Comparing and Contrasting DNA Replication, Transcription, and Translation in a Student-Centered Environment

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ABSTRACT

During my previous semester as an associate instructor for an introductory molecular biology class, I noticed that students were having problems understanding and comparing and contrasting the 3 core molecular processes of DNA replication, transcription, and translation. I chose to emphasize these 3 processes throughout the semester during my voluntary supplemental instruction (SI) sessions by maintaining a student-centered classroom that utilized worksheet activities, case studies, and interactive iPad exercises. To assess my emphasis on the processes of replication, transcription, and translation, I performed a pre- and post-test covering this material, as well as an analysis on my mid-semester evaluations and the results of our iPad activities. The results from the pre-/post-test indicate that students who regularly attended my SI sessions increased their performance on the test, especially on the more challenging questions. My analysis of the mid-semester evaluations and iPad activities stimulated my thinking on how to run a student-centered classroom and gave me insight into student thinking when they are presented with complex problems.

INTRODUCTION

Molecular Biology L211 is an introductory lecture class that covers a wide variety of topics in the field of molecular biology, including nucleic acid structure, the central processes of DNA replication, transcription, and translation, and gene regulation. The course enrollment is 240 students, and the class is available to sophomores, juniors, and seniors who have taken an introductory biology course. The class meets twice a week for 75 min lectures, which are taught by the main professor, Dr. Joe Pomerening. The majority of the students’ grade comes from four non-cumulative multiple choice exams and one cumulative final. In addition, there are four multiple choice quizzes and in-class clicker questions. The clicker questions provide real-time assessment of the lecture material but are not graded on accuracy, only on participation.

In addition to lecture, there are 50 minute voluntary supplemental instruction (SI) sessions taught each week by two associate instructors (AIs). As one of the associate instructors in this course, I taught SI sessions twice a week. The goal of these sessions is to reinforce the main ideas covered in that week’s lectures and expand upon specific details or experimental techniques. In addition, SI sessions provide the students with sample test questions and the logic for solving them. The format of the SI sessions is up to the two AIs, although historically in this course, these sessions have taken on a lecture-style format that follows a handout created by the AIs. As one of the AIs this semester, my role was to help design the handout/worksheet we would use to cover the material, prepare any activities to review the material, develop the practice test questions, and teach the sessions.
OBJECTIVES AND LEARNING CHALLENGE

My broad objectives for the course were for students to gain a deep understanding of molecular biology, not by memorizing facts but by understanding key principles and then using critical thinking to apply their knowledge to real biological situations and problems. In an attempt to help students develop a deep understanding of molecular biology through critical thinking, I decided to utilize student-centered activities in my SI discussion. In the book “Exploring Signature Pedagogies,” the chapter by Angela Bauer-Dantoin stresses that lecture-style teaching is suited towards students learning by memorization but that it is ineffective at helping students develop an understanding of biology or acquiring critical thinking and problem solving skills. This chapter illustrates that using a student centered environment with active learning strategies (problem solving or case studies) has been shown to foster higher order thinking skills and promote overall academic achievement. These points are also emphasized in a review article by DiCarlo (2006) that discusses how problem-based learning, case studies, and concept maps can bring collaborative inquiry into the classroom. An article by Knight and Wood (2005) discusses a specific example in which changing the style of a classroom from a lecture to a style incorporating student participation and cooperative problem solving increased student performance on homework problems and post-test results. These articles and additional readings show that students will start thinking more like scientists and improve their problem solving skills when they are faced with situations such as predicting the results of an experiment, determining what might happen if a variable is changed, interpreting data, or working through a complex problem step-by-step. Developing problem solving skills is important because biologists just don’t work with memorized facts. We use known facts along with critical thinking and problem solving in order to make new discoveries.

The specific learning challenge that I chose to address is the students’ ability to understand as well as compare and contrast the three key processes of DNA replication, transcription, and translation. DNA replication, transcription, and translation are known as the central dogma in the field of molecular biology, and all other topics in molecular biology require an understanding of these processes. Despite their importance and how much they are stressed in a molecular biology course, I still feel students struggle with them and have problems keeping the three processes straight in their mind. I taught this same class (with a different professor) in the fall, and in a review for the final exam, students were struggling with the details of all three processes. Students may feel that they know the necessary information about one process, but when they are asked to compare and contrast between the three processes, they get confused and struggle with the material. Comparing and contrasting is a very important skill in general within biology and should be a point of emphasis that we work on with biology undergraduate students.

Overall, I had two major objectives. My first major goal was to maintain a student-centered classroom throughout the semester, regardless of the topic being covered. My second goal was to stress the ability to compare and contrast the concepts of DNA replication, transcription, and translation whenever appropriate throughout the semester. These processes were emphasized throughout the semester, and the students were provided with multiple opportunities to compare and contrast them so they could learn their individual importance as well as also how they all function together in a cell.
IMPLEMENTATION

Student-centered Worksheets and Classroom Activities

I implemented both goals through the design of our classroom worksheets and classroom activities. One sample SI worksheet can be seen in Appendix I. Within this worksheet, there are several class activities designed to get the class discussing, working in groups, and working on the board. The very 1st activity on this worksheet is a memory matrix covering different DNA polymerases in prokaryotes and eukaryotes. Not only was this one of their first introductions to DNA replication but it also stressed the skill of comparing and contrasting. There is also a section of the worksheet that requires the students to get into groups and work through the steps of a process depicted on the worksheet. This got the students talking and was an easy way to avoid me simply giving them a recitation of the facts. The multiple choice questions throughout the worksheet give the students practice for the exams, and they have to work through them in groups and explain their answers to the class. All of these activities were designed to make the class interactive and avoid a lecture-style environment. Lastly, the end of this particular worksheet contains a memory matrix for comparing DNA replication, transcription, and translation. At this point, the students had only learned about DNA replication so they only filled out the first column. But I stressed to them that they would see this table again and would have to fill it out for all 3 processes once we had covered them in class. This set the students up for knowing that they were going to have to understand all of the processes in relation to each other. Once we covered material on all 3 processes and the students filled this table out in its entirety, it led to a great discussion about similarities and differences between these core processes. For example, there were questions concerning why DNA and RNA polymerase are multi-subunit proteins but the ribosome is composed of both protein and RNA and why couldn’t DNA and RNA polymerase bind to RNA and use it as a template for cellular reactions.

Case study on Central Dogma

After covering the material from all three molecular processes, the students were given a “Case Study on the Central Dogma”. This was a set of six multiple choice questions that utilized information from all three processes and required them to use their knowledge of all three processes to get the answers correct. Two example questions are given below.

Question 1
For what cellular process must the chromatin be unwound and NOT compacted?
   a. DNA replication
   b. Transcription
   c. Translation
   d. Both a and b
   e. Both b and c

Question 2
For which cellular process does the final product remain bound the template after termination is complete?
   a. DNA replication
   b. Transcription
   c. Translation
   d. All of the above
   e. None of the above
The students worked in groups to answer the questions and then different groups presented and explained their answers to the class. Since the case study was in the form of multiple choice questions, it was great practice for the exam but it also really made the students think about all three processes at once.

**Interactive iPad Exercises**

Lastly, one of the more interesting student-centered activities we did in SI session involved the use of iPads. The professor of this class is involved in a pilot project to examine the impact of iPads on teaching and learning at the university level. Over the course of two lectures, he used multiple iPads in the large lecture setting to ask questions to the students and have them visually share their problem-solving steps as they reached their answer. The other AI and I felt that this could also be a very valuable tool for our SI sessions. We were able to use 2 iPads per classroom for a week. We designed two questions that required the students to progress through multiple steps to reach the right answer. The first question is shown below.

**iPad Question 1:**

Below is a DNA coding strand:

5' TAAGATGCCAATAGTCTTTGAAGCCTGACG 3'

First, identify the correct reading frame and separate the codons in that reading frame with vertical lines.

Second, using the correct reading frame, translate the DNA sequence into the correct protein sequence.

For this question, the students had to understand what DNA strand was given to them, “transcribe” the DNA sequence into mRNA, and then use the codon table given to “translate” the mRNA into protein. For the students to get the correct answer, they needed to understand the processes of transcription and translation. Thus, this was a good interactive question for my overall focus on the processes of the central dogma. The students had to work in groups and develop their answers, which they drew on the iPad. The answers were projected for the class to see and the groups then had to explain their answers.
Here is an example of one of the group’s answers.

Below is a DNA coding strand:

5’ TAAGATGGCAATA GTGTTTGAAGCC TGA CG 3’

Start

First, identify the correct reading frame and separate the codons in that reading frame with vertical lines.

Second, using the correct reading frame, translate the DNA sequence into the correct protein sequence.

Pro - Ile - Val - Phe - Glu - Ala

This group’s answer was a great teachable moment because they got the majority of the answer correct. They correctly identified the reading frame, the start and stop codon, and the majority of the correct protein sequence. However, they failed to include the amino acid coded for by the start codon (Met), which should be the first amino acid of the protein. As they were explaining their answer, they realized themselves what they did wrong and explained to the class what the correct answer should be. This activity inspired much classroom discussion and interaction. Overall, it was a wonderful way to get students involved, both through group work and technology.

ASSESSMENT

The SI sessions were voluntary, which means that different students could come every week and student attendance varied. To determine the frequency of student attendance, I had students fill out a sign in sheet during each session. After every session, I entered that data into an excel sheet and I determined those students who attended regularly (>70% of sessions, 21 students), attended sporadically (between 20% and 70% attendance, 47 students) and attended only once or twice (<20% attendance, 21 students). I use this information in several analyses below.

Pre-/Post-Test Analysis

The first assessment that I did was to perform a pre- and post-test during SI sessions, covering questions relating to DNA replication, transcription, and translation. The pre-test (Appendix II) was given during the first week of SI sessions.
Thirty-one students took the pre-test and the results from the 7 multiple choice questions are seen below.

### Pre-test

<table>
<thead>
<tr>
<th>Question</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
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<td>Q2</td>
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</table>

Questions 1-4 all have a similar accuracy rate (~80%) and in my opinion, are of a similar difficulty. Questions 5-7 are more variable, with question 6 being the most difficult question (52% correct).

I gave the exact same assessment as a post-test at the end of the semester. Twenty-eight students took the post-test. Of these 28 students, 19 attended SI session regularly throughout the semester (>70% attendance) and 9 attended sporadically (between 20-70% attendance). I took the overall average of all 28 students (blue bars), and then I broke the data down into the % correct for those students that attended SI session regularly (maroon bars) and sporadically (green bars). The results are given below.

### Post-test

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<tr>
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<tr>
<td>Q2</td>
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<td>Q3</td>
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<tr>
<td>Q4</td>
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<tr>
<td>Q5</td>
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<td>Q7</td>
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</table>

Overall, the student’s performance on all 7 multiple choice questions improved from the pre-test to the post-test. The overall averages for questions 1-4 was > 90%, and 100% of students answered questions 1 and 4 correctly. These four questions should be easy for a student who has taken molecular biology so these results are reassuring. The students also increased their performance on questions 5-7. Questions 5 and 7 showed a ~ 20% jump in the number of students that got them right, and question 6
showed the greatest increase in performance, from 51.6% to 82.1% of the students getting it correct. Questions 5-7 are more challenging than questions 1-4, which is reflected in the number of students getting the questions correct, but questions 5-7 should be straightforward for a student at the end of a molecular biology class.

The majority of the performance increase at the post-test was probably due to the students having spent an entire semester learning about molecular biology and about the details of DNA replication, transcription, and translation. To examine if my focus on these processes in SI session had any affect on the overall performance increase, I broke down the post-test results by those students who attended SI regularly vs. sporadically. For several questions (questions 1, 3, 4, and 7), there was little to no difference between these two groups of students. Although whenever there was a performance difference between the two groups, the students who attended SI session regularly performed better. The largest difference between the two groups can be seen in question 6, which was the question that students struggled with most on the pre-test. In the post-test, 77.8% of students with sporadic attendance got it correct compared to 89.5% of students with regular attendance who got it correct. This suggests that attending SI sessions with a strong focus on the three core processes did improve performance, especially on more challenging questions. It should be noted that improved performance by students attending SI sessions regularly could simply be due to the fact that they attended more review sessions and thus had more practice with the material. In addition, there could be inherent differences between students who attended SI sessions at different frequencies (for example, students who attended more SI sessions could spend more time studying overall). Despite these caveats, my preliminary data indicate that attending SI sessions with a strong focus on DNA replication, transcription, and translation improved performance on this pre-test over the course of the semester and a slightly greater increase was seen in those students that attended the SI sessions frequently.

I also had one short answer question on the pre- and post-test. I asked the students to give me 2 differences between transcription and translation. I scored the answers using the following scale. If a student gave 2 differences and they were correct, they got 2 points. If they only gave 1 answer or only had 1 correct answer, they got 1 point. If they left it blank or had an entirely incorrect answer, they scored 0 points. In the pre-test, there was a relatively even distribution across all three point categories. For the post-test, nobody scored 0 points and, by far, the majority of the students scored at the 2 point level.
An example of a 2 point answer from the pre-test was:
“1) in eukaryotes, transcription occurs in the nucleus, translation in the cytoplasm
2) transcription produces RNA, translation produces strings of amino acids”

Examples of 2 point answers from the post-test ranged from:
“Transcription starts with DNA and produces RNA while translation starts with RNA and produces protein” to
“Transcription uses the enzyme RNA polymerase to synthesize RNA (mRNA, rRNA, tRNA). In translation, the ribosome (using tRNA as an adaptor molecule) uses mRNA to make protein.”

At the end of the semester, students had a very easy time coming up differences between transcription and translation, as evidenced by no 0 point answers and a majority of 2 point answers. The level of complexity of the 2 point answers also greatly increased.

**Mid-semester evaluations**

To get feedback on the SI sessions in general, I had the students fill out anonymous mid-semester evaluations after our second exam. The first question was “What do you find most effective about SI sessions?” There were numerous positive comments to this question, including:
“Helps to clear up any confusion and always summarizes the main points”
“Things are explained from a different perspective and goes at a slower pace than lecture”
“I find the small group format to be helpful in asking questions and understanding the material”
“Practice problems are great”

The comments from this question were all positive and it was helpful for me to see what the students were taking away from the sessions.

The second question was “How could SI sessions be improved to help your learning in this course?” Numerous responses indicated “Nothing” or “They couldn’t; the SI sessions are very helpful”. But several responses suggested that the students felt the sessions were too much like a lecture.
“Some of them are just a lecture – which isn’t always helpful”
“I want the AIs to encourage more student involvement during SI session. The SI sessions provide a better resource to students if they are less like lecture and more like a discussion.”

These comments were very helpful and struck home because I specifically wanted to run a student-centered classroom and didn’t want to lecture. As we covered more detailed material in the class lecture, I struggled to find a balance between covering the majority of the material with the time that it takes to do student-centered activities. These comments reminded me that it’s important to include interactive activities for student learning and that I had to make it a priority every week to balance content with collaborative scientific inquiry through problem-based learning, case studies, and interactive questions.

**Analysis of iPad Activities**

The comments from my mid-semester evaluations made me strive even harder to implement student-centered activities in the SI sessions and led me to develop and use the iPad exercises described in the implementation section above. The iPad questions were interactive on several levels – the students utilized and interacted with technology to think about biology, the students worked in groups to answer
the questions, and the entire class was involved as the iPad work was projected for the whole class to see. The two SI sessions in which we used iPads contained some of the most lively discussion that I had all semester long. In addition to facilitating discussion, they also gave me insight into what information the students knew and what they were struggling with. When we did iPad Question 1 in one of the SI sessions, the 2 iPad groups produced vastly different results. The 1st group got the complete question correct in the amount of time that I gave them. The 2nd group only got through about 50% of the question in the same about of time. Their answer is given below.

Below is a DNA coding strand:

\[ 5' \text{TAAGATGCCAATAGTCTTTGAAGCCTGACG} \ 3' \]

First, identify the correct reading frame and separate the codons in that reading frame with vertical lines.

Second, using the correct reading frame, translate the DNA sequence into the correct protein sequence.

When I saw this answer, I knew that the group was having problems in one of two areas – either in determining the correct reading frame or in determining the mRNA sequence from the DNA strand given. I asked them to explain which part of the problem they were struggling with, and they said they couldn’t remember if the mRNA was complimentary to the coding strand or the same sequence as the coding strand (except as RNA). They also said that once they saw the “ATG” in the coding strand sequence, they assumed that the mRNA was the same sequence as the coding strand and that is when they started writing out the RNA sequence. Seeing and discussing this answer really helped me understand what the students were having problems with and it also helped me see how they tried thinking about it when they were stuck. After finishing this question, we did 2 impromptu questions on the board covering DNA coding and template strands. I know this problem helped me see what the students were thinking, and I hope that it gave the students a concrete example in which to learn the material.

**REFLECTION**

One of my major goals this semester was to lead a student-centered classroom throughout the semester. This was consistently a struggle for me as I found myself falling back to a lecture-style whenever we had a lot of material to cover. However, I also feel that I never lost sight of my goal as I consciously thought of what kinds of interactive activities I could use in my classroom every week. Some of my most successful weeks, as deemed from the level of discussion in the classroom, involved doing case
studies and the iPad exercises. Even in weeks in which there were just a few group multiple choice questions, there was still some discussion and the students just didn’t sit still and listen to me for an hour. I also really noticed that the amount of discussion increased in the second half of the semester. I’m sure this had to do with the students getting comfortable with me and with their peers, but I also feel that it had to do with the activities and environment in the classroom. In fact, I had one student come up to me after the final exam and express that she really felt the SI sessions helped her in the class and that she came to them because they weren’t just a lecture and she felt comfortable asking questions in them.

Our class reading helped me greatly in my thinking about a student centered classroom because they stressed the benefits of such a teaching style (problem solving and critical thinking), and they also provided concrete examples in the forms of various Classroom Assessment Techniques (or CATs). As I move forward in my teaching, I am certain that I will build on the successful interactive activities that I used this semester and add some additional activities, in-class demonstrations, and CATs. In the future, I would like to do more in-class reflection on various activities to see what they students think about them. For example, I really wish I had asked for some written feedback after the iPad exercises.

My other major goal was to emphasize the skill of comparing and contrasting the concepts of DNA replication, transcription, and translation. I did this through several activities that brought all three processes together so the students had to think about them in parallel. The pre-/post-test analysis (multiple choice and short answer questions) showed that, over the course of the semester, students improved in their ability to correctly answer questions pertaining to all three subjects. My analysis of the post-test results by SI session attendance indicated that regularly attending the sessions slightly increased performance on the pre-/post-test questions compared to students who did not attend as regularly. This in encouraging, but I wish I had done a few other assessments to gauge my intervention. For example, I wish I had asked the professor to include one or two questions on the cumulative final that were similar to the questions from my “Case Study on the Central Dogma” so I could have analyzed the results of those questions based on student attendance of SI sessions.

Overall, I think I made great strides in emphasizing the processes of the central dogma and in utilizing student-centered activities in my classroom. One of the larger points that I took away from my emphasis on DNA replication, transcription, and translation is that, regardless of the specific topic, it is important to tie the current topic back to previously covered topics within the class so that students can see the interconnectedness both within and between Biology classes. I also know that I will use several of my student-centered classroom activities in future classes, and I look forward to trying out additional ones.

REFERENCES


APPENDIX I: SAMPLE SI WORKSHEET (2 PAGES)

DNA Polymerases in Prokaryotes and Eukaryotes

<table>
<thead>
<tr>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
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<tbody>
<tr>
<td>DNA Pol I</td>
<td>DNA Pol α</td>
</tr>
<tr>
<td>DNA Pol III</td>
<td>DNA Pol δ</td>
</tr>
<tr>
<td>DNA Pol ε</td>
<td>DNA Pol δ</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Processive</th>
<th>Major Purpose</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Apoenzyme = just core enzyme</td>
</tr>
<tr>
<td></td>
<td>Holoenzyme = apoenzyme together with all of its co-factors</td>
</tr>
</tbody>
</table>

**Question 1**
Which of the following statements is true?

a. DNA Pol III holoenzyme is not processive
b. DNA Pol III fills in the short gaps left after the RNA primer is removed
c. DNA Pol IV is responsible for DNA replication
d. DNA Pol I has proofreading activity

**DNA Sliding Clamp**
- Presence of sliding clamp is what gives DNA polymerases their processivity!
- Encircles double-stranded DNA and holds DNA polymerase onto the DNA at the primer:template junction
- On the lagging strand, once DNA pol reaches the end of an Okazaki fragment, it changes shape and is released
- Get into groups and describe the steps illustrated on the left for loading the sliding clamp

<table>
<thead>
<tr>
<th>DNA Sliding Clamp</th>
<th>问1</th>
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<td></td>
<td>a.</td>
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**Question 2**
What might happen if a mutation in the sliding clamp loader makes it unable to hydrolyze ATP?

a. The sliding clamp loader cannot bind the sliding clamp.
b. The sliding clamp loader cannot open the sliding clamp.
c. The sliding clamp loader cannot close the sliding clamp around DNA.
d. The sliding clamp loader cannot open its arms.
DNA Replication in E. coli

**Question 3**

Label the following parts of the replisome:

A. Helicase
B. Single stranded binding protein
C. DNA polymerase apoenzyme
D. Sliding clamp
E. Sliding clamp loader
F. Tau (τ) proteins
G. Leading strand
H. Lagging strand

- Helicase unwinds the dsDNA
- SSB coats the ssDNA (on both strands) to prevent it from base pairing
- Primase comes in and synthesizes a new primer on the lagging strand; once primer is synthesized primase is released
- Sliding clamp loaded onto lagging strand
- DNA pol associates with sliding clamp and synthesizes a new Okazaki fragment
- DNA pol is released from DNA sliding clamp after completion of Okazaki fragment

**Question 4**

In this picture, which event in DNA replication has just occurred?

- DNA helicase activity has just slowed down roughly 10 fold.
- A sliding clamp has just been loaded onto the leading strand.
- A sliding clamp has just been loaded onto the lagging strand.
- Single stranded binding protein has just coated the completed Okazaki fragment

**Outline of 3 core processes in the Central Dogma**

<table>
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<th>Template</th>
<th>DNA Replication</th>
<th>Transcription</th>
<th>Translation</th>
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<tbody>
<tr>
<td>Enzyme/Protein Complex used for Catalysis</td>
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<td>Direction of Synthesis</td>
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APPENDIX II: PRE-/POST-TEST

1) The template for DNA replication is which one of the following?
   a  DNA
   b  RNA
   c  Protein

2) The template for transcription is which one of the following?
   a  DNA
   b  RNA
   c  Protein

3) The final product of transcription is which one of the following?
   a  DNA
   b  RNA
   c  Protein

4) The final product of translation is which one of the following?
   a  DNA
   b  RNA
   c  Protein

5) Which one of the following statements about DNA replication is correct?
   a  DNA replication is initiated at the promoter.
   b  DNA replication involves a leading strand and a lagging strand.
   c  DNA replication is catalyzed by the ribosome.

6) Which one of the following statements about transcription is correct?
   a  In eukaryotic cells, transcription occurs in the nucleus.
   b  Transcription is terminated at the stop codon.
   c  Transcription is catalyzed by DNA polymerase.

7) Which one of the following statements about translation is correct?
   a  Translation is initiated at an origin of replication.
   b  RNA serves as the template for translation.
   c  During translation, RNA polymerase adds amino acids.

8) What are 2 differences between transcription and translation?