MISCONCEPTIONS IN BIOLOGY AND WHAT TO DO ABOUT THEM

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- **20 multiple-choice questions assessment tool**
  - Designed around core concepts and SLOs of the introductory biology for majors course Bio 121
  - Administered as a pilot and edited by the biology department assessment committee twice
  - Fall 2018: Administered as a pre-test to **260 students**

    Administered as a post-test to **155 students**

    134 students took both, the pre-test and post-test assessments
  - The average student performance in the **post-test (mean=61.58%)** was **statistically significantly higher** than the average student performance in the **pre-test (mean=50.56%).**

Relative size	Effect size
	0.0
Small	0.2
Medium	0.5
Large	0.8

  - P-value = 4.27×10^{-5} (at the standard 0.05 level)
  - The effect size, also known as **"learning gain"** (indicates the importance of difference between the pre-test and post-test), was **0.77**

Caveat: In this analysis we are not looking at learning of individual students but of an **overall student population** that is taking the Bio 121 course, thus, for example, when I state that students have a good background mastery of a particular concept, it means that more than 70% of students answered the question addressing that particular concept in the pre-test correctly.

Five main observations from the assessment data for this project:

Observation 1: Students began the course with different levels of understanding of key biological concepts ranging from very poor to good (based on pre-assessment)

Observation 2: Students left the course with a significant learning gain and with different levels of understanding of key biological concepts ranging from poor to good (based on post-assessment)

Observation 3: As students progressed through the course, their improvement in mastery of different concepts varied from nonexistent to significant (depending on the concept)

Observation 4: Students have misconceptions about certain biological concepts which can prevent them from learning those concepts

Observation 5: Taking the course allowed students to clear some (but not all) of the biological misconceptions

Observation 1: **Students began the course with different levels of understanding of key biological concepts ranging from very poor to good (based on pre-assessment)**

Question	PRE-TEST Correct answer (%) in declinining order	Groups
Q18	82.31%	Over 70% of students answered the questions correctly "good knowledge"
Q5	75.77%	
Q13	68.85%	Over 50 to 70% of students answered the questions correctly "moderate knowledge"
Q1	66.92%	
Q7	66.54%	
Q19	61.92%	
Q20	56.92%	
Q11	56.54%	
Q2	54.62%	
Q4	54.62%	
Q16	53.08%	
Q6	50.00%	30 to 50% of students answered the questions correctly "poor knowledge"
Q10	48.85%	
Q17	42.31%	
Q9	39.23%	
Q3	35.00%	
Q8	30.00%	
Q12	26.92%	Less than 30% of students answered the question correctly "very poor knowledge"
Q15	23.46%	
Q14	16.54%	

For the purposes of data analysis, I divided assessment tool questions into categories, based on the proportion of correct answers students provided to each in the pre-assessment

- **Category 1:** over 75 % students answered these questions correctly, so the student population, on the whole, demonstrated a **"good knowledge"** of the concepts targeted by these questions
- **Category 2:** majority of students (50 to 70%) answered these questions correctly, so the student population, on the whole, demonstrated a **"moderate knowledge"**
- **Category 3:** only 30 to 50% of students could answer these questions correctly, so the student population, on the whole, demonstrated a **"poor knowledge"**
- **Category 4:** less than 30% of students answered these questions correctly, so the student population, on the whole, demonstrated a **"very poor knowledge"** of the concepts targeted by these questions

If students appear to have a good background knowledge for one question it doesn't guarantee that they will have one of another question that targets the same concept.

Matching biological concepts	Question	PRE-TEST Correct answer (%) in declinining order	Groups
C14. Compare and contrast the outcomes of cell division via mitosis and meiosis	Q18	82.31%	Over 70% of students answered the questions correctly "good knowledge"
C5. Compare and contrast 4 classes of biological molecules (carbohydrates, lipids, proteins, nucleic acids)	Q5	75.77%	
C12. Explain how mistakes in cell division can lead to cancer and chromosomal abnormalities	Q13	68.85%	Over 50 to 70% of students answered the questions correctly "moderate knowledge"
C1. Recognize dependent, independent and controlled variables in an experiment	Q1	66.92%	
C6. Compare the structural hallmarks of bacterial (prokaryotic) cells and eukaryotic cells	Q7	66.54%	
C15. Recognize that DNA sequences have a meaning	Q19	61.92%	
C15. Recognize that DNA sequences have a meaning	Q20	56.92%	
C 9. Distinguish and compare the processes by which organisms fuel growth and cellular activities	Q11	56.54%	
C2. Summarize the basics of atomic structure	Q2	54.62%	
C4. Distinguish between three main types of chemical bonds: covalent, ionic and hydrogen	Q4	54.62%	
C13. Diagram the flow of genetic information in cell	Q16	53.08%	
C5. Compare and contrast 4 classes of biological molecules (carbohydrates, lipids, proteins, nucleic acids)	Q6	50.00%	30 to 50% of students answered the questions correctly "poor knowledge"
C 9. Distinguish and compare the processes by which organisms fuel growth and cellular activities	Q10	48.85%	
C14. Compare and contrast the outcomes of cell division via mitosis and meiosis	Q17	42.31%	
C8. Explain the principles of enzyme function	Q9	39.23%	
C3. Recognize and predict molecules or parts of molecules that are hydrophobic or hydrophilic	Q3	35.00%	
C7. Differentiate among different types of transport across plasma membrane	Q8	30.00%	
C14. Compare and contrast the outcomes of cell division via mitosis and meiosis	Q12	26.92%	Less than 30% of students answered the question correctly "very poor knowledge"
C13. Diagram the flow of genetic information in cell	Q15	23.46%	
C16. Explain what mutations are and how they affect genetic code	Q14	16.54%	

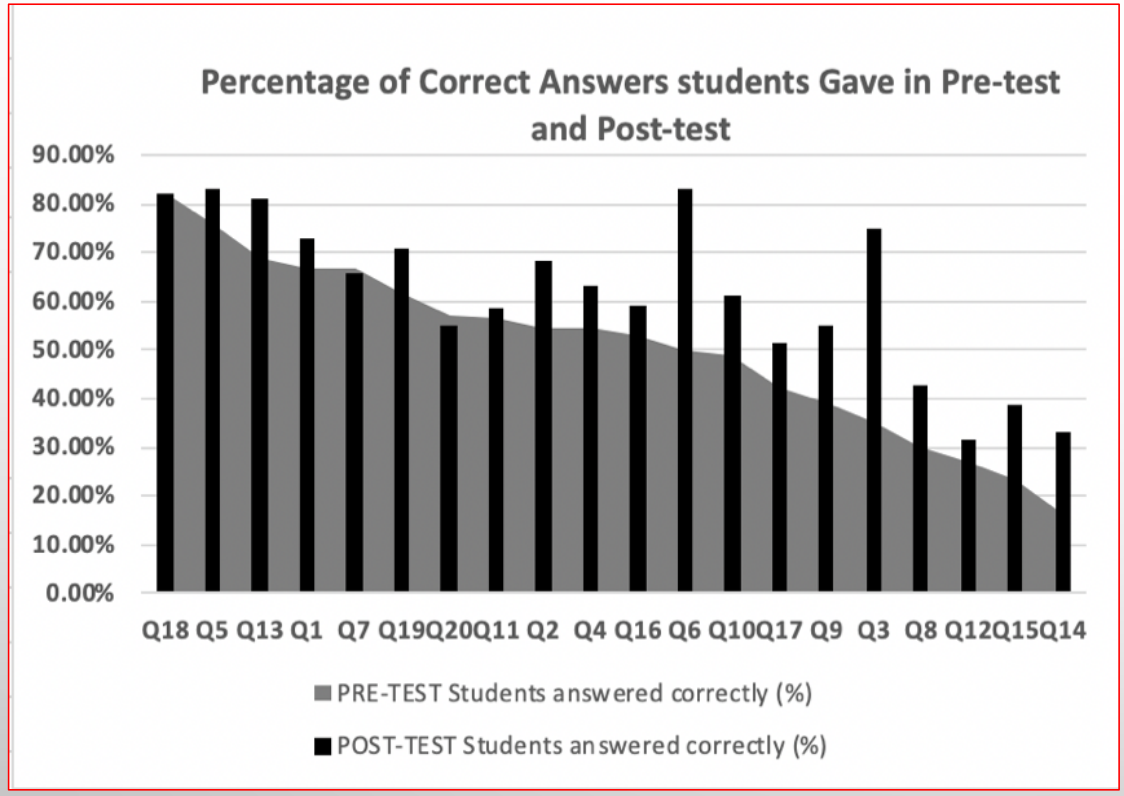
Observation 2: Students left the course with a significant learning gain and with different levels of understanding of key biological concepts ranging from poor to good (based on post-test)

Question	PRE-TEST Correct answers (%) in declinining order	PRE-TEST Groups	POST-TEST Groups	Question	POST-TEST Correct answers (%) in declinining order
Q18	82.31%	"good knowledge"	"good knowledge"	Q5	83.23%
Q5	75.77%			Q6	83.23%
Q13	68.85%	"moderate knowledge"		Q18	81.94%
Q1	66.92%			Q13	81.29%
Q7	66.54%			Q3	74.84%
Q19	61.92%			Q1	72.90%
Q20	56.92%			Q19	70.97%
Q11	56.54%		"moderate knowledge"	Q2	68.39%
Q2	54.62%			Q7	65.81%
Q4	54.62%			Q4	63.23%
Q16	53.08%			Q10	61.29%
Q6	50.00%	"poor knowledge"		Q16	59.35%
Q10	48.85%			Q11	58.71%
Q17	42.31%			Q9	54.84%
Q9	39.23%			Q20	54.84%
Q3	35.00%			Q17	51.61%
Q8	30.00%		"poor knowledge"	Q8	42.58%
Q12	26.92%	very poor knowledge		Q15	38.71%
Q15	23.46%			Q14	32.90%
Q14	16.54%			Q12	31.79%

The pre-assessment observation that if students appear to have a good background knowledge for one question doesn't guarantee that they will have one of another question that targets the same concept persists in the post-assessment

Question	POST-TEST Correct answers (%) in declinining order	Matching biological concepts
Q5	83.23%	C5. Compare and contrast 4 classes of biological molecules (carbohydrates, lipids, proteins, nucleic acids)
Q6	83.23%	C5. Compare and contrast 4 classes of biological molecules (carbohydrates, lipids, proteins, nucleic acids)
Q18	81.94%	C14. Compare and contrast the outcomes of cell division via mitosis and meiosis
Q13	81.29%	C13. Diagram the flow of genetic information in cell
Q3	74.84%	C3. Recognize and predict molecules or parts of molecules that are hydrophobic or hydrophilic
Q1	72.90%	C1. Recognize dependent, independent and controlled variables in an experiment
Q19	70.97%	C15. Recognize that DNA sequences have a meaning
Q2	68.39%	C2. Summarize the basics of atomic structure
Q7	65.81%	C6. Compare the structural hallmarks of bacterial (prokaryotic) cells and eukaryotic cells
Q4	63.23%	C4. Distinguish between three main types of chemical bonds: covalent, ionic and hydrogen
Q10	61.29%	C 9. Distinguish and compare the processes by which organisms fuel growth and cellular activities
Q16	59.35%	C13. Diagram the flow of genetic information in cell
Q11	58.71%	C 9. Distinguish and compare the processes by which organisms fuel growth and cellular activities
Q9	54.84%	C8. Explain the principles of enzyme function
Q20	54.84%	C15. Recognize that DNA sequences have a meaning
Q17	51.61%	C14. Compare and contrast the outcomes of cell division via mitosis and meiosis
Q8	42.58%	C7. Differentiate among different types of transport across plasma membrane
Q15	38.71%	C13. Diagram the flow of genetic information in cell
Q14	32.90%	C16. Explain what mutations are and how they affect genetic code
Q12	31.79%	C14. Compare and contrast the outcomes of cell division via mitosis and meiosis

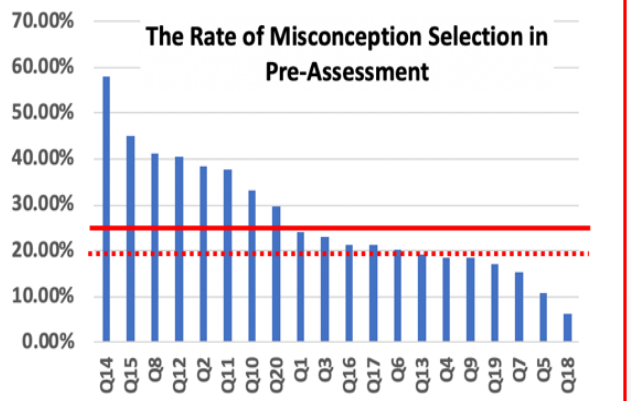
Observation 3: As students progressed through the course, their improvement in mastery of different concepts varied from nonexistent to significant (depending on the question and concept)

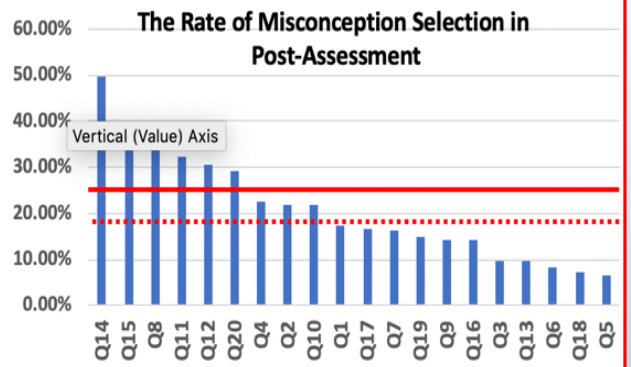


Question	Difference between post-test and pre-test	Groups
Q3	39.84%	Good improvement
Q6	33.23%	
Q14	16.36%	Moderate improvement
Q9	15.61%	
Q15	15.25%	
Q2	13.77%	
Q8	12.58%	
Q10	12.44%	
Q13	12.44%	
Q17	9.30%	Slight improvement
Q19	9.05%	
Q4	8.61%	
Q5	7.46%	
Q16	6.27%	
Q1	5.98%	
Q12	4.87%	No improvement
Q11	2.17%	
Q18	-0.37%	
Q7	-0.73%	
Q20	-2.08%	

Observation 4: **Students have misconceptions about certain biological concepts which can prevent them from learning those concepts**

Question	Misconceptions (%) Pretest	Question	Misconceptions (%) Posttest
Q14	58.08%	Q14	49.68%
Q15	45.00%	Q15	37.42%
Q8	41.15%	Q8	35.48%
Q12	40.38%	Q11	32.26%
Q2	38.46%	Q12	30.46%
Q11	37.69%	Q20	29.03%
Q10	33.08%	Q4	22.58%
Q20	29.62%	Q2	21.94%
Q1	24.23%	Q10	21.94%
Q3	23.08%	Q1	17.42%
Q16	21.15%	Q17	16.77%
Q17	21.15%	Q7	16.13%
Q6	20.38%	Q19	14.84%
Q13	19.23%	Q9	14.19%
Q4	18.46%	Q16	14.19%
Q9	18.46%	Q3	9.68%
Q19	16.92%	Q13	9.68%
Q7	15.38%	Q6	8.39%
Q5	10.77%	Q18	7.10%
Q18	6.15%	Q5	6.45%

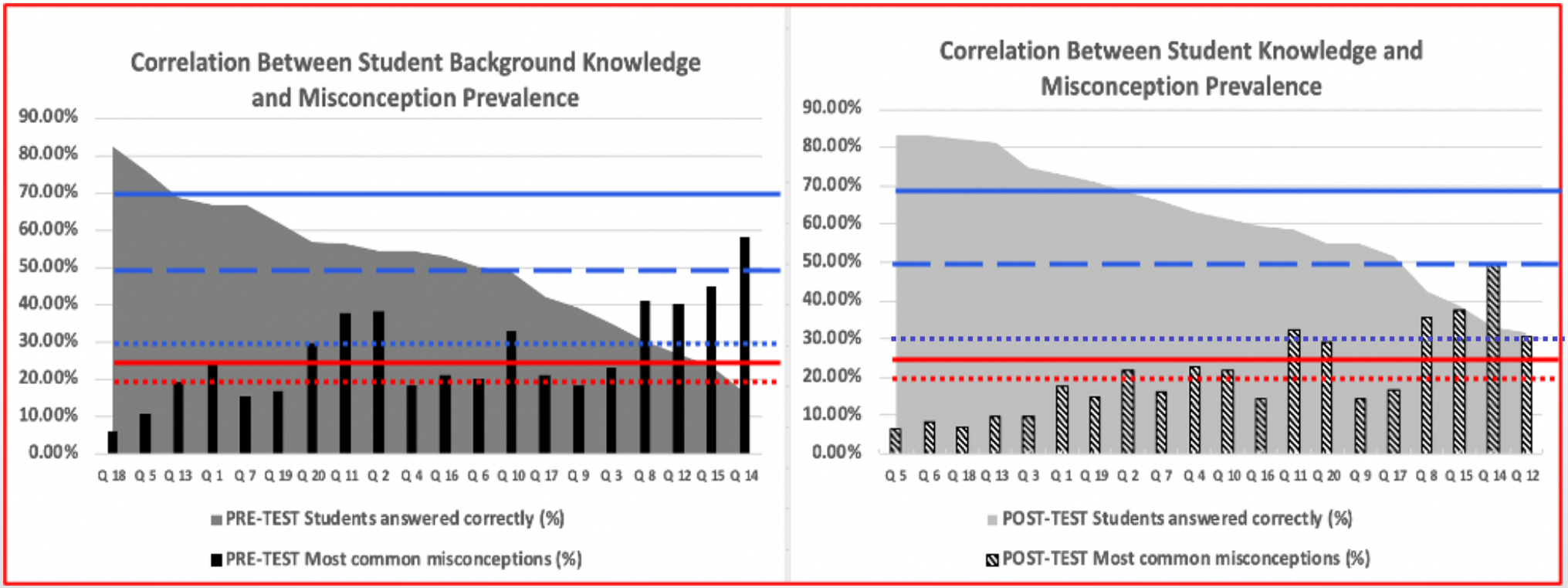




Incorrect answers in pre- and post-assessment:

Solid red line represents a cut-off for misconceptions that were selected at a rate higher than 25%

Dotted red line represents a cut-off for potential misconceptions selected at a rate 19-25%



Solid blue line marks the cut off for **"good knowledge"** category (70% or more correct answers)
Dashed blue line marks the cut off for **"moderate knowledge"** category (50-70%),
Dotted blue line divides the "**poor knowledge"** (30-50% or more correct answers) and **"very poor knowledge"** (below 30%)
Solid red line represents a cut-off for misconceptions that were selected at a rate higher than 25%
Dotted red line represents a cut-off for potential misconceptions selected at a rate 19-25%,

Observation 5: Taking the course allowed students to clear some (but not all) of the biological misconceptions

Question	Misconceptions (%) Pretest	Question	Misconceptions (%) Posttest	Post-test/ pre-test difference Δ, %
Q14	58.08%	Q14	49.68%	-8.40
Q15	45.00%	Q15	37.42%	-7.58
Q8	41.15%	Q8	35.48%	-5.67
Q12	40.38%	Q11	32.26%	-5.43
Q2	38.46%	Q12	30.46%	-9.92
Q11	37.69%	Q20	29.03%	-0.59
Q10	33.08%	Q4	22.58%	+4.12
Q20	29.62%	Q2	21.94%	-16.52
Q1	24.23%	Q10	21.94%	-11.14
Q3	23.08%	Q1	17.42%	-6.81
Q16	21.15%	Q17	16.77%	-4.38
Q17	21.15%	Q7	16.13%	+0.75
Q6	20.38%	Q19	14.84%	-2.08
Q13	19.23%	Q9	14.19%	-4.27
Q4	18.46%	Q16	14.19%	-6.96
Q9	18.46%	Q3	9.68%	-13.43
Q19	16.92%	Q13	9.68%	-9.55
Q7	15.38%	Q6	8.39%	-11.99
Q5	10.77%	Q18	7.10%	+0.95
Q18	6.15%	Q5	6.45%	-4.32

Group 1:
For some topics the same misconceptions persist in the post-test (Q 14, 15, 8, 11, 12, 20)

Group 2:
Some topics discussed in the course appear to clear misconceptions in the post-test (Q 2 and 10)

Group 3:
Some of the topics that had potential misconceptions in the pre-test that were "cleared" in post-test (Q 1, 16, 3, 13, 6)

Group 4: questions that had inconclusive misconception picture (Q 4, 17, 7, 19, 9, 18, 5)

Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)

Q 14. A young man develops skin cancer that does not spread to any other tissues; the mutation responsible for the cancer arose in a single skin cell. If he and his wife (who does not have skin cancer) subsequently have children, which of the following statements is CORRECT?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. All the man's children will inherit the mutation responsible for skin cancer.			
B. All the man's children will inherit the mutation responsible for skin cancer if the mutation is dominant.			
C. Some of the man's children may inherit the mutation responsible for skin cancer depending on which of his chromosomes they inherit. (Common Misconception)	58.08	49.69	-8.40
D. None of the man's children will inherit the mutation responsible for skin cancer. (Correct Answer)	16.54 very poor	32.90 poor	16.36 moderate improvement

- Very poor background knowledge of the concept, then moderate improvement in the post-test, but still insufficient for a good concept mastery
- **Misconception C** presents a significant interference in learning - **recommendations are needed**

Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)

Q 15. What does the genetic information usually provide instructions for?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. Assembling amino acids into protein molecules (Correct Answer)	23.46 very poor	38.71 poor	15.25 moderate improvement
B. Assembling protein molecules into amino acids			
C. Assembling nucleotides into proteins			
D. Assembling amino acids into RNA (Common Misconception)	45.00	37.42	-7.58

- Very poor background knowledge of the concept, followed by moderate improvement in the post-test but still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- **Misconception D** presents an interference in learning

Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)

Q 8. Which of the following substances will diffuse through a phospholipid bilayer membrane that contains NO proteins?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. ions			
B. glucose (Common Misconception)	41.15	35.48	-5.68
C. vitamins			
D. oxygen gas (Correct Answer)	30.00 poor	42.58 poor	12.58 moderate improvement.

- Poor background knowledge of the concept, followed by moderate improvement in the post-test but still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- **Misconception B** presents an interference in learning

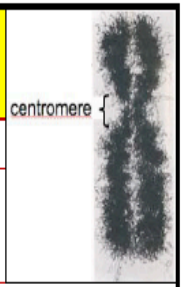
Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)

Q 11. Which of the following statements is the most accurate?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. Plants carry out cellular respiration and photosynthesis. (Correct Answer)	56.54 moderate	58.71 moderate	2.17 no improvement
B. Plants carry out only photosynthesis. (Common Misconception)	37.69	32.26	-5.43
C. Animals carry out cellular respiration and photosynthesis.			
D. Animals carry out only photosynthesis.			

- Poor background knowledge of the concept, followed by moderate improvement in the post-test but still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- **Misconception B** presents an interference in learning

Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)



Q 12. The following photograph shows a single replicated chromosome (consisting of two sister chromatids) just before mitosis. This chromosome contains:

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. two single-stranded DNA molecules.			
B. one double-stranded DNA molecule. (Common Misconception)	40.38	30.46	-9.92
C. two double-stranded DNA molecules. (Correct Answer)	26.92 very poor	31.79 poor	4.87 no improvement
D. one single-stranded DNA molecules.			

- Very poor background knowledge of the concept and no improvement in the post-test
- **Recommendations are needed to improve student learning of this concept**
- **Misconception B** presents an interference in learning

Group 1:
For some topics the same misconceptions persisted in the post-test (Q 14, 15, 8, 11, 12, 20)

Q 20. Which of the following could be affected by the information in the DNA molecules of an organism?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. Both an organism's physical characteristics and its behavior. (Correct Answer)	56.92 moderate	54.84 moderate	-2.08 no improvement
B. An organism's physical characteristics but not its behavior. (Common Misconception)	29.62	29.03	-0.59
C. An organism's behavior but not its physical characteristics.			
D. Neither an organism's physical characteristics nor its behavior.			

- Moderate background knowledge of the concept and no improvement in the post-test
- **Recommendations are needed to improve student learning of this concept**
- **Misconception B** may present an interference in learning
- Note: Is this something we discuss in Bio 121?

Group 2:

Some topics discussed in the course appear to clear misconceptions in the post-test (Q 2 and 10)

Q 2. What do molecules of water consist of?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. Atoms of oxygen and nitrogen.			
B. Molecules of oxygen and hydrogen. (Common Misconception)	38.46	21.94	-16.52
C. Atoms of oxygen and hydrogen. (Correct Answer)	54.62 moderate	68.39 moderate	13.77 moderate improvement
D. Molecules of oxygen and nitrogen.			

- Moderate background knowledge of the concept followed by moderate improvement in the post-test, but still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- **Misconception B** was significant in the pre-test but appears to be **cleared in the post-test (?)**

Group 2:

Some topics discussed in the course appear to clear misconceptions in the post-test (Q 2 and 10)

Q 10. You eat a grape high in glucose content. How could a glucose molecule from the grape provide energy to fuel your body?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. Glucose is digested into simpler molecules, leading to breakdown of ATP. (Common Misconception)	33.08	21.94	-11.94
B. The chemical energy of glucose is completely converted to heat.			
C. The chemical energy of glucose is used to produce ATP. (Correct Answer)	48.85 poor	61.29 moderate	12.44 moderate improvement
D. The chemical energy of glucose is used to breakdown ATP.			

- Poor background knowledge of the concept followed by moderate improvement in the post-test, but still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- **Misconception A** was significant in the pre-test but appears to be **cleared in the post-test (?)**

Note that reduction in selection of the misconception approximately matches the increase in correct answers

Group 3:

Some of the topics showed a significant reduction of misconceptions in post-test even though the initial percentage of misconceptions slightly lower than 25% still (Q 1, 16, 3, 13, 6)

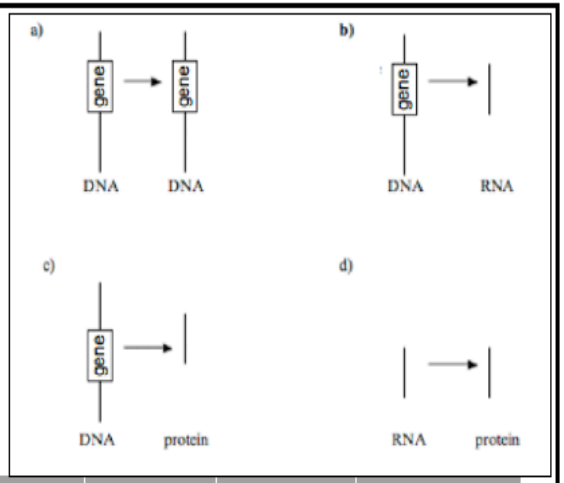
Q 1. A farmer thinks that type of soil and amount of water affect the growth of his carrot plants, and he wants to find out if he is right. The farmer first tests if the type of soil affects the growth of the carrot plants. He uses three different types of soil, and he places 10 carrot plants in each type of soil. He uses the same amount of water for all the plants. Why is it important to use the same amount of water for all the plants?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. By using the same amount of water, the farmer can learn about both the effect of the amount of water and the effect of the type of soil. (Common Misconception)	24.23	17.42	-6.81
B. By using the same amount of water, the farmer can learn about the effect of the amount of water.			
C. If he does not use the same amount of water, the farmer cannot learn about the effect of the type of soil. (Correct Answer)	66.92 moderate	72.90 good	5.98 slight imp.
D. It is NOT important to use the same amount of water because the farmer is not testing the effect of the amount of water.			

- Moderate background knowledge of the concept followed by a slight improvement achieved a good understanding level of the concept by student population
- Recommendations can still be made to improve student understanding of the concept
- Misconception A may have presented an interference in pre-test but was cleared in the post-test

Group 3:

Some of the topics showed a significant reduction of misconceptions in post-test even though the initial percentage of misconceptions slightly lower than 25% still (Q 1, 16, 3, 13, 6)



Q 16. Transcription is represented best by which of the following diagrams?

Answer choices	Pre-test %	Post-test %	Post-/ Pre-test Δ
A. DNA to DNA (Common Misconception)	21.15	14.19	-6.96
B. DNA to RNA (Correct Answer)	53.08 moderate	59.35 moderate	6.27 slight imp.
C. DNA to protein			
D. RNA to protein			

- Moderate background knowledge of the concept followed by a slight improvement was still insufficient for a good concept mastery
- **Recommendations are needed to improve student learning of this concept**
- Misconception A may have presented an interference in pre-test but was cleared in the post-test