheme	Mechanistic Description Excerpt Example (DNA Replication, Transcription, Translation)
Normative: All molecular entities included in description of the mechanism of DNA replication are scientifically normative*, mechanism-appropriate.	“After transcription, you have this mature mRNA. So, mRNA. And you get this ribosome that comes and binds to it. From this mRNA, it basically reads them, the nucleotides in the mRNA, and you get these tRNAs, which are attached to amino acids. And the tRNAs match up with codons, and they have anticodons that are complementary to the codons in the mRNA. And they come in, and the order they come in determines the order that the amino acids attach, and then you get this amino acid chain--or a polypeptide--that is resulting from this process....” (Excerpt from translation explanation; Sally, upper-division student)
Non-Normative: One or more molecular entities included in description of the mechanism of DNA replication are scientifically non-normative*, mechanism-inappropriate.	“DNA polymerase? [...] I think it happens in the ribosomes, either in the rough ER or just the cytosol. And it replicates the DNA with DNA polymerase, which just uses, makes the whatever it's called...replication forks which makes like the circle thing, and it like spreads apart [...] And, oh the replication bubble. That's what it's called. And it does that until it like splits I guess. There's like different enzymes but I don't remember which ones. I think helicase is the one that finishes it. I don't know.” (Excerpt from DNA replication explanation; Claire, introductory student)

Entities highlighted in grey represent mechanism-appropriate entities. Entities highlighted in black represent mechanism-inappropriate entities.

*Note: Scientifically normative within reasonable parameters for undergraduate understanding.

**Note: Only student responses to the probes asking for students to describe the processes of DNA replication, transcription and translation were coded with this scheme.

***Note: Only entities provided by the student during their verbal explanation were coded as normative or non-normative.

Mechanism Connection to Cellular Function

Coding Scheme	Mechanism Connection to Function Excerpt Example (DNA Replication, Transcription, Translation)
Normative: Description contains scientifically accurate or plausible rationale(s).	“So that it can express the protein that's encoded from the mRNA.” (Excerpt from student’s response to the prompt “why does a cell undergo translation?”; Nikki; upper-division student)
Non-Normative: Description contains one or more scientifically non-normative or implausible rationale(s).	“The cell has to undergo replication in order to make more DNA in order to make more protein, essentially. This is normally due to some sort of environmental signal. I don't know...let's use puberty as an example. You need to synthesize more hormones. You would copy more of the DNA so you can make estrogen, or for other reasons. Yeah. So, it's just to make more of a certain molecule.” (Excerpt from student’s response to the prompt “why does a cell undergo DNA replication?”; Amy, upper-division student)

*Note: Scientifically normative within reasonable parameters for undergraduate understanding.

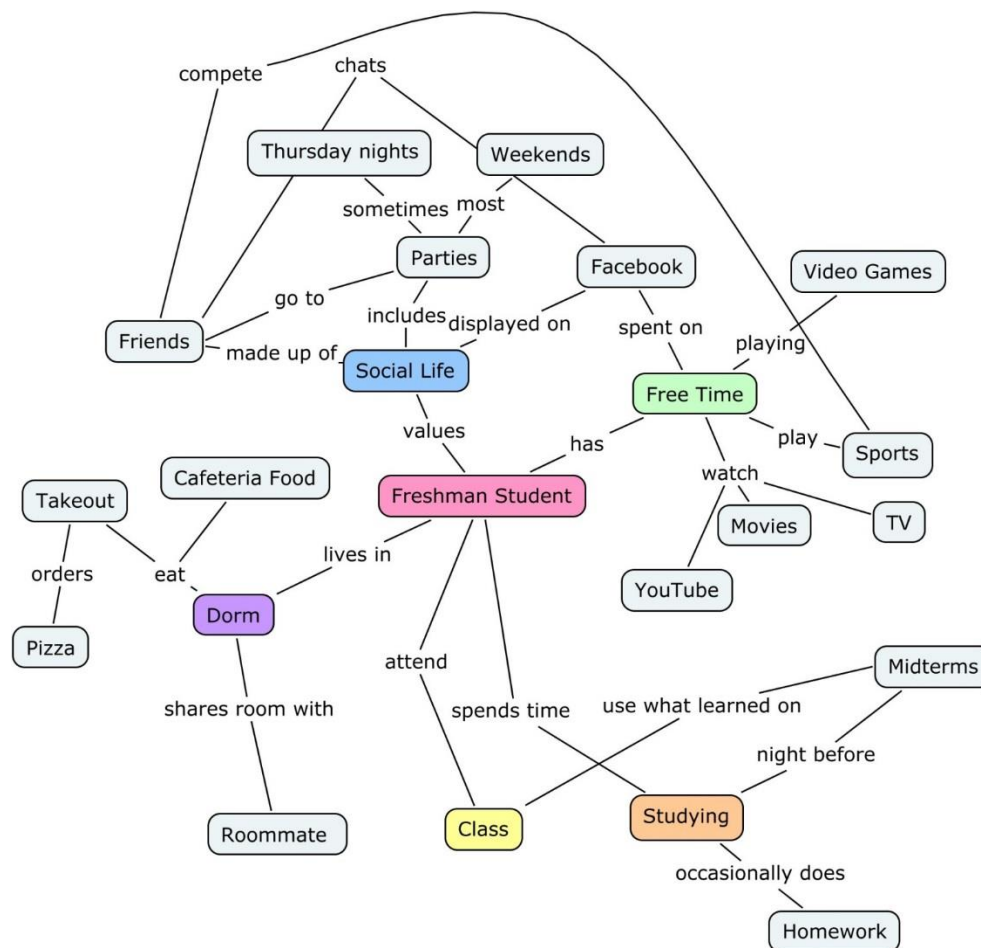
**Note: Only student responses to the probes asking for students to explain why a cell undergoes the processes of DNA replication, transcription and translation were coded with this scheme.

SM4: Interview Protocol: Concept Mapping Activity

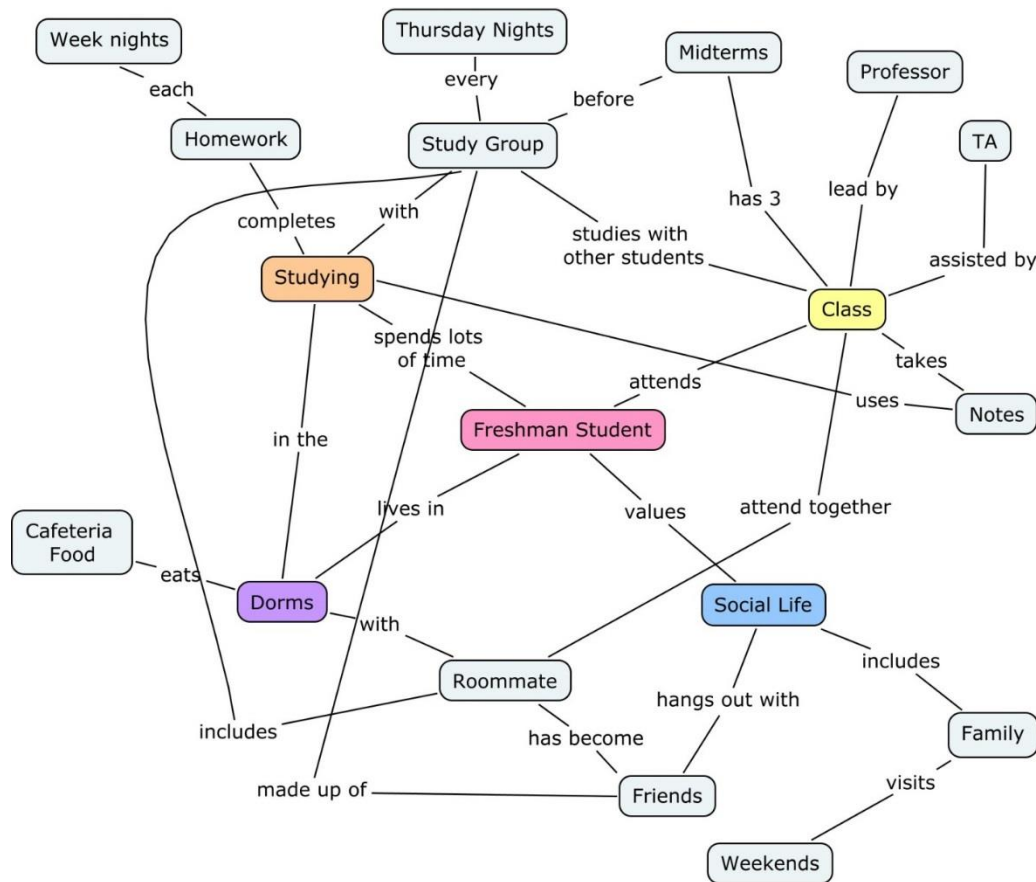
Introduction to Concept Mapping

Interviewer: "A concept map is a tool developed by researchers who study how people learn. It serves 2 primary purposes: 1) It helps us become more aware of our own thought process as we learn a concept or look back on a previously learned concept (and many times will help us uncover any trouble spots we have in our understanding). 2) It helps visually put on paper how we organize our thoughts about a subject. The main idea of a concept map is that there are key ideas, or "terms", that are attached by connections to show the relationship between them. Please take a look at the following example of a basic concept map on the central idea "freshman life"."

Freshman Life 1



Freshman Life 2



Note: Illustrative concept maps “Freshman Life 1&2” were shown to students during concept mapping introduction and available for reference at any point during interview.

Interviewer: “Notice that the central term “Freshman Student” has connections linking it to descriptive topics such as “Dorm”, “Class”, “Studying”, etc. (*Point to relevant parts of concept map as explaining*) These connections include “linker words”, which are short descriptions of the connections between the concepts. More terms have been added to further describe and demonstrate connections between terms. Notice how this concept map draws multiple connections between terms, and used linker words to describe the relationship. Again this is a very basic example, but gives you an idea of how concept maps are created. What are some other connections you could draw between these terms?”

Interviewer: “Concept maps will look different between individuals even when centered on the same topic. Take a look at the following concept map “Freshman Life 2”. Here we have many of the same terms, but this individual connected them in different ways. Take a minute to look at this map and compare it to the first map. What are some similarities and some differences between the two “Freshman Life” concept maps?”

Concept Mapping Activity

Interviewer: “Now that we understand what concept maps are and a little bit about how they are created, I am going to ask you to construct a concept map using your knowledge of the Central Dogma. Use the following terms to begin creating a concept map integrating the things you have learned up to this point about proteins. Your concept map should begin with what you see as most central to the central dogma. Remember to describe the connections between terms by using short “linker words”. As you create your map, I would like you to say out loud everything you are thinking as you are putting together the concept map; why you are choosing to organize the terms in a certain way, how you are making decisions of what to link and why...etc. If you have never heard of one of these words, you can just leave it on the paper and not include it in your map. I also have extra sticky notes here if you would like to add any words at any point.”

Terms:

Cell	Phenotype	Nucleic Acid	Gene Regulation
Inheritance	Enzyme	Membrane	Protein
DNA	Transcription	Ribosome	Replication
Mutations	Gene	Genetic Disease	Amino Acid
Neuron	Translation	RNA	Skin Cell

Brief Rationale for Concept Map Terms:

The terms “nucleic acid”, “enzyme”, “protein”, “DNA”, “transcription”, “ribosome”, “Replication”, “amino acid”, “translation”, and “RNA” were selected as concept mapping terms in order to explore how students discussed relationships between ideas related to the three target mechanisms (DNA replication, transcription, and translation). Terms such as “gene regulation”, “gene”, “phenotype”, “mutations”, “gene”, and “genetic disease” were included to observe how students discussed information flow in the central dogma of molecular biology and the impact of mutations. The terms “inheritance”, “mutation”, “genetic disease” were also used to observe how students would discuss the inheritance of genetic material. “Cell” and “membrane” were given to explore how students made connections between the molecular and cellular level. And finally, terms such as “skin cell” and “neuron” were used to observe whether students would connect gene expression/regulation to cellular differentiation.

Note: Terms already labeled on sticky notes of a certain color, ordered as seen above. Another stack of sticky notes of a different color are available if the student feels it is necessary to add any terms to accurately represent her or his thinking.

Note: After the student completed the concept mapping activity, students were asked: “Can you walk me through your concept map?”

SM5: Coding Scheme: Student Concept Maps

Concept Map Code	Type 1	Type 2	Type 3
Description	Blank or associative connections	Connections indicating vague actions, structural associations (location, composition, etc.), vague role in process, or indicating the term as a type or example.	Connections indicating function, causation, mechanism, or an action.
Examples	<ul style="list-style-type: none"> - Mutations* related [to] genetic disease (Bianca, UD**) - Genetic disease “can affect” cell (Emma, UD) - Gene regulation influences translation (Bobby, UD) 	<ul style="list-style-type: none"> - DNA made up of nucleic acid (Brittany, UD) - Enzyme is a type of protein (Amy, IN) - DNA is enclosed [in] membrane (Cindy, IN) 	<ul style="list-style-type: none"> - Enzyme catalyzes translation (Ciara, IN) - DNA copied during replication (Lydia, IN) - Amino acid folds into protein (Bianca, UD) - Genetic disease caused by mutation (Jenny, IN)

*Provided concept map terms highlighted in grey. Linker words or phrases provided by student highlighted in black.

**UD refers to upper-division students. IN refers to introductory students.