

POINT LOMA NAZARENE UNIVERSITY

Using Case Studies for High School Students'
Learning of Abstract Concepts in Molecular Genetics

A thesis submitted in partial satisfaction of the
requirements for the degree of

Masters of Science

in General Biology

by

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Abstract of Thesis

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Dr. April Maskiewicz, Chair

Disciplines such as law, business, and medicine have used case studies for decades to teach students about their field through comprehension, application, analysis, synthesis, and evaluation skills. The case study method involves learning by doing where students work through the problem of the case study to come up with possible solutions. Rarely has this technique been used in high school science. The aim of this study was to determine if a case study is effective in promoting conceptual change in high school students' understanding of molecular genetics (structure and function of DNA and proteins) when compared with traditional textbook-based instruction. A mixed methods approach was used which included a pre/post assessment and interviews. The results of the assessment revealed that case study instruction did promote conceptual change in the experimental group, but there was not a statistically significant difference when compared with the comparison group. However, when students were interviewed about their reasoning, students from the case study group were more verbal during their interviews and showed greater understanding of the relationship between DNA, proteins, mutations and resulting phenotypes. The mixed results of this study indicate the need for further research into case study instruction and assessment.

Introduction

One source of difficulty in learning certain concepts in high school biology is when those concepts are abstract and intangible to students. One such area of study that students find difficult to learn is molecular genetics. When learning genetics, students fail to understand the underlying processes that involve DNA and proteins. In my experience teaching high school biology for eight years, I have found that students do not appropriately understand or use molecular genetics to explain various genetic predispositions or phenotypes. In most classrooms, teaching strategies focus on standardized tests and students can be successful by just memorizing facts. Students rarely have to use reasoning skills or make connections between what is being learned in the classroom to real situations or to their daily lives. Research conducted with high school and college undergraduates showed that there were differences in the way that the students and teacher viewed the difficulties of learning genetics (Bahar, Johnstone & Hansell, 1999). The authors claim that it may not be so much the difficulty of the topic, but the way that the material is presented that adds to the difficulty of the subject matter.

Research has shown that one successful strategy for introducing abstract concepts so that students find relevance in the material is through problem based learning. Problem based learning is an instructional strategy that is used widely in medical schools. In the context of clinical situations, students are presented with a problem or scenario and are asked to work independently to solve the problem before meeting in small groups to discuss their findings. The end result is that students acquire new knowledge as well as communication skills, teamwork experiences, problem solving abilities, independent responsibility for learning, and respect for others (Wood, 2003). Presenting students with

the knowledge that they are required to learn through scenarios or situations makes it possible for students to find relevance in what they are learning and makes the information less abstract. It also provides a platform for students to use reasoning skills that are otherwise rarely used in the science classroom. Additionally, working in small groups can allow content to become more accessible to students as they discuss their thoughts and negotiate understanding.

The purpose of this research project is to study the effectiveness of problem-based learning for high school biology students through the use of a case study in molecular genetics. An embedded mixed methods design was used in which qualitative data was collected subsequent to a quantitative phase to explain or follow up on the quantitative data in more depth. Two biology classrooms of approximately 30 students each participated in this study. One class was presented with concepts in molecular biology, in particular DNA structure, protein synthesis, and phenotypic outcomes through traditional lecture and worksheets. The second class was presented, by the same teacher, with the same information through a case study. In the quantitative phase of the study, pre- and post- scores from multiple choice and short answer questions were collected. These scores quantitatively assessed the effect on student learning of molecular genetics when using a case study as an instructional strategy compared to traditional instruction. The qualitative phase was conducted in order to identify through interviews and written responses how students processed information by solving the case study and relating it to the study of molecular genetics (DNA structure and function, protein synthesis, expression of proteins). The qualitative data is used to explain the results of the intervention.

Theoretical Perspective

According to educational research, knowledge development is a social construct (John-Steiner & Mahn, 1996; O'Loughlin, 1992). What this means for science is that science information is shared through various networks of individuals and labs in various countries. Scientists do not isolate themselves from other scientists, but rather collaborate with other scientists to share practices and data, gain new knowledge, and build upon existing knowledge. In this environment there is interdependence between individual and social processes (John-Steiner & Mahn; 1996). Learning about scientific knowledge, especially abstract concepts like molecular genetics should be treated the same way in the classroom. Studies show that knowledge construction occurs through the sharing of ideas in collaborative groups where ideas are supported and or challenged by group members (Chang-Wells & Wells, 1993). Richmond and Striley (1996) also found that science learning is more than a product of student ideas; it is also a result of the way these ideas are introduced, debated, and accepted or rejected as a result of the interactions students have with one another. As such, education must be thought of in terms of transformation where socially shared activities are transformed into internalized processes that can be used in new contexts (John-Steiner & Mahn, 1996).

Literature Review

Significance of Learning Molecular Genetics

In a study conducted by Organisation for Economic Cooperation and Development (OECD) Programme for International Student Assessment (PISA) (2006), students in the United States have not shown any significant gains in science as compared to students in other countries in their study. Rutherford and Ahlgren (1989) insist that

scientific literacy is vital for students – or all humans for that matter – to develop the understandings and habits necessary to be able to decipher the world around them and become better problem solvers. Specifically, the importance of learning molecular genetics, biotechnology, and Mendelian genetics is illustrated by the interdependence of science and society (Sadler & Zeidler, 2004). Recent legislation has led to the removal of barriers to stem cell research and has thus reinvigorated the need to understand the science and decision making involved with new scientific investigation. Decisions about stem cell research, cloning, transgenic organisms, and other modern technologies rely heavily on one's knowledge and understanding of genetics (Tsui & Treagust, 2007). As medical research and other scientific discoveries advance, so does the need for students to understand molecular genetics so that they may make more informed decisions that will affect both them and future generations.

Student Difficulties in Learning Molecular Genetics

Several studies have shown that students have difficulty with understanding genetics concepts (Bryce & Gray, 2004; Duncan & Reiser, 2007; Johnstone & Mahmoud, 1980; Marbach-Ad & Stavy, 2000; Marbach-Ad, Rotbain, & Stavy, 2008). One of the reasons that studying molecular genetics is difficult for students is the invisibility and inaccessibility of genetic phenomena (Duncan & Reiser, 2007). In addition, Tsui and Treagust (2003) explain genetics as a difficult concept because of the different levels of thought that are required to understand the concepts. Understanding genetics requires students to traverse macro, micro, and symbolic levels of thought all at once (Johnstone, 1991; Mbajiorgu, Ezechi, & Idoko, 2007; Tsui & Treagust, 2003, 2004). An example of the macro level is the visible phenotype or what is observable in organisms. The micro

level is the genotype or cellular level where students may be able to observe structures like chromosomes through microscopes, but not genotypes. Lastly, through symbols for alleles, the student can represent the particular gene using capital and lower case letters for the trait in question. What adds to the difficulty of symbolic representations is that some teachers fail to use mathematical or symbolic representations consistently (Bahar, Johnstone, & Hansell, 1999; Topcu & Sahin-Pekmez, 2009). Students can learn to manipulate these symbols in Punnett squares, but the symbols may not have any meaning for the student. In other words, it is possible that a student would not understand the biology behind the Punnett squares even though he could complete the problems correctly. Marbach-Ad and Stavy (2000) found that students struggle with distinguishing the three levels of thought when they are taught simultaneously. Kaptejin (1990) adds that in order for students to have a better understanding of macroscopic phenomena, they have to understand concepts at both the cellular and biochemical levels and recommends that students be exposed to learning activities that target the integration and not separation of the different levels.

Duncan and Reiser (2007) provide another explanation for the difficulty students have when learning molecular genetics: ontological differences between levels of genetic phenomena make learning genetics difficult. According to Duncan and Reiser, there is a physical and informational level that must be understood when learning molecular genetics. Simply stated, one needs to understand the nature of the informational content, the way in which information is revealed in specific physical elements of the system, and the physical mechanisms involved in bringing about the information's ultimate effects. For example, genes are the informational units that determine the structure of proteins by

specifying the order of amino acids within the protein. The structure of the protein in turn determines its function. This might present difficulties for learners because the physical entities, such as the genes and proteins, fall within the micro level of thought that is not readily observable by students, resulting in difficulty grasping the informational content.

Another proposed explanation for the difficulties students have in learning biology focuses on student world views. Students often come to class with nonscientific presuppositions stemming from culture, pop culture, and underlying philosophical or theoretical principles (Mbajiorgu, et. al., 2007). Within each community there exists a particular view of the world that is strongly held and influences the way its members think and act. In turn, these views are used to explain natural phenomena. Mbajiorgu et. al. (2007) found that students could explain the scientific principles involved in a scientific phenomenon, but the students would then return to non-scientific presuppositions to explain the phenomena itself or to solve a problem. For example, students in several African communities explain a disease, such as sickle cell or albinism, by kinship, but when describing how the disease continues to spread or treatments for the disease, students often make reference to spiritual beliefs (Mbajiorgu et. al., 2007; Nzewi, 2001; Okoro, 1975). Thus, nonscientific presuppositions must also be addressed in order for knowledge construction in molecular genetics to occur.

Molecular Genetics

Molecular genetics involves the study of the central dogma (DNA → mRNA → protein) which describes the structure and function of genes at the molecular level. DNA contains the information, in small coding regions called genes, for cells to construct proteins. These proteins, in turn, shape the phenotype of the organism, as coded by the

DNA. In order for cells to construct proteins, they must perform two processes, transcription—which converts information in DNA to messenger RNA—and translation—which takes information from the mRNA and assembles the primary structure of the protein at the ribosome. Every cell, except for the gametes, in a single organism contains all of the genetic information needed to make all of the proteins, but not every cell makes every protein. Cells only transcribe the genes into proteins that are required for their specific function, hence why a specialized skin cell does not function as a kidney cell.

Depending on the type that occurs, mutations in genes may or may not affect the structure and function of proteins. When the protein structure is affected, the function of the protein may be compromised resulting in an abnormal phenotype. Mutant alleles on chromosomes can be inherited from parents as a result of meiosis and fertilization or they can randomly occur during DNA replication or transcription. In the case of genetic disorders, an individual might inherit one copy of the mutant allele and be considered a carrier of that allele. In order for the genetic disorder to physically appear in an individual, the individual must inherit two copies of the mutant alleles, one from each parent if the disorder is recessive. If the genetic disorder is dominant, only a single mutant allele is required to result in the disorder.

Students' Alternative Conceptions of Molecular Genetics

As a result of the difficulties in learning molecular genetics, students often harbor alternative conceptions about DNA, proteins, and resulting phenotypes. A number of research studies have identified several recurring alternative conceptions about molecular genetics that biology students hold. One alternative conception is that students do not

understand the physical relationship between DNA, chromosomes, and genes (Duncan & Reiser, 2007; Friedrichsen & Stone, 2004; Lewis, 2000). In a study by Friedrichsen and Stone (2004), when students were asked to draw DNA, chromosomes, and genes, a majority of the students could not draw or identify components of the structures even if they were able to draw basic representations of them. Also, when asked to explain the relationship between DNA, genes, and chromosomes, one student indicated that a gene was located on the rungs of the DNA ladder. A number of students also explained that all chromosomes were either X or Y.

Another common alternative conception among students is that specialized cells only contain the genes necessary to perform their functions. The correct concept is that all cells, except for the gametes, contain the entire genome and only the required genes are transcribed into proteins and all other genes are inactivated (Duncan & Reiser, 2007; Friedrichsen & Stone, 2004). Duncan, Freidenreich, Chinn, and Bausch (2009) found that students explained genes as passive entities that coded for their traits. This explanation leaves out and circumvents the need to explain the mechanism for how the proteins are made that bring about observable features.

Topcu and Sahin-Pekmez (2009) identified difficulties in students' ability to explain functions of genetic structures and size relationships. Additionally, the students were not able to explain how genetic information was transferred. Friedrichsen and Stone (2004) also found that students had difficulties with size relationships or scale changes between DNA, chromosomes, and genes. One student reported that the pictures of DNA were always enlarged to show it much larger than chromosomes and that when they drew chromosomes, they were always drawn small. Topcu and Sahin-Pekmez (2009) and

Friedrichsen and Stone (2004) both recommend that teachers use multiple tools, such as animations, tutorial games, and simulations to provide more accessibility and visibility of genetic concepts. An alternative approach, although not widely studied, is to help students develop a scientific understanding of molecular genetics and other abstract science concepts through the use of problem based learning.

Problem-based Learning

Problem-based learning (PBL) is an instructional strategy that was first developed in the 1960's for medical school education so that medical students would be prepared to deal with new information, think critically, and solve complex problems (Major & Palmer, 2001). Today it has been widely applied in multiple settings such as allied health professions and various high school topics. PBL uses complex problems that serve as the context and stimulus for learning (Major & Palmer, 2001; McParland, Noble, & Livingston, 2004). As students try to solve ill-structured problems, they have opportunities to interact with their environment (Araz & Sungur, 2007). An ill-structured problem is one that lacks the necessary information to develop a solution, mirrors real world situations or problems, and is often open-ended. The problem itself can have multiple solutions and even as information is gathered, the definition of the problem may change (Chinn & Chia, 2004), leading students to actively participate in their own learning. Thus, ill-structured problems provide opportunities for students to assume the roles of scientists as they assess what they know, identify what they need to know, gather information, and collaborate with others to reach a justified argument for their solution (Stepien & Gallagher, 1993). In contrast, a well-structured problem presents students with all the elements of a problem with the goal of yielding a known solution. Well-

structured problems are the most frequent types of problems found in textbooks, and a set of well-defined parameters and principles are applied to solving a well-structured problem. When solving well-structured problems, students rarely access their alternative conceptions as they search the textbook or their notes for answers. The advantage of PBL is that it utilizes ill-structured problems that orient students towards meaning-making over fact collecting (Rhem, 1998), which in molecular genetics, can aid students in making connections between different thought levels.

Another aspect of PBL that promotes conceptual change is the use of collaborative groups. During collaborative group work, students can acquire new knowledge and restructure existing knowledge as individuals with different viewpoints, experiences, and level of knowledge engage in testing, reconciling, and eventually coming up with a new shared understanding of a particular topic (Cockrell, Caplow, & Donaldson, 2000). In PBL, students are typically divided into small groups, and if properly facilitated, the members of the group work together to define the learning issues and decide how to approach the problem in order to find a solution. Blumenfeld, Marx, Soloway, and Krajcik (1996) suggest that in order for collaborative groups to result in positive learning outcomes, close attention must be paid to group norms, tasks, social and academic structure of group members, and the skills to be learned. Another important role within the collaborative group setting is the role of the instructor as a facilitator or coach. Dori, Tal, and Tsaushu (2003) revealed that when instructors encouraged students to express their opinions and maintained class discourse, students of various academic levels improved in their higher order thinking skills, knowledge, and understanding of

biotechnology. The authors also concluded that this action promoted students' scientific literacy and interest.

Araz and Sungur (2007) have shown that achievement and performance skills scores for students studying genetics through PBL were higher than students taught through traditional instruction. Their study also demonstrated knowledge through social negotiation. Social negotiation happens when students working in small groups take alternative points of view and strategies into consideration to construct new knowledge and then apply that knowledge to new areas. McParland, Noble, and Livingston (2004) found similar achievement results in psychology students when comparing traditional and problem-based learning settings. However, they caution that different subject areas may produce different results.

Benefits of Using a Specific Type of PBL: Case Studies

Zohar and Nemet (2002) claim that retention, understanding, and the active use of knowledge can be brought about only by learning environments in which learners are encouraged to be active thinkers about what they are learning. Case studies are a class of PBL strategies that involve students in active thinking by giving them a part to play in the case. The teacher presents the learner with a problem that involves characters with problems that mimic real life scenarios. These scenarios can address students' conceptual understandings, ability to pose questions, critical thinking ability, and even motivation. An example of a case study is one that uses a fictional story about a couple that wants to identify the cause of a disease in their child. Students assume the role of an outside consultant to determine the cause of the child's disease. To solve the case, students take on the responsibility of understanding or explaining a particular process or entire concept,

and this activity can facilitate conceptual understanding. Case studies can also reinforce the idea that there is interdependence between science and society, and can involve ethical issues and values that motivate students to engage in the problem and improve higher order thinking skills (Dori, et. al., 2003). More importantly, the content to be learned is put into a context that makes more sense to students as opposed to the traditional textbook approach where a series of arbitrary facts limits students' ability to traverse macro, micro and symbolic levels of thought.

There are databases available that provide examples of case studies for the purpose of learning science, for example the National Center for Case Study Teaching in Science. However, there are only a few cases developed for high school students that address genetics and rarely do they address the concepts of DNA, protein synthesis, mutations, and resulting phenotypes. In a study by Friedrichsen and Stone (2004), the researchers used a case study pertaining to sickle cell syndrome to specifically address how mutations affected proteins. Additionally, Dori, et. al. (2003) used case studies to teach biotechnology. Existing research on using case studies do not, however, specifically address the effect that they might have on students' understanding of molecular genetics. Therefore, the application of problem based learning to molecular genetics should afford students the opportunity to learn through the sharing of knowledge from one individual or group to another. The case study presented to the students in this study was developed to afford them the opportunity to share ideas with each other in order to gain a better understanding of the material. The students worked in collaborative groups to solve ill-structured problems based on real-life situations with the intent that each group member would, in some way, contribute to the clarification and explanation of the concepts to be

learned by all the members of the group. As they solved the case study, students taught each other about molecular genetics. Meanwhile the instructor served as a facilitator, intervening only to bring focus back to the problem at hand. The purpose of my study was to investigate high school students' learning after solving a case study relating to molecular genetics. Specifically, my goal was to answer the following questions:

1. Can a case study effectively promote conceptual change in high school students' understanding of molecular genetics (structure and function of DNA and proteins)?
2. Is a case study more effective than traditional textbook-based instruction in helping students apply their understanding of molecular genetics to new or unfamiliar contexts?

Methodology

Mixed Methods Approach

This study was conducted using a mixed-methods embedded experimental design (see Figure 1) where the qualitative data provided support for the quantitative data (Creswell & Clark, 2007). Because the purpose of this project was to assess the effectiveness of case studies on students' learning of molecular genetics, students' understanding of the subject matter was determined before and after the instruction. The qualitative data, in the form of interviews and recorded student discussions, was embedded within the experimental design and aided in the examination of the effectiveness of the case study intervention by elaborating on student responses to the pre- and post-assessment.

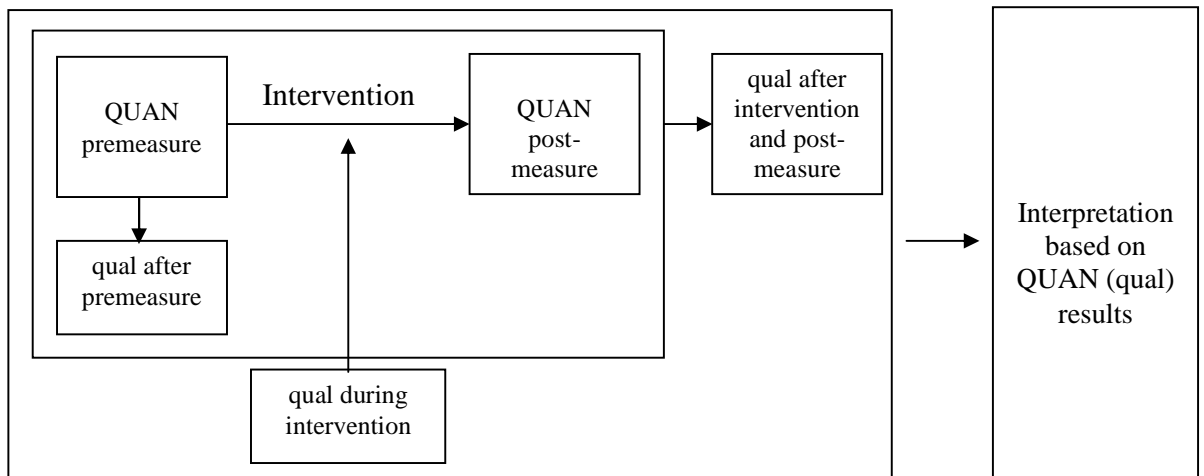


Figure 1. Embedded Experimental Design

Participants and Setting

This study was conducted in a growing suburban high school in Riverside County during the 2009-2010 school year. Based on the 2010 School Accountability Report Card, there were a total of 3,121 students enrolled in the school. Table 1 below provides a breakdown of the school’s population by ethnicity. The high school’s base API score for the 2009-2010 school year was 814 with a statewide API of 8 and a similar schools rank of 7. The school’s graduation rate was at 96% with 94.5% completing all high school graduation requirements. Science classes had a student to teacher ratio of 30.4:1.

Table 1
Breakdown of 2009-2010 student enrollment

Student Enrollment by Ethnic Group 2009-2010	
White	49%
African American	7%
American Indian or Alaska Native	1%
Asian	3.97%
Filipino	6%

Hispanic or Latino	29%
Native Hawaiian/Pacific Islander	0.77%

There were approximately 59 students, ages 14-17, from two biology classes that participated in the overall instruction, either lecture-format or case study, but only six students—three from the comparison group and three from the experimental group—were used for the pre- and post-interview portion of the study. All participants were currently enrolled in a year-long high school biology course taught by myself. A majority of the students that participated were at the 9th grade level (54/59, 91.5%) and had already completed a unit in Mendelian genetics. The two classes were assigned to either the comparison group or experimental group. This study was approved by the Point Loma Nazarene University Institutional Review Board (Appendix A).

Quantitative and Qualitative Data Collection

Overview. This study compared the learning in one biology class (comparison group, n=29) presented with traditional instruction to another biology class (experimental group, n=30) receiving problem-based learning instruction. Prior to the unit of instruction, all students were given a pre-assessment consisting of five multiple choice questions, a label the diagram question, and four open-ended questions that were generated by myself and other biology colleagues (see Appendix B). One of the open-ended response questions required that students use problem-solving skills to answer the question. Following instruction, students took the same assessment as a post-test.

In addition to the assessment data, semi-structured interviews were conducted both before and after instruction. Prior to the instructional intervention, three students

from each class were interviewed to provide further insight into students' conceptual understanding and to clarify responses to open ended questions (see Appendix C). The interviews were recorded and then transcribed for analysis. The same students were again interviewed after the post-assessment. The purpose of the post interview was to identify any recurring alternative conceptions, clarify responses to open-ended test questions, and to identify how instruction may have influenced conceptual change. All interview subjects had given permission for their interviews to be used as data in this study (see Appendix D).

During the instructional time, additional qualitative data in the form of recorded small group or class discussions was also collected. These recordings were carefully analyzed to look for any evidence that could support or refute the use of case studies in teaching molecular genetics. The intent was also for the recordings to provide information about student engagement and/or reasoning that may not have come up during the post-test interviews. After listening to the recordings, however, the data was not analyzed because a majority of the conversations involved student sharing their answers and repeating definitions to terminology.

Classroom Instruction

The intervention took place over a one week period for both classes (approximately 5 hours of instruction) midway through the second semester of the school year. The comparison group received traditional instruction in the form of lectures and worksheets, while the experimental group received instruction in the form of the case study which was adapted from Dion, Allen, and Duch (1998) (see Appendix E for

summary of the case study). The learning objectives for both groups are summarized below:

- Describe the structures and functions of DNA, chromosomes, genes, mutations
- Explain the relationship between DNA, chromosomes, genes, mutations, and traits
- Explain why different cells have the same DNA but have different proteins and functions.
- Explain how a mutation could lead to a particular phenotype
- Explain how offspring could obtain mutations from carrier parents

Experimental group. On day 1, students in the experimental class were placed into small groups and presented with the case study. The students were assigned to small groups of three or four based on their grades. Each group had at least one high, low, and average achieving student. Students were asked to read the case study, discuss the story with their group, and generate questions about the case study story that may have needed further research. They were also asked to create a list of terminology that they were unfamiliar with. On the second day of instruction, these students were given time in the computer lab to research their questions. The instructor also provided a few focus questions that students had not generated the day before to redirect students towards the learning objectives (Appendix E). One focus group, consisting of students that had given permission for data collection, was audio recorded during their work in small group discussions. Whole class discussions were conducted on the following days and audio recorded.

Comparison group. During the same week, students in the comparison group received traditional instruction in the form of short 15-20 minute lectures and worksheets that outlined the information in the textbook for the rest of the class period. Each day, students were provided lecture notes on one of the following topics: the structure and

function of DNA, protein synthesis, mutations, or biotechnology. A summary comparing the instructional week for both the comparison and experimental group is shown in Table 2 below. To address group work as being a possible second variable in addition to the difference in instructional approaches, students in the comparison were also allowed to complete their worksheets in small groups.

Table 2

Summary of instructional week for comparison group and experimental group

	Comparison Group	Experimental group
Day 1	<ul style="list-style-type: none"> ▪ Notes on S/F of DNA ▪ Worksheet chapter 11.1 	<ul style="list-style-type: none"> ▪ Students independently read case study ▪ Small group discussion with focus questions
Day 2	<ul style="list-style-type: none"> ▪ Review previous day's work ▪ Notes on protein synthesis ▪ Worksheet chapter 11.2 	<ul style="list-style-type: none"> ▪ Review previous day's discussions ▪ Computer lab research
Day 3	<ul style="list-style-type: none"> ▪ Review previous day's work ▪ Notes on mutations ▪ Worksheet chapter 11.3 	<ul style="list-style-type: none"> ▪ Review research from computer lab. ▪ Discussion about DNA and protein synthesis
Day 4	<ul style="list-style-type: none"> ▪ Review previous day's work ▪ Notes on biotechnology ▪ Worksheet chapter 13 	<ul style="list-style-type: none"> ▪ Discuss genetic engineering and screening of diseases ▪ Small group discussion on final conclusions
Day 5	<ul style="list-style-type: none"> ▪ Review previous day's work 	<ul style="list-style-type: none"> ▪ Whole class discussion, tie up loose ends

Data Analysis and Statistical Procedures

Quantitative. Both pre- and post-assessments were coded to identify the concepts students understood as well as misunderstandings and alternative conceptions regarding DNA, protein synthesis, and resulting phenotypes. Once the test had been administered, one of the open-ended test questions was not counted in student test scores due to the difficulty of the question as surmised by the lack of student responses. Also, one part of the diagram question was not counted because it was not addressed by the

intervention. The remainder of the test was scored with each multiple choice question worth one point and each correctly labeled part of the diagram (three parts) worth one point; no points were given for incorrect responses. The open ended questions were scored based on a rubric created by myself and verified with another biology teacher. Any discrepancies were discussed and negotiated to at least 90% reliability. See Table 3 for an example of how question 9 was coded and see Appendix B for additional open-ended questions. The three open-ended questions that were counted in the students overall score were worth a total of 15 points.

Table 3
Coding scheme and example of points assigned to open-ended questions for pre- and post- test scores

Points Possible	<u>3 points</u>	<u>2 points</u>	<u>1 point</u>
	All statements were scientifically accurate with the correct answer included (Scientific understanding)	Some statements were scientifically accurate but the answer was unclear or inaccurate (Mixed understanding)	Most statements are not scientifically correct (Informal/Naïve understanding)
Question 9: What is the relationship between genes and proteins	Genes code for proteins; instructions for assembling proteins	Different genes cause different proteins, genes make proteins	Proteins build up/are in genes

The first open-ended test question asked students to explain the relationship between DNA and mutations, and genes and mutations (3 points). The second question asked students to explain the relationship between genes and proteins (3 points). The final question asked students to apply their knowledge of DNA, genes, proteins, and mutations (9 points). This question was similar to the problem found in the case study where students were asked to identify how the trait in question was inherited, how the mutation could have caused the phenotype of the individual, and how an individual might be able

to identify the presence of the disorder. The test was worth a total of 23 points (15 points short answer and 8 points multiple choice and diagram label).

The pre-test scores for the two classes were statistically compared with the expectation that there was no significant difference between the two groups of students. After instruction, statistical analysis was performed on the pre-and post-test scores within and between each class to determine if case study instruction and/or traditional instruction had any significant difference on knowledge construction. Post-test score differences between the comparison and experimental group were also analyzed. A paired *t*-test was used to compare the pre- and post-test scores within the comparison and experimental class. Pre- and post-test scores between both groups were compared using the two-tailed *t*-test assuming unequal variances. Gains for each student were then also calculated and compared with a *t*-test, however, there is a limitation when statistically comparing raw gains. Consider, for example, student A who scores a 15/23 on the pretest and 20/23 on the post-test, resulting in a gain of five points. Suppose student B scores 5/23 on the pretest and 10/23 on the post-test also resulting in a gain of five points. Because both students had a gain of five points, it appears that their learning improved by the same amount which may not figure to be statistically significant. Student A actually has a greater gain because she had less room for improvement and raw gains do not take this into account. Therefore, in addition to calculating student gain, normalized gain (Hake, 1998) was also calculated to provide a clearer picture of each student's improved content knowledge. Normalized gain is defined as the change in score divided by the maximum possible increase (Coletta & Phillips, 2005).

$$g = \frac{\text{Posttest} - \text{Pretest}}{\text{Max Possible Score} - \text{Pretest}}$$

Normalized gain takes into account differences in student population and guessing on a test and measures the fraction of the available improvement that can be gained (Stewart & Stewart, 2010). By using normalized gain, student A in the example above had a normalized gain score of $g = 0.71$ which means that she improved her content knowledge by 71% of the total possible improvement. Student B had a normalized gain score of $g = 0.27$, which shows that he improved his content knowledge by 27% of the total possible improvement. This tells us that student A had a greater gain of content knowledge from the pre-test to the post-test than student B.

Qualitative. Three students from each group, comparison and experimental, were interviewed after the pre-tests, but before the intervention. The interviews served as a means to understand and identify students' alternative conceptions about DNA, proteins, genes and mutations. During each interview, the student was asked to explain his or her reasoning behind each answer provided on the pre-test. After the intervention, students were once again given the same assessment and interviewed to identify any enduring alternative conceptions about DNA, proteins, genes, and mutations or any newly formed ideas.

The interviews were transcribed and Table 4 describes the rubric that was designed by myself and verified by another biology teacher to produce a score for student responses. Discrepancies in scoring student responses from the interviews were also discussed and negotiated to at least 90% reliability. A 5-point rubric (0-4 points) was used in order to distinguish between responses that were considered to have a high degree of mixed reasoning (3 points) and a low degree of mixed reasoning (2 points). A score of four was given for responses that included all scientifically accurate statements and the

correct answer. A three or high-mixed response was scored as such when a student provided the correct answer but may have used an incorrect scientific statement to explain their answer. A two or low-mixed response indicated that some of the statements were scientifically correct yet the answer to the question was unclear in their explanation. A one was given for responses that were not scientifically accurate or where students restated their answer from the assessment. A zero was given for no response or when a student responded with “I don’t know”.

Table 4

Scoring rubric for interviews with example student responses for question 8. Italicized phrases are provided by the researcher and are included in the rubric because there was no available student response

Points Possible	4 – All statements are scientifically accurate. Correct answer is included	3 – Correct answer is included, but some statements are not scientifically correct (high-mixed)	2 – Some statements are scientifically accurate, but correct answer is not clear or accurate, or does not provide an explanation for their answer (low-mixed)	1 – Most statements are not scientifically accurate	0 – Does not answer question, No Response or “I don’t know”
Interview Questions: Please explain why you chose your answer. Explain this term or concept.					
Question 8: What effect will a mutation have on a gene? On DNA?	<i>A mutation may result in a gene with a different coding sequence which may positively or negatively affect the protein structure it codes for. For DNA, a mutation can result in a change in single base or several bases,</i>	A mutation may alter a gene and hence changing the trait that expresses it. A mutation can alter only one base, um nitrogen base, which can alter the whole sequence into different DNA	The mutation could cause the physical appearance to change. It could cause a frameshift mutation, deletion, insertion, and translocation mutation, which could mess up the order of the nitrogen bases	It just basically could give a new ability, a new adaptation it gets from the mutation. It could rearrange everything in it, in the DNA structure	I don’t know I remembered you said...

	<i>coding for a different amino acid or the same one. Student may list and explain effect of different types of mutations</i>				
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Student responses were scored based on their entire response or explanation of each question on the test. Question 10 was counted as three separate questions because it was a three part question (12 points). The interview was worth a total of 48 points (36 points for questions 1-9 and 12 points for questions 10). Pre- and post-interview scores for both groups of students were compared by calculating normalized gain.

Results

Quantitative Results

The comparison group consisted of 29 students that completed both the pre- and post-test. With the test worth 23 points, students in the comparison group showed an average gain from pre to post of 3.41 points. This improvement was statistically significant ($t(28) = -5.09, p=0.00002$ (two-tailed)) (See Tables 5 and 6). The average normalized gain between the pre- and post-test was 0.22, indicating a 22% increase in understanding of content knowledge after instruction.

The experimental group consisted of 30 students that completed both the pre- and post-test. They showed an average gain from pre to post of 3.43 points ($t(29) = -6.19, p=0.0000009$ (two-tailed)) (See Tables 5 and 6). The average normalized gain between

the pre- and post-test was 0.24, indicating a 24% increase in understanding of molecular genetics.

Table 5
Summary of the means, standard deviation, gains, and normalized gains for the comparison and experimental group

	Count	StDev		Mean		Gain Mean	Normalized Gain Mean
		Pre	Post	Pre	Post		
Comparison Group	29	2.57	4.5	6.66	10.07	3.41	0.22
Experimental group	30	3.62	3.96	8.70	12.13	3.43	0.24

Table 6
Summary of t-values, degrees of freedom, and p-values for within group pre- and post-test

	<i>t</i> (two-tailed)	df	<i>p</i> value
Comparison Group	-5.09	28	0.00002*
Experimental group	-6.19	29	0.0000009*

* $p < 0.05$

Comparison of the pre-test scores between the comparison group and the experimental group revealed a statistically significant difference between the groups prior to instruction. The comparison group scored lower on the pre-test ($t(52) = 2.51, p=0.02$) (See Table 7) suggesting that they came to the class with less understanding than the experimental group. Because the two groups were not comparable at the onset of the study, difference scores (actual gain) and normalized gain scores were used to compare the progress of both groups.

Table 7
Summary of t-value, degrees of freedom, and p-value between groups

Comparison vs. Experimental	<i>t</i> (two-tailed)	df	<i>p</i> value
Pre-Test	2.51	52	0.02*
Post-Test	1.87	56	0.07
Gain	0.02	55	0.98
Normalized Gain	0.35	56	0.72

* $p < 0.05$

The comparison of the normalized gain of both classes resulted in no statistical difference between the two groups ($t(56) = 0.35, p = 0.72$). Though both groups appeared to have gained content knowledge as demonstrated in Tables 5 & 6, the experimental group did not appear to have a significantly greater gain than the comparison group (See Table 7).

Multiple choice. Table 8 and Figure 2 describe the percentage of students from both the comparison group and the experimental group who answered questions 1-5 correctly on the pre and post-test. These questions provide a comparison of which concepts the comparison and experimental groups understood well or still had difficulty with. Students from the experimental group demonstrated an increase in the percentage of correct responses for questions 1-5. In the comparison group, the percentage of students answering correctly increased for questions 1, 2, and 4. The experimental group answered correctly 5-25% more often than the comparison group on all 5 questions.

Table 8

Percentage of correct answers for students in comparison group and experimental group for pre- and post-test questions 1-5

	Question 1		Question 2		Question 3		Question 4		Question 5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Experimental group										
# Correct responses	8	20	13	19	19	21	12	28	25	26
Total # responses	30	30	30	30	30	30	30	30	30	30
% Correct	26.7	66.7	43.3	63.3	63.3	70.0	40.0	93.3	83.3	86.7
Comparison Group										
# Correct responses	8	15	10	17	15	14	18	20	22	22
Total # responses	29	29	29	29	29	29	29	29	29	29
% Correct	27.6	51.7	34.5	58.6	51.7	48.3	62.1	69.0	75.9	75.9

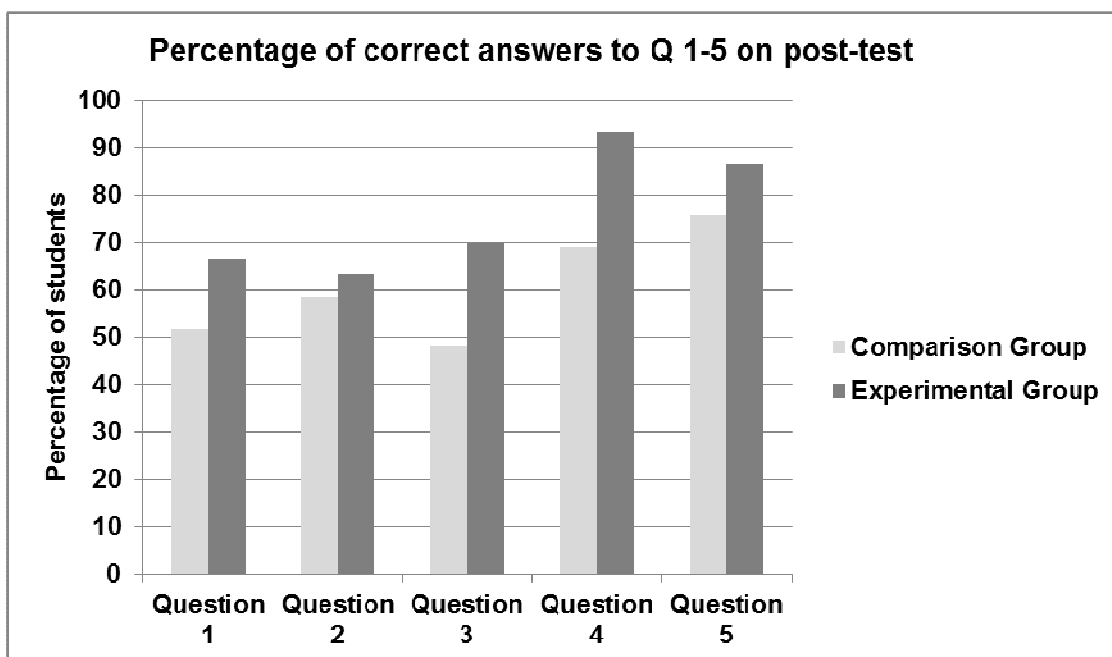


Figure 2. Percentage of students from comparison and experimental group with correct responses to questions 1-5.

Question 7. For question 7, students were asked to label DNA, chromosome, gene, and nucleotide on Figure 3. Nucleotide was not included in the quantitative data analysis because it was not specifically addressed during instruction and very few students correctly labeled it on the test. A majority of students from both classes were able to correctly identify DNA and chromosome on the diagram before and after instruction (see Table 9). Prior to instruction both groups had difficulty with identifying gene on the diagram. Even after instruction only five students (16.7%) from the experimental group and four students (13.8%) from the comparison group correctly identified gene, indicating that students did not have a clear understanding of what a gene is and how it is related to DNA. A common alternative conception that persisted among the students was labeling the nitrogen bases or the base pairs as gene.

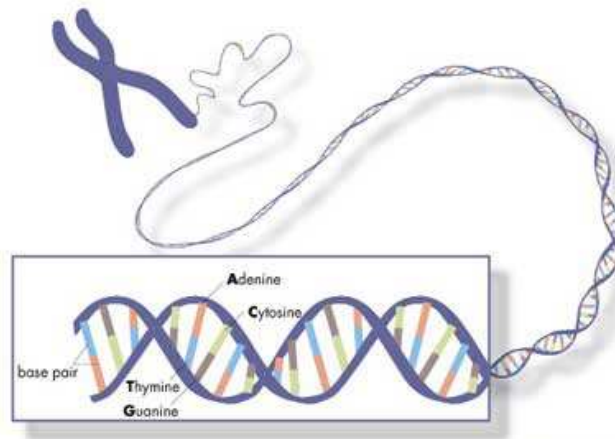


Figure 3. Labeling diagram for question 7

Table 9

Percentage of students correctly identifying chromosome, DNA, and gene for question 7

	Pre-Test			Post-Test		
	Chromosome	DNA	Gene	Chromosome	DNA	Gene
Experimental group						
# of Correct	27	28	2	25	29	5
Total responses	30	30	30	30	30	30
% Correct	90.0	93.3	6.7	83.3	96.7	16.7
Comparison Group						
# of Correct	28	25	5	26	25	4
Total responses	29	29	29	29	29	29
% Correct	96.6	86.2	17.2	89.7	86.2	13.8

Open-ended questions. Analysis of the open-ended questions revealed that the experimental group performed slightly better than the comparison group students. The experimental group had a higher point average out of the 15 points possible (6.4 compared with 4.9). Analysis of question 8, which asked how a mutation would affect DNA and a gene, and question 9, which asked for the relationship between genes and proteins, resulted in the data presented in Table 10. Note that there was a large proportion of students that did not answer either question on the pre-test. After instruction, there were fewer students from both groups leaving the questions blank; however, there was

still a large proportion of students with informal understanding (1 point), especially for question 9 (comparison group 65% and experimental group 57%). This data shows that both groups had difficulty with the concept of the relationship between genes and proteins. Only 21% of the comparison group, while 16% of the experimental group, held mixed or scientific understanding. A common misconception held by students was that proteins build or make genes.

Table 10
Percentage of students with informal, mixed, and scientific understanding for questions 8 and 9

	1 point – Informal/Naïve Understanding		2 points - Mixed Understanding		3 points - Scientific Understanding		No response	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Question 8								
Comparison Group	48%	34%	20%	45%	0%	7%	31%	17%
Experimental group	37%	27%	33%	56%	7%	10%	23%	7%
Question 9								
Comparison Group	48%	65%	10%	14%	0%	7%	41%	14%
Experimental group	40%	57%	10%	3%	0%	13%	50%	27%

The percentage of students responding to question 10 with informal, mixed, and scientific understanding is summarized in Table 11. Even after instruction, less than 50% of the students in the comparison group answered question 10a compared to 30% of the experimental group. Students with mixed understanding correctly identified the parents as carriers, but did not complete the pedigree or Punnett square correctly, or students generated a Punnett square or pedigree without any explanation of the inheritance pattern. Question 10b asked students to explain how a mutation could result in the phenotype of the individual in the vignette. The experimental groups performed slightly better than the comparison group on this question. Although, it appears that the comparison group had greater improvement on this question in terms of more students improving to have mixed

understanding. The written responses for students with mixed understanding explained that the mutation changed the gene and that led to the inability to digest lipids, not explaining that that the mutation in the gene resulted in a dysfunctional protein. Students in both groups had difficulty relating gene to protein to phenotype. Question 10c asked students to explain how a mutation could be identified in an individual. Two common responses were given by each group. The first commonly given response was “you could get tested,” which was a general statement and was awarded one point. The other commonly provided response was to have genetic testing done or check the DNA sequence, which was given three points for scientific understanding. There were more students in the experimental group that were able to provide a scientific answer to question 10c than the comparison group. At least one-third of the students from each class did not respond to question 10 on the post-test; however, there were a greater percentage of students in the comparison class than the test class that did not respond to the three part question. Figure 4 summarizes the data between the comparison and experimental group for question 10 showing a greater percentage of students in the experimental group with mixed or scientific understanding than the comparison group. Another difference apparent in the graph is that there was a greater percentage of students in the comparison group with informal/naïve understanding for all three parts of question 10.

Table 11

Percentage of students in the comparison and experimental group with informal, mixed, and scientific understanding for question 10

	1 point - Informal/Naïve Understanding		2 points - Mixed Understanding		3 points - Scientific Understanding		No response	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Question 10a								
Comparison Group	10%	28%	7%	14%	0%	7%	83%	51%
Experimental group	17%	20%	30%	47%	7%	3%	46%	30%

Question 10b	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Comparison Group	7%	31%	3%	21%	0%	7%	90%	41%
Experimental group	13%	27%	27%	33%	0%	7%	60%	33%
Question 10c	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Comparison Group	7%	28%	3%	14%	0%	7%	90%	51%
Experimental group	23%	17%	10%	0%	10%	40%	47%	43%

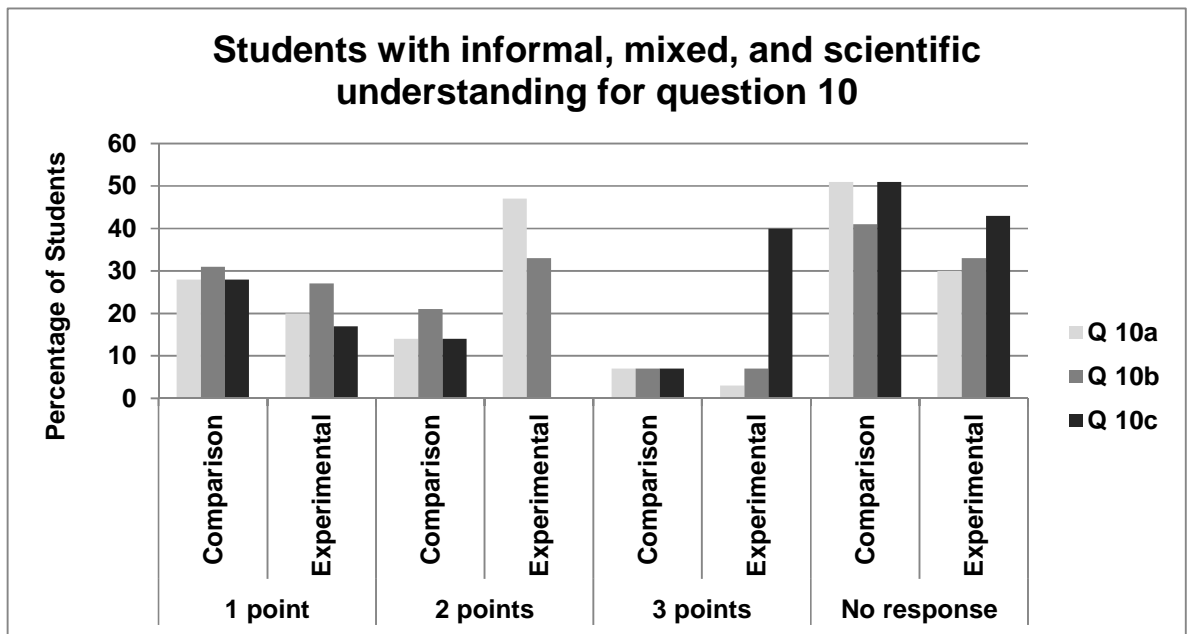


Figure 4. Percentage of students with informal, mixed, and scientific understanding on post-test for question 10a-c.

Qualitative Results

As previously explained, following the pre-test and prior to instruction, three students from each group volunteered to participate in interviews. The comparison group interviewees consisted of two male students and one female student. By the end of the semester two of these students earned A's in the biology course and the third earned a B. The experimental group interviewees consisted of one male and two female students with two students earning A's and the third earning a C grade at the end of the semester. All interviewees were in the ninth grade. Table 12 summarizes the scores earned in the

quantitative portion of the study for the interview students. All six students demonstrated gains from the pre- to post-test.

Table 12
Summary of quantitative scores on written test for interview subjects

		Pre-test	Post-test	Gain	Normalized Gain
Comparison Group	Student 1	12	15	3	0.27
	Student 2	2	17	15	0.71
	Student 3	12	16	4	0.36
Experimental group	Student 4	13	20	7	0.70
	Student 5	4	9	5	0.26
	Student 6	6	11	5	0.29

The interviews consisted of students being asked to explain their reasoning behind the answer they chose for each question on the pre/post-test. Table 13 and Figure 5 summarize the scores that students earned during their pre- and post-interviews. For the comparison group, pre-interview scores ranged from 15 to 24 points and 14 to 21 points on post interview. The comparison group scored an average of 1.25 to 2.0 points on each question during the pre-interview and an average range of 1.17 to 1.75 points on each question in the post-interview. For the experimental group, pre-interview scores ranged from 12 to 20 and post-interview scores ranged from 17 to 23 points. Pre-interview scores for the experimental group ranged from an average of 1.0 to 1.67 points on each question and 1.33 to 1.95 points per question on the post-interview. Two of the interviewed students from the comparison group had no gain between the pre-interview and post-interview, and in fact, did worse on the post-interview although they had gains on the quantitative portion of the study. The third student in the comparison group had gain of three points, which equated to a normalized gain of $g = 0.10$ or an increase in content knowledge of only 10% of the possible gain. All three students from the experimental

group had positive gains between the pre- and post-interview ranging from two to eleven points, which equated to a normalized gain ranging from $g = 0.07$ to $g = 0.28$.

Table 13
Summary of scores for pre- and post-interviews for comparison and experimental group students.

		Pre-Interview		Post Interview		Gain	Normalized Gain
		Total Points	Mean	Total Points	Mean		
Comparison Group	Student 1	24	2.00	21	1.75	-3	-0.13
	Student 2	15	1.25	14	1.17	-1	-0.03
	Student 3	18	1.50	21	1.75	3	0.10
Experimental group	Student 4	12	1.00	23	1.92	11	0.28
	Student 5	20	1.67	22	1.75	2	0.07
	Student 6	12	1.00	17	1.42	5	0.14

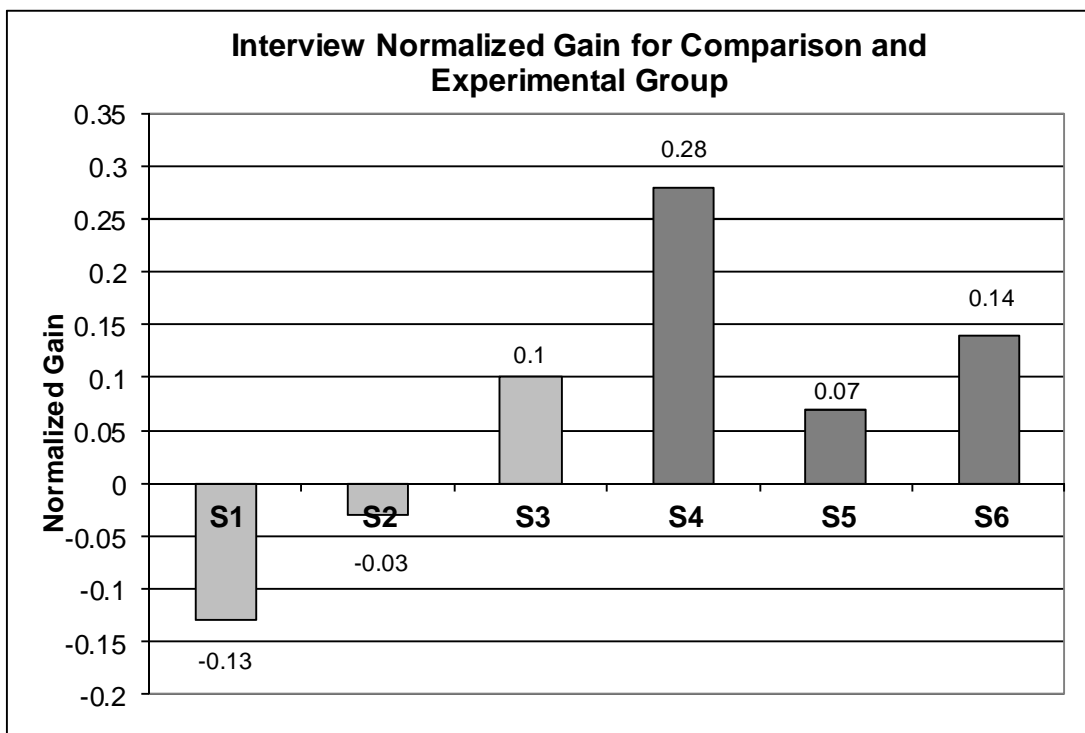


Figure 5. Normalized gains between pre- and post-interviews. S1-3 are the students from the comparison group. S4-6 are students from the experimental group.

Question 1. One notable difference between the interviewees was that during the post interview, students in the experimental group were better able to explain some of the

concepts and meanings behind their responses than students in the comparison group. For example, in question 1, when asked to explain why different proteins in cells make a kidney cell different from a skin cell even though they have the same DNA, Student 5 explained that “proteins do different things for each cell, like a kidney cell might have to do with a specific function and it needs specific proteins to do that specific function.” Student 5 related the function of proteins to the specific cell and the cells to the specific tissue. None of the students from the comparison class were able to describe this connection between protein, cells, and tissues. Student 3 had chosen the correct answer on the test, but explained: “they have different protein and those different proteins control different parts of the body.” This student provided the reasoning that proteins control the body parts, but not the hierarchy of cells or tissues specifically; therefore this student’s idea of specialization or differentiation of cells was not complete.

Question 10. Each interview question was scored on a 0-4 point scale and the scoring rubric used for the interviews is found in Table 4 (see Methods). An example of the scoring of pre- and post-interview responses for questions 10a and 10b from the comparison group and experimental group are summarized in Table 14. Scores for each student’s reply are found below each response for that particular student. A comparison of responses further reveals some of the differences in the quality of student responses and explanations between groups during the interviews.

Table 14

Scored pre- and post-interview responses for comparison and experimental group for question 10a and 10b. Underlined statements indicate key student responses.

<p>Question 10: Assume that a particular genetic condition in humans causes an inability to digest lipids that accumulate in the brain. The lipids build up around the brain and eventually results in death of the offspring. This disorder occurs equally between males and females. In all cases, the parents of the affected offspring will not have the condition.</p>
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<p>Question 10a: Describe the most probable pattern of inheritance for this condition. Explain your</p>

reasoning. Include a pedigree or cross to demonstrate the inheritance pattern

Comparison Group Post Interview Responses

T: You did the same drawing again, can you explain how you got to your answer this time, because you didn't answer last time

S1:...silence...so if they don't have, if the offspring have the condition but the parents doesn't, they are both probably recessive to the trait cause the Punnett square shows the offspring could be the last box which means that both he or she got both the recessive trait

T: and both parents have to be...

S1: recessive

S1: yeah probably

SCORE = 2

Experimental Group Post Interview Responses

T: First of all. is this trait dominant or recessive

S4: Um, it doesn't say, like this reminded me of the case study because you said that it depends on whether it is dominant or recessive so I did two charts

T: Okay tell me about your two charts. What are those called?

S4: Okay those are pedigrees...If it is recessive then don't both of the parents have to have the condition, what's it called, the thing the disease, the disorder both of the parents have to have the disorder (uses finger to show quotes) in order for the kid to have it and if it is dominant then only one parent has to have the disorder (again in quotes) for it, the genetic disorder in order for it to be passed on

T: Okay my question for you for this one though, is this is dominant also, right? (referring to student's pedigree)

S4: Um, dominant, what are you talking about

T: Big r big r, isn't that also having a dominant trait

S4: Oh was that supposed to be little r little r? I forgot...That was supposed to be little r little r because this person, no wait no, (mumbles to self)...I don't remember what I did

T: Want to draw it out again and try?

S4: Yeah

T: So which of your two Punnett squares should it be

S4: (Mumbles parts of question to self) So they won't have it, it won't be expressed, but they will still have the trait, no wait the disorder, so they have to be carriers, so it should be recessive, so isn't that one right? This is right then? Okay then this one was just doodling

T: Okay. So describe the probable pattern of inheritance, and you are saying that the disease is recessive?

S4: Yup

SCORE = 2

<p>S2: It is inheriting by both parents, but I read it wrong <u>cause it says will not have the condition, but they said will have the condition...so my guess will be that it is just a mutation that occurs...through reproduction...that's it</u></p> <p>T: Do you know if the trait is dominant or recessive?</p> <p>S2: I think it's <u>dominant because it will affect both females and males</u> and...</p> <p>T: Ok</p> <p>SCORE = 1</p>	<p>S5: <u>If both parents were big h little h then they would have one affected offspring, little h little h, if both parents were big h big h none of the children will be affected and then if both parents were little h little h then all of their children will be affected</u></p> <p>SCORE = 3</p>
<p>S3: I put every other generation, because they can be carriers that carry on to their offspring, <u>like mom and dad could be both carriers, so they give it but they don't have it, but they give it to their offspring and their offspring has it and then their offspring ends up being carriers</u></p> <p>SCORE = 2</p>	<p>S6: I put a <u>mutation in the offspring's genes</u></p> <p>T: <u>Okay. Can I ask you, do you think that this trait is dominant or recessive?</u></p> <p>S6: Recessive</p> <p>T: Why?</p> <p>S6: Because the parents don't have it, I don't know if that right</p> <p>T: Well if the parents don't have it how is it that the kid could have it?</p> <p>S6: <u>That's what I didn't understand. Because it's dominant. But how did the kid get it? Oh from something else huh?</u></p> <p>T: What do you mean something else?</p> <p>S6: <u>Nothing, the parents like, something else that's dirty, disease filled, like a rusty nail?...maybe</u></p> <p>SCORE = 1</p>
<p>Question 10b: Explain how a mutation could cause this inability to digest lipids</p>	
<p>S1: It probably could, <u>the mutation turned off the function or the ability to turn off that um digestion of lipids</u> so probably that mutation cause him to not be able to break lipids down or something</p> <p>SCORE = 1</p>	<p>S4: <u>Okay mutation in a DNA sequence can cause a fault in the protein production, so this means that a protein might not be made, and then like if the protein is not made then it can cause like a disorder. Right? Yeah</u></p> <p>SCORE = 3</p>
<p>S2: Its would just....pause...<u>it messes up a protein....that will....I don't really know</u></p> <p>SCORE = 1</p>	<p>S5: <u>The mutation caused a mutation on the gene and now it can't digest lipids. I don't really know how to explain that one, that's the only way I really know how to explain it</u></p> <p>SCORE = 2</p>
<p>S3: A frameshift mutation could cause this, <u>so shifting to a different code of DNA</u> (in written response: "a code for a protein")</p>	<p>S6: <u>A mutation could mess up the chromosomes and mess up the body not letting it digest lipids</u></p>

SCORE = 1	<p>T: So a mutation could mess up the chromosomes? (S6 Nods Yes)</p> <p>SCORE = 1</p>
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Question 10a asked students to explain how the trait in question was inherited. Students in the comparison group were not able to use appropriate scientific terms to describe how the trait in question was passed on from parent to offspring. Student 1 correctly identified the pattern of inheritance as recessive, but used the phrase “recessive trait” throughout his response instead of the phrase “recessive alleles,” as well as referred to the parents as both being recessive for the trait instead of carriers. He was not able to attribute alleles as the material that was transferred from parent to offspring; but rather, the trait itself was passed on to offspring. Student 1 stated: “if the offspring have the condition but the parents doesn’t, they are both probably recessive to the trait” (see Table 14). Student 2 did not relate the idea that in order for an offspring to have a particular set of alleles, the offspring must inherit the alleles from the parents. He also assumed that because the parents did not have the disease, it meant that they did not have any genetic material that could be passed onto the offspring’ and the reason that the offspring developed the trait was due to a random mutation. Student 3 was correct in saying that the parents had to be carriers to not be affected by the “it”, but went on to say that the offspring had “it” and were carriers. Her response was vague in explaining exactly what was being passed on from parent to offspring because of the lack of scientific terminology that she used. Student 3’s belief that the trait was inherited every other generation did not change.

Unlike the comparison group, two of the three students in the experimental group were able to explain the passing of *alleles* from parent to offspring. They also used their

diagrams of pedigrees or Punnett squares to explain how the trait was inherited. Student 4 redrew her Punnett squares from her post-test to explain the inheritance pattern for the disorder. During her explanation of the inheritance pattern, she could not recall the correct term to describe what the parents were passing on, but used quotation fingers every time she used the term “disorder.” Although Student 4 did use the term “disorder” instead of “alleles” when describing the parents as carriers, a majority of her response included the explanation of alleles. Student 5 had drawn the same Punnett square in both her pre and post-test. In her initial interview response, she had concluded that the trait was dominantly inherited. When questioned about why the heterozygote was only a carrier and not affected like the homozygous dominant genotype, she could not explain why. In her post-interview response, she correctly identified the pattern of inheritance as recessive and provided three different scenarios to show that both parents had to be carriers. Student 6 had a similar response to Student 2 in that the development of the trait in the offspring was due to some outside factor because the parents did not have the disorder or trait. He initially responded with the trait being recessively inherited, but could not explain how that could result from two phenotypically normal parents. In Student 6’s case, he said that the child must have developed the condition from a “rusty nail.”

Question 10b asked students to explain how a mutation led to the phenotype in question. Again, the comparison group did not make correct connections between the concepts. Student 1 claimed that the mutation “turned off” the ability to digest lipids. This student did not directly relate mutation with genes and protein production and function or explain how the mutation could turn off the ability to digest lipids. Student 2

identified that a mutation could “mess up the proteins,” but could not explain how the mutation would change the gene or how that incidence could lead to the disorder. Student 3 gave an example of a type of mutation and in her written response explained how a frameshift mutation leads to a different DNA code. In her written response she wrote that the DNA code was a code for protein.

Students 4 and 5 from the experimental group both connected *mutation* to DNA or gene, but Student 5 did not associate the concept of the mutated gene to a mutated protein. Student 4 stated “mutation in a DNA sequence can cause a fault in the protein production, so this means that a protein might not be made, and then like if the protein is not made then it can cause like a disorder.” This student was more direct in her explanation of the relationship between mutations and genes, and that a mutation in DNA could lead to the production of a non-functioning protein, which in turn leads to a disorder. Student 6 reasoned that the chromosome as a whole was mutated and that was the reason for the body not being able to digest lipids. Because the question was so general, it appears that the students did not know enough about the disorder and therefore could not specifically point to the protein that is faulty in the disorder. However, two out of three students in the experimental group made clear associations between the concepts of mutation, gene, and proteins.

Concept map. Question 6 was not included in the quantitative portion of the study due to the lack of student responses, yet, it is important to consider because of the types of responses students were able to provide. On the pre- and post-test, students were asked to create a concept map using the following terms: DNA, gene, protein, amino acid, trait, transcription, translation, mutation, chromosome, and cell. Rather than make a

concept map, which is what students seemed to have difficulty with, during the post-test the question was modified and instead students were asked to explain how they thought the terms provided were related.

In the comparison group 14 out of 29 students attempted to answer this question on the pretest. Of these 14 students, 11 drew concept maps or lines to connect terms but did not explain how the terms were related. Student 1 was one of the 14 that answered this question and when asked to explain his drawing during the interview (see Figure 6), he said:

“Well I could start here [pointing to chromosome] chromosome, DNA...as you dig in deeper, it goes down like um it goes smaller and smaller until the end. [Regarding the terms cell, translation, trait, mutation] My guess was like, every single one has a trait and if it’s mutated it affects the cell and everything else here, until it goes down to the smallest level.”

For Student 1, there seemed to be a lack of understanding of size and hierarchical relationship. Student 1 claimed that a mutation of a trait caused a change or affected everything at lower hierarchical levels, rather than the mutation affecting the gene and then the expression of the gene.

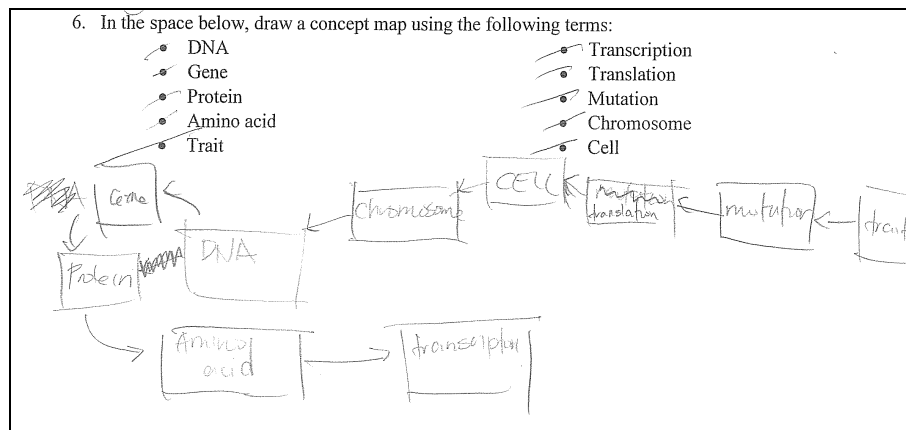


Figure 6. Student 1’s response to question 6 on the pre-test. 11 out of 14 students in the comparison class had similar responses.

On the post-test, 23 out of 29 students in the comparison group provided an answer to question six. 15 of the 23 students drew concept maps or lines connecting terms similar to what was seen in the pre-test (see Figure 6), without explaining the relationship between the terms. Five of these students drew and labeled pictures for the terms that they knew or the process of transcription and translation. Figure 7 depicts Student 1's response to question 6 on the post-test. The student was able to draw out the events that take place during transcription and translation. When asked to explain how a mutation or trait was related to the process he explained:

“Well I remember at the lunch that we did [referring to reviewing the process of transcription and translation] so yeah...basically the cell like in the human skin, so it's expressed so it's a trait, it's the outside [pointing to far right of drawing on paper] and this is like a cell. A mutation affects a cell. The chromosomes are gonna be in here and this is the process of transcription and translation and whatever happens here is gonna affect the cell and the trait.”

Student 1's drawing looks very similar to the textbook depiction of transcription and translation. Therefore, it is likely that this student remembered or memorized the drawing of the process of transcription and translation without necessarily understanding how a mutation can affect this process or how the trait was expressed as a result of the process.

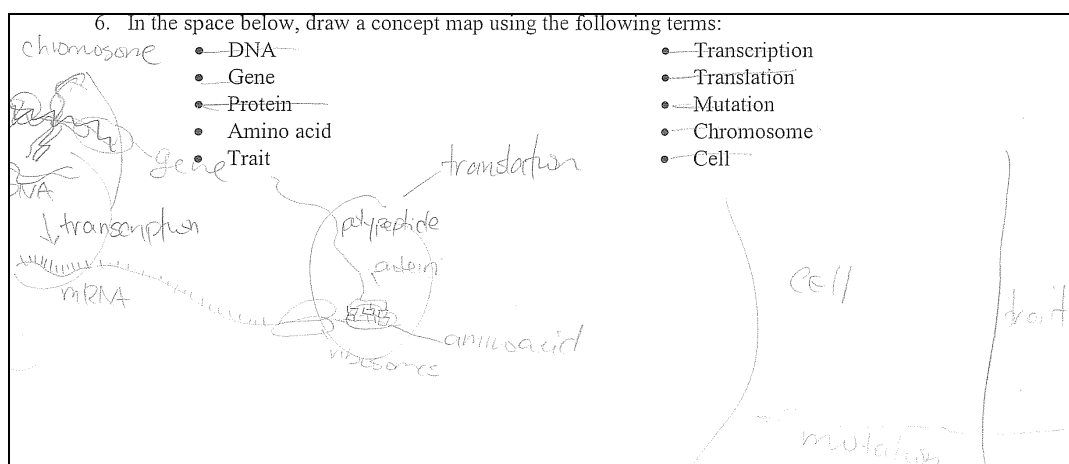


Figure 7. Student 1's response to question 6 on the post test.

For the experimental group, on the pretest 6 out of 30 students attempted to answer question 6, and one student wrote: “I don’t even know what a concept map is.” Another student in the class answered using a Venn diagram (see Figure 8). Student 5 drew lines between the terms listed (see Figure 9). All other responses to question 6 in the pre-test were similar to the comparison group in that they did not include any text to explain the lines they drew from one term to another. When asked during the interview about her lines, Student 5 explained:

“I did DNA to chromosome...because like DNA, like, aren't chromosomes, there's DNA in chromosomes or something. That's what I was thinking that there's DNA in chromosomes or chromosomes, they kinda go together, I don't know if I did that one first, because I think I did them out of order, but um then I did gene to mutation because a gene can get mutated. Then protein to translation, I don't know why I did that one, I kinda guessed on proteins to translation and amino acid to transcription. Then trait to cell because they were left over.”

Student 5 attempted to answer question 6, but did not have complete understanding of the terms listed. Later in her response, she added that she did not think that words could be used more than once and because words were written into two columns the student thought that one column paired with the other column.

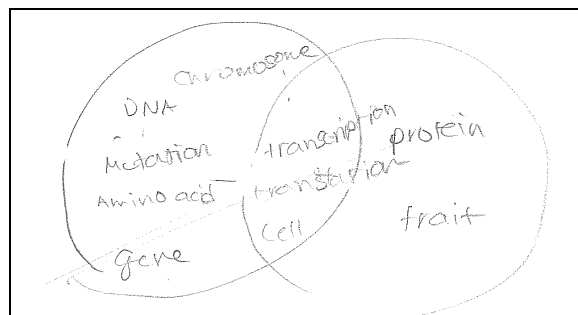


Figure 8. Sample response to question 6 from Student X in the experimental class on pre-test.

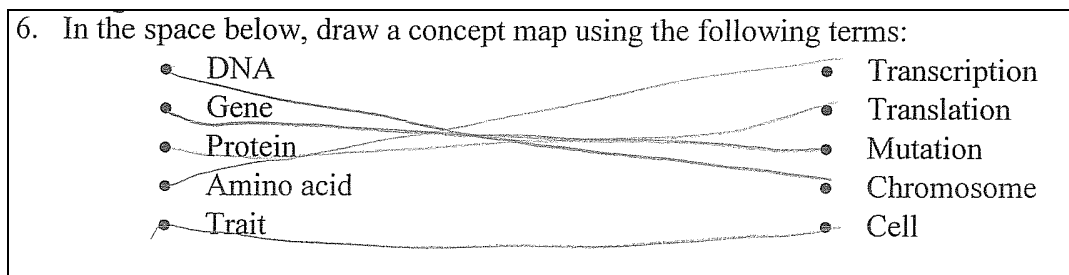


Figure 9. Student 5's pre-test response to question 6.

On the post-test, 26 out of the 30 students in the experimental group attempted a response to question six, a substantial increase from only six on the pre-test. Of the 26, 19 students attempted to make associations between terms. Student 4 did not answer question 6 on the pre-test, but the following is her response on the post-test:

“Transcription is the process where DNA is converted into mRNA in the cell. Then the information in mRNA is used to create amino acids in translations. Then the amino acids create a large chain called polypeptide then eventually form a protein. The proteins determine genes which make traits. But mutations in the sequence of nitrogen bases can effect which proteins are produced. This means that means that genes and traits are subject to change.”

Although a majority of her response was conceptually correct, when asked to elaborate on what a gene was, she could not provide a definition for gene which likely leads to her statement about proteins determining genes instead of the other way around. For the most part, students in the test class were able to correctly connect a majority of the concepts about DNA, genes, proteins, and mutations together, but could not necessarily provide meanings for terms. On the other hand, students in the comparison group could provide basic definitions, but not relationships between the concepts.

Opinion question. At the end of the interview, students from the experimental group were asked for their opinion about the case study lesson. Two of the three students commented that the case study had made them more interested in learning about DNA. Student 4 commented “DNA is boring, it is like, [and] apart from atoms it’s the most

boring thing in the whole entire book, and that [the case study] was the main thing that made me interested.” Another student that was not interviewed before the intervention, but was interviewed after said, “I think I found the research [for the case study] the most interesting, because all of our questions that we had we answered. It helped us learn the relationship [between proteins and genes] by showing...how the DNA being mutated could cause different proteins and making Huntington’s disease.” Two out of the three interviewees from the comparison group said that lecture notes were most helpful to their understanding of molecular genetics compared with the worksheets that supplemented the notes.

Conclusion

Clyde Freeman Herreid, director of the National Center for Case Study Teaching in Science, stated the following about case study use: “The goal in...case study teaching is not so much to teach the content of science (although that does clearly happen) but to teach how the process of science works and to develop higher-order skills of learning” (Herreid, 1994, p.222). Case studies emphasize comprehension of ideas rather than memorization of facts because students are required to research answers to their own questions and collaborate on solutions to problem tasks. In order for students to come up with a solution, they have to understand the content of the case and decipher the dilemma, background information and the effects of the solutions that they propose. As students work through the case study problem, they essentially teach themselves and each other, through collaboration and discussion, the scientific knowledge. The aim of this project was to determine whether or not case study instruction was effective in promoting conceptual change in high school students’ understanding of molecular genetics and

whether or not case studies were more effective than traditional textbook-based instruction in helping students understand molecular genetics. The results obtained from this study are mixed. Students in the experimental group performed similarly to the comparison group on the post-test; however, when interviewed about their answers, students in the experimental group had more to say in their responses and were more likely to use correct terminology and concepts.

The pre- and post-test results provided evidence to answer the first research question which examined whether or not case study instruction was effective in promoting conceptual change. The results showed that the case study instruction did in fact promote conceptual change in the experimental group. Calculation of the normalized gains revealed an increase in content knowledge learning for the experimental group. Although there was no significant difference between the experimental group and the comparison group on the post test, the experimental group still showed significant gains between the pre and post-test ($t(29) = -6.19, p=0.0000009$). This suggests that case study instruction can promote conceptual change.

Why is there no difference between the comparison group and the experimental group? One possible reason may be the test itself. The test given to both groups only consisted of 10 questions, one of which was thrown out because of the lack of student responses, making it difficult to find a significant difference between group scores with so few questions. As such, the test questions may not have been an accurate measure of what the students actually learned from the case study instruction. It would have been ideal to have a concept inventory specific to the particular topics the case study promoted. Concept inventories are research-based instruments that measure students'

conceptual understanding of topics that can provide information about what students do not understand and identify which alternative conceptions students hold after instruction (D'Avanzo, 2008; Elrod, 2010). Concept inventories for topics in biology are still being developed and for the most part are used at the undergraduate level. An appropriate concept inventory for the concepts addressed in the case study for this project was not available, and therefore, the similar scores between groups is likely the result of the challenge of writing test questions that can measure conceptual understanding. Concept maps have been suggested as an assessment to measure conceptual understanding (Rigby, Dark, Ekstrom, & Rogers, 2008; Tastan, Dikmenli, & Cardak, 2007; Smith & Dwyer, 1995); however, Rigby et. al. (2008) note that there is difficulty in scoring concept maps unless a rubric can be created for what would belong in that particular map, as suggested by Novak and Gowin (1984). Even with a rubric, concept map scores do not always correlate with traditional testing measures (Ryan & Samson, 1998). Also, as demonstrated in this study, students had difficulty creating concept maps, even though they had been used earlier in the school year, and as a result, that question was not counted in the scoring.

What differences arose between the pre- and post-test scores of the comparison group and the experimental group as a result of the difference in instruction? Analysis of the percentage of correct responses for questions 1-5 revealed that a greater number of students in the experimental group were able to identify the correct answer (see Table 8). One of the significant differences between the performance of the comparison and experimental group was question four which asked students to identify what attributed to the different amino acid sequences for proteins of different organisms. The experimental

group had a 50 percentage point jump in the number of correct responses between pre- and post-test as compared with the comparison group's meager six percentage point difference. This result suggests students in the experimental group had a better understanding of the concept of how different proteins are a result of different DNA sequences than the comparison group. This conceptual understanding can be attributed to the nature of the story of the case study. In the case, students were given background about a genetic disorder in which the DNA sequence—and protein production as a result of that sequence—was a factor in the disorder. As one experimental group student commented at the end of his interview, “It [the case study] helped us learn the relationship [between proteins and genes] by showing...how the DNA being mutated could cause different proteins and making Huntington's disease.” By making the information about protein synthesis relevant to students, it allowed students to understand the relationship between DNA sequences and amino acids.

Question 3 on the test, which asked for the relationship between a gene and a trait, also revealed another difference between the conceptual understandings of the two groups. The experimental group outperformed the comparison group by over 20 percent on this question. The difference in performance could be explained by the alignment of instruction for the comparison group with the California Science Content Standards (2000). Content standard 4 states, “Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism.” None of the sub-standards under this content standard specifically states that students understand how genes result in specific traits, but rather only how genes lead to specific amino acid sequences for proteins. Instruction for this

standard to the comparison group was very specific about how a sequence of DNA leads to an amino acid and a protein. Duncan and Reiser (2007) claim that instruction needs to engage students with genetic phenomena in its entirety and not just the process involved with the central dogma. The case study instruction allowed students in the experimental group to be exposed to genetics concepts in its entirety, not just the central dogma, because they had to explain inheritance and analyze how the DNA in Huntington's patients led to that particular phenotype or trait and not just the process of protein production.

Analysis of the open-ended questions, questions 8-10, revealed that both groups showed gains; however, the experimental group had a higher point average. One of the open-ended questions that students from both groups had difficulty with was question 9 which asked students to explain the relationship between genes and proteins. In the comparison group, students that answered the question on the post-test described the relationship between genes and proteins in one of two ways. A majority of the written responses stated that "genes make proteins" or "proteins build the genes." Similarly, students in the experimental group that answered the question had similar answers. This indicates that neither the traditional instruction nor the case study approach specifically addressed or clarified this concept for students. Student 4 from the experimental group had difficulty with the definition for the term gene throughout the majority of the interview. During Student 4's interview she said, "I know what a gene is, but I can't explain it...I need to know the definition of a gene." Later, she was eventually able to define the term gene, but only after further prompting and questioning. Students' difficulty with the concept of gene was also seen on question seven, where only a handful

of students correctly identified the relationship between gene and DNA on Figure 3.

During the interviews only Student 1, from the comparison group, was able to correctly identify and define gene.

Further analysis of the open-ended questions revealed concepts that students held informal or naïve, mixed, and scientific understandings for. Data from question 8—which asked students what the effect of a mutation would be on a gene and on DNA—and 10b—which asked how a mutation could result in a particular phenotype—showed that one-third of the students in both groups still had informal or naïve understanding of the concept after instruction. Instruction for both groups resulted in slightly fewer students with informal or naïve understanding on the post-test and at least a 20 percentage point increase to mixed understanding. Students with mixed understanding for both groups had similar responses to question 8. Some of their responses included mutations making changes to the DNA, gene, or nitrogen base sequence resulting in a disease, change in human health, the trait, the protein, or making the gene or DNA different. A majority of the statements were vague as students did not explain their statements about how these events took place. It can be suggested that instruction of this concept needs to be more specific about the immediate effect of mutations.

Question 10 provided an opportunity for students to apply knowledge of DNA, genes, protein synthesis, and mutations to a particular phenotype. Part A of question 10 asked students to describe the probable pattern of inheritance and in their response include a pedigree or Punnett square. Prior to the unit on molecular genetics, both groups had already completed a unit on Mendelian genetics. It can be assumed that students in both groups would be able to create a pedigree or Punnett square to show how a trait

might be inherited. However, that was not the case. Fewer than 50% of the students in the comparison group answered this question on the post-test compared to 27% who did not answer from the experimental group. The difference here is the case study in which instruction tied the Mendelian genetics and molecular genetics units together. Students in the experimental group were afforded the opportunity to review Punnett squares and pedigrees during the case study instruction because they had to research the inheritance pattern of the disease. As a result, students in the experimental group were better able to provide more complete responses to question 10a. This provides support for instruction of molecular and Mendelian genetics to be taught together rather than as two separate units (Duncan & Reiser, 2007; Kaptejin, 1990; Marbach & Stavy, 2000).

After analysis of the pre- and post-test results, another possible reason for the low gains (see Table 5) could be that the length of the study may not have allowed enough time for students to develop mastery of the concepts. Students may have only had enough time to be exposed to or memorize certain facts. When only provided minimal time on a difficult topic, students could have difficulty understanding the “why?” and the “how come?” Rigby et. al. (2008) state that time for initial learning—mastery over a particular topic—is important for students to store facts into long term memory and organize the information in order to be able to apply it to new situations, or what is called “transfer.”

The second research question in the study asked whether or not case studies were more effective than traditional textbook-based instruction in helping students understand molecular genetics and results were determined via interviews. When asked during the interviews to explain their answers to questions on the post-test, students in the experimental group were better able to articulate and make associations between

concepts. The experimental group used the terminology correctly and they quantitatively talked more when explaining their answers compared to the students in the comparison group. Two of the three interviewees from the comparison group had no gains between the pre and post interview, whereas all three interviewees from the experimental group had gains. Students in the experimental group had earned more points overall from their interview responses, whereas the comparison group lost points. Although the average points earned per question (see Table 13) seems low (out of four points for each question) for both groups, there was a gain in the average score per question for all three students interviewed from the experimental group. An increase in scores indicates correct usage of terms and correct identification or explanation of concept relationships between DNA, genes, amino acids, proteins, and traits. For example, question 8 asked students to explain how genes and DNA could be affected by a mutation. Student 5 from the experimental group responded by listing the types of mutations and how each “messes up the order of the nitrogen bases.” In contrast, Student 1 from the comparison group answered by saying that a mutation on DNA would change “the way you will look in the future or your health.” Where Student 1 related mutation directly to phenotype—where a mutation may not always affect the phenotype of an individual—Student 5 related the concept of a mutation to what would be immediately affected by the mutation, the sequence of nitrogen bases. All three interviewees in the experimental group had positive gains from the pre to the post-interview (see Table 9 and Figure 2 in Results).

On average, experimental group post-interviews lasted three minutes longer (12.6 minutes versus 9 minutes) than the comparison group interviews. Students 4, 5, and 6 (experimental group) were more likely to add to their explanations and think out loud

during the interviews than students 1, 2, and 3 (comparison group). For example, Student 4 had difficulty explaining her answer to question 10 and when offered the opportunity to work it out again, she worked out the problem while mumbling through the work. When Student 3 was asked to explain her answer for the same question and for several of her other answers she would reword what she had answered on her test instead of explaining *why* she chose that answer or what had led her to the answer. Although Student 1 could explain the concepts he was thinking about when we discussed each question, his responses were succinct. Student 2 responded with “I don’t know” or “I don’t know how to explain it” to seven of the ten questions when asked to elaborate on his answers. Similar to Student 2, Student 6 gave an answer of “I don’t know” or “just because” six times during the interview, but he continued to try to explain what he could remember rather than end his answers with I don’t know. Nevertheless, students in the experimental group seemed to have more confidence in their reasoning than students in the comparison group as demonstrated by their ability to specifically recall the work that they had completed in class that helped them answer the test questions. Student 5 commented that she had “thought of the case study and then I was like okay so I had to think back on what we did and how we figured out if...um, the parent had it or whatever the deal was.” These students referred to the case study activity when responding to the interview questions.

Limitations of the Study

Several limitations presented themselves during the analysis of the results. One of the limitations of this study was sample size. Because there was no significant difference between the two groups on the post-test, it would be interesting to see if a larger sample

size might make a difference. I would also recommend more students be interviewed before and after instruction as this would provide more information about students' comprehension and reasoning.

Another limitation of the study was the test itself. The test given to both groups only consisted of 10 questions, and more questions are needed to accurately assess one's conceptual understanding. At the time of the study a concept inventory was not available for molecular genetics. A conceptual inventory, may provide very different results.

For this study, students were exposed only once to case study instruction. Throughout the rest of the year traditional instruction was used to deliver information to students. Students may not have been comfortable with the format of the new instruction and that may have hindered learning. Herreid (1994) explains that as students become more comfortable with the instruction, they develop speaking, analytical, and decision making skills as well as confidence in themselves and peer relationships.

Finally the case study itself could have been revised to focus more specifically on the objectives for the molecular genetics unit. It may have had too much information for students to process. Vocabulary on the case study also may have been too difficult for the level of students in the course. Vocabulary practice prior to the case study instruction may have helped students better define the parameters of the problem presented in the case study.

Future Research

The case study instruction sought to promote student comprehension of the process of science and along the way the students learned the content by teaching themselves. Based on the mixed results of this study, there exists a need for this study to

be replicated in order to determine the effectiveness of case studies not only for this particular topic, but in other areas of biology. This study also opens the door for developing, implementing, and testing more case studies that can be used on a regular basis in the science classroom.

Another area of future research is the development of a better measure for conceptual change for this topic. As this study reveals, there exists a need to develop a library of conceptual questions for molecular genetics; questions that require students to apply, analyze, synthesize, and evaluate information that they discover through solving case studies. Test banks that accompany textbooks are typically full of fact-based questions that only require students to recall information, thus the need for more research into the development of concept inventories for secondary education.

References

- Araz, G. & Sungur, S. (2007). Effectiveness of problem-based learning on academic performance in genetics. *Biochemistry and Molecular Biology Education*, 35(6), 448-451.
- Bahar, M., Johnstone, A.H., & Hansell, M.H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education*, 33(2), 84-86.
- Blumenfeld, P. C., Marx, R. W., Soloway, E., Krajcik, J (1996). Learning with peers: From small group cooperation to collaborative communities. *Educational Researcher*, 25(8), 37-40.
- Bossert, S. T. (1988-1989). Cooperative activities in the classroom. *Review of Research in Education*, 15, 225-252.
- Bryce, T. & Gray, D. (2004). Tough acts to follow: The challenges to science teachers presented by biotechnological progress. *International Journal of Science Education*, 26(6), 717-733.
- California Department of Education (2000). *Science Content Standards for California Public Schools: Kindergarten Through Grade Twelve* (pp. 51-56). Sacramento, California: CDE Press.
- Chang-Wells, G. L. M. & Wells, G. (1993). Dynamics of discourse: Literacy and the construction of knowledge. In E. A. Forman, N. Minik, & C. A. Stone (Eds.), *Contexts for learning: Sociocultural dynamics in children's development*, pp. 58-90. New York: Oxford University Press.
- Chaparral High School (2010) School Accountability Report Card. Retrieved from <http://www.tvusd.k12.ca.us/sarc>
- Chin, C. & Chia, L. (2004). Problem-based learning: Using students' questions to drive knowledge construction. *Science Education*, 88, 707-727.
- Cockrell, K. S., Caplow, J. A. H., & Donaldson, J. F. (2000). A context for learning: Collaborative groups in the problem based learning environment. *The Review of Higher Education*, 23(3), 347-363.
- Colleta, V. P. & Phillips, J. A. (2005). Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability. *American Journal of Physics Teachers*, 73(12), 172-182.
- Creswell, J. W. & Clark, V. L. P. (2007) *Designing and conducting mixed methods research*. Thousand Oaks, California: Sage Publications, Inc.
- D'Avanzo C. (2008). Biology concept inventories: Overview, status, and next steps. *BioScience* 58(11), 1-7.
- Dion, L.K. (1998). To be tested or not to be tested. In Allen, D. E. & Duch, B. J. (Eds.), *Thinking towards solutions: Problem-based learning activities for general biology*. Fort Worth, TX: Saunders College Publishing.
- Dori, Y. J., Tal, R. T., & Tsaushu, M. (2003). Teaching biotechnology through case studies – Can we improve higher order thinking skills of non-science majors? *Science Education*, 87, 767-793.
- Duncan, R. G., Freidenreich, H. B., Chinn, C. A., & Bausch, A. (2009). Promoting middle school students' understandings of molecular genetics. *Research in Science Education*, DOI: 10.1007/s11165-009-9150-0.

- Duncan, R. G. & Reiser, B. J. (2007). Reasoning across ontologically distinct levels: Students' understandings of molecular genetics. *Journal of Research in Science Teaching*, 44(7), 938-959.
- Elrod, S. (2007). Genetics concept inventory. Retrieved from <http://bioliteracy.colorado.edu/Readings/papersSubmittedPDF/Elrod.pdf>
- Friedrichsen, P. M. & Stone, B. (2004). Examining students' conceptions of molecular genetics in an introductory biology course for non-science majors: A self study. NARST International Conference, Vancouver, WA.
- Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.
- Herreid, C.F. (1994). Case studies in science – A novel method of science education. *Journal of College Science Teaching*, 23(4), 221-229.
- John-Steiner, V. & Mahn, H. (1996). Sociocultural approaches to learning and development: A Vygotskian framework. *Educational Psychologist*, 31(3/4), 191-206.
- Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7, 75-83.
- Johnstone, A. H. & Mahmoud, N. A. (1980). Isolating topics of high perceived difficulty in school biology. *Journal of Biological Education*, 14, 163–166.
- Kaptejin, M. (1990). The functions of organizational levels in biology for describing and planning biology education. In Lijnse, P. L., Licht, P., de Vos, W., and Vaario, A. J. (eds.), *Relating macroscopic phenomena to microscopic particles*, pp.139-150. Utrecht, Netherlands: CD-Press.
- Lewis, J. (2000). Genes, chromosomes, cell division, and inheritance – do students see any relationship? *International Journal of Science Education*, 22(2), 177-195.
- Major, C. H. & Palmer, B. (2001). Assessing the effectiveness of problem-based learning in higher education: Lessons from the literature. *Academic Exchange Quarterly*, 5(1). Retrieved from http://findarticles.com/p/articles/mi_hb3325/is_1_5/ai_n28831728/
- Marbach-Ad, G. & Stavy, R. (2000). Students' cellular and molecular explanations of genetic phenomena. *Journal of Biological Education*, 34(4), 200-205.
- Marbach-Ad, G., Rotbain, Y., & Stavy, R. (2008). Using computer animation and illustration activities to improve high school students' achievement in molecular genetics. *Journal of Research in Science Teaching*, 45(3), 273-292.
- Mbajorgu, N. M., Ezechi, N. G., & Idoko, E. C. (2007). Addressing nonscientific presuppositions in genetics using a conceptual change strategy. *Science Education*, 91(3), 419-438.
- McParland, M., Noble, L. M., & Livingston, G. (2004). The effectiveness of problem based learning compared to traditional teaching in undergraduate psychiatry. *Medical Education*, 38, 859-867.
- Novak, J. D. & Gowin D. B. (1984) *Learning how to learn*. NY and Cambridge, UK; Cambridge University Press.
- Nzewi, E. (2001). Malevolent *ogbanje*: Recurrent reincarnation or sickle cell disease? *Social Science and Medicine*, 52(9), 1403-1416.
- O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism

- toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching*, 29(8), 791-820.
- OECD (2009) Top of the Class - High Performers in Science in PISA 2006. Retrieved from http://www.oecd.org/document/51/0,3343,en_32252351_32236191_42642227_1_1_1,00.html
- Okoro, A. N. (1975). Albinism in Nigeria. *British Journal of Dermatology*, 92, 485-492.
- Rhem, James (1998). Problem-based learning: An introduction. *The National Teaching and Learning Forum*, 8(1), 1-4.
- Richmond, G. & Striley, J. (1996). Making meaning in classrooms: Social processes in small-group discourse and scientific knowledge building. *Journal of Research in Science Teaching*, 33(8),839-858.
- Rigby, S., Dark, M., Ekstrom, J., & Rogers, M. (2008). Measuring conceptual understanding: A case study. SIGITE'08 Proceedings of the 9th ACM SIGITE Conference on Information Technology Education, New York, 11-16.
- Rutherford, F. J. & Ahlgren, A. (1989). *Science for all Americans*. New York, Oxford: Oxford University Press.
- Ryan J. M. & Samson, S. M. (1998). Using concept maps to assess student learning in the science classroom: Must different methods compete? *Journal of Research in Science Teaching*, 35(10), 1103-1127.
- Sadler, T. D. & Zeidler D. L. (2004). The significance of content knowledge for informal reasoning regarding socio-scientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education*, 89, 71-93.
- Smith, K. M. & Dwyer, F. M. (1995). The effect of concept mapping strategies in facilitating student achievement. *International Journal of Instructional Media*. 22, 25-31.
- Stepien, W. & Gallagher, S. (1993). Problem-based learning: As authentic as it gets. *Educational Leadership*, 50(7), 25-28.
- Stewart, J. & Stewart, G. (2010). Correcting the normalized gain for guessing. *The Physics Teacher*, 48, 194-196.
- Tastan, I., Dikmenli, M., & Cardak, O. (2008). Effectiveness of the conceptual change texts accompanied by concept maps about students' understanding of the molecules carrying genetical information. *Asia-Pacific Forum on Science Learning and Teaching*. 9(1), Article 11, 1.
- Topcu, M. S. & Sahin-Pekmez, E. (2009). Turkish middle school students' difficulties in learning genetics concepts. *Journal of Turkish Science Education*, 6(2)
- Tsui, C. & Treagust, D. F. (2003). Genetics reasoning with multiple external representations. *Research in Science Education*, 33, 111-135.
- Tsui, C. & Treagust, D. F. (2004). Conceptual change in learning genetics: An ontological perspective. *Research in Science and Technological Education*, 22(2), 185-202.
- Tsui, C. & Treagust, D. F. (2007). Understanding genetics: Analysis of secondary students' conceptual status. *Journal of Research in Science Teaching*, 44(2), 205-235.
- Wood, Diana F. (2003). ABC of learning and teaching in medicine problem based learning. *British Medical Journal*, 326, 328-330.

Zohar, A. & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35-62.

Appendix A: Point Loma Nazarene University IRB Approval Form

**Full IRB Review
693**

March 8, 2010

PI: Michelle Bacong Baun

Faculty Advisor: April Maskiewicz

Title: Using Case Studies for High School Students' Learning of Abstract Concepts in Molecular Genetics

The research proposal was reviewed and verified as a Full Review and has been approved in accordance with PLNU's IRB and federal requirements pertaining to human subjects protections within the **Federal Law 45 CFR 46.101 b**. Your project will be subject to approval for one year from the March 8, 2010 date of approval. After completion of your study or by March 8, 2010, you must submit a summary of your project or a request for continuation to the IRB. If any changes to your study are planned or you require additional time to complete your project, please notify the IRB chair. The IRB approved and officially stamped Consent and Assent forms are have been mailed via campus mail to Dr. Maskiewicz.

For questions related to this correspondence, please contact the IRB Chair, Leon M. Kugler, Ph.D., at the contact information below. To access the IRB to request a review for a modification or renewal of your protocol, or to access relevant policies and guidelines related to the involvement of human subjects in research, please visit the PLNU IRB web site.

Best wishes on your study,

Leon M. Kugler Ph.D., ATC
Director, Exercise Science
Advisor, Pre-Physical Therapy
Chair, IRB

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3900 Lomaland Dr.
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Appendix B: Pre- and Post-Assessment

DNA and Protein Synthesis Assessment

1. Every cell, except for the gametes, contains the same DNA. So why is a kidney cells different from a skin cell?
 - a. They have different nucleotides in the DNA
 - b. They have different proteins in the cells
 - c. They have different genetic material
 - d. They have different genes

2. Your muscle cells, nerve cells, and skin cells have different functions because each kind of cell
 - a. Contains different kinds of genes
 - b. Is located in different parts of the body
 - c. Activates different genes
 - d. Contains different numbers of genes
 - e. Has experienced different mutations

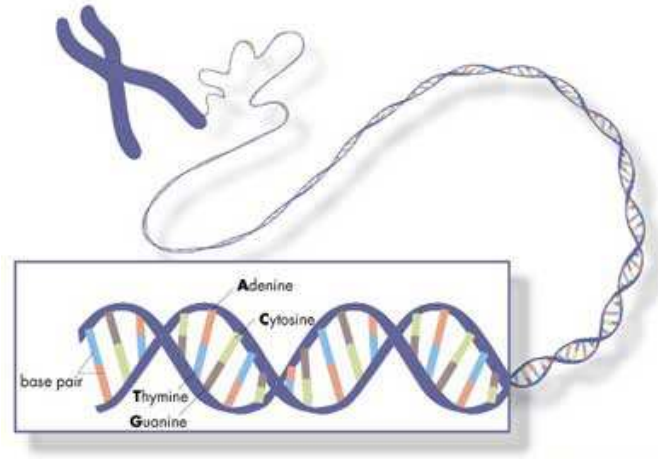
3. What is the relationship between a gene and a trait?
 - a. The gene is a trait
 - b. The trait exists inside the gene
 - c. The gene physically builds the trait
 - d. The trait is an expression of the gene

4. The differences in the sequence of amino acids in the protein molecules of different organisms is due to
 - a. The sequence of nitrogen bases in the DNA molecule
 - b. The types of nitrogen bases in the DNA molecule
 - c. The proportion of different nitrogen bases in the DNA molecule
 - d. The types of amino acids that the organism consumes

5. Which of the following may result from a mutation in DNA?
 - a. A change in the sequence of mRNA
 - b. A change in the structure of a protein
 - c. A change in the phenotype
 - d. A change in human health
 - e. All of the above

6. Draw a concept map using the following terms:
 - DNA
 - Gene
 - Protein
 - Amino acid
 - Trait
 - Transcription
 - Translation
 - Mutation
 - Chromosome
 - Cell

7. On the diagram below, label the following things:
- Chromosome
 - DNA
 - Gene
 - Nucleotide



8. What effect will a mutation have on a gene? On DNA?
9. What is the relationship between genes and proteins?
10. Assume that a particular genetic condition in humans causes an inability to digest lipids that accumulate in the brain. The lipids build up around the brain and eventually results in death of the offspring. This disorder occurs equally between males and females. In all cases, the parents of the affected offspring will not have the condition.
- Describe the most probable pattern of inheritance for this condition. Explain your reasoning. Include a pedigree or cross to demonstrate the inheritance pattern
 - Explain how a mutation could cause this inability to digest lipids
 - Explain how you could determine whether the mutant allele is present in an individual.

Appendix C: Interview protocol

Pre-Assessment

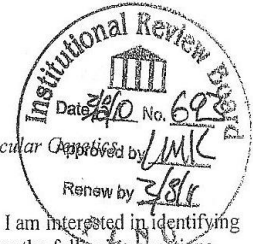
1. For identification question:
 - a. Why did you label this part _____?
 - b. What is the function of this part?
 - c. How are these structures related?
2. For concept map question:
 - a. Can you explain how these terms are related?
3. For Open-ended scenario question:
 - a. Can you explain why or how your diagram describes the inheritance pattern?
 - b. What does each part of your picture do or mean?
 - c. What did you mean by _____?
 - d. Can you elaborate or give me more detail about your answer here?

Post-Assessment

1. You answered ___ on the pre-test and then you answered ____ on the post-test. Can you explain to me why?
2. Do you still have questions about this topic?
3. For concept map question:
 - a. You said drew your concept map this way initially, why did you do it this way?
 - b. How are these terms related?
4. For Open-ended scenario questions:
 - a. Can you explain why or how your diagram describes the inheritance pattern?
 - b. What does each part of your picture do or mean?
5. What did you mean by _____?
6. Can you elaborate or give me more detail about your answer here?

Appendix D: Student Consent Form to be a Research Subject

**Point Loma Nazarene University
Assent To Be A Research Subject**



Project Title: *Using Case Studies for High School Students' Learning of Abstract Concepts in Molecular Genetics*

A. What is this study about?

I (Ms. Michelle Baun), am a biology graduate student at Point Loma Nazarene University. I am interested in identifying the effects of case studies on student content learning. Specifically I am attempting to answer the following questions, 1) Are case studies effective in promoting conceptual change in high school students' understanding of molecular genetics? and 2) Is a case study more effective than traditional textbook-based instruction to help students apply their understanding of molecular genetics to new situations? Because you are a teenager in high school, you are being asked to participate in this study.

B. What will happen to me if I am in this study?

1. First, I will give you two copies of a different form to have your parent/guardian read, sign, and return if you are allowed to participate. Then, I will read this form to you. Please follow along with me, because I want to make sure you sign this paper only if you know what you are signing. Then, I will ask if you want to volunteer to be a part of this study. If so, I will ask you to sign this paper and to keep a second copy. When you and your parent/guardian have given permission, you will volunteer for an interview time with me.
2. During a specially designed lesson, you and other participants will be audio-taped during class discussions lead by your teacher, Ms. Baun. The recordings will only be reviewed by me as I write my final report and I am the only one who will know your identity and specific responses. Your responses will have no effect on your class grades.
3. At an interview time that is convenient for you, you will participate in a one-on-one, video-taped interview with me. The interview will be 20-30 minutes long. The interview will be repeated approximately 1 week later. Your name will never be used in the report that I will write, and I am the only one who will know your specific responses. Also, your responses will have no effect at all on your class grades.

C. What will it feel like?

Usually kids like to give their opinion on what they think about things. In this interview, you will be giving your opinion about molecular genetics topics. You will provide your answers while being as honest as possible about what you know. It is possible that you may feel some discomfort or unease if you do not know an answer to some questions, but this is not any different than the experience in a typical classroom.

D. Do I get anything?

Yes, an opportunity to gain additional scientific knowledge about DNA and gene expression following the completion of the lesson and interview.

E. What if I have questions?

You can ask me questions at any time about the study in sufficient detail for you to clearly understand the level of your participation as well as the significance of the research. If after the interview, if you have any more questions or want a summary of the results, you can call or email me and ask questions any time at mbaun100@pointloma.edu and/or Dr. April Maskiewicz, my supervising professor aprilmaskiewicz@pointloma.edu.

F. What are my choices?

You have three choices:

- You can be a part of this project if you want to – sign below.
- You can choose to not be involved in this project. If you decide to not participate, that is OK. Nobody will get mad at you if you don't want to do this, and it will not affect your grades in any way.
- If you decide to be a part of this project and you change your mind later, that is OK too. You just have to tell one of the people in charge of the study – sign below.

Signature of student

Date

Name of student (printed)

Name of principal investigator

Date

Please keep one copy of this letter and return the other copy to Ms. Baun

*Appendix E: Case Study Summary – Adapted from Dion, Allen, and Duch (1998)
Thinking Towards Solutions*

Genetic Testing

Part 1 – The Meeting

You and your partner are having your first child. You come across an advertisement about genetic testing. You are interested in having genetic counseling and testing because of your father. Your father has had uncontrollable twitches for the last year and was recently diagnosed with Huntington's disease. Huntington's is a genetic disorder that causes destruction of brain cells which leads to uncontrollable movements, memory loss, and slurred speech. In 1993, it was discovered that the cause of Huntington's was an abnormal number of repetitive CAG sequences in the DNA.

Redirect Questions:

1. What is the problem?
2. Draw the possible pedigree for this family
3. Why would this mutation make any difference in a person's phenotype?
4. Suggest how a mutation like this would have occurred.

Part 2 – The Gene

A protein called huntingtin is produced from the Huntington's gene. In the mutated form, it is believed to interact with an enzyme called GAPDH and inhibit its function, possibly causing the Huntington's phenotype.

You are worried about your unborn child. There are about 30,000 people in the United States with Huntington's disease and your father was diagnosed when he was 45 years old. You are afraid that you could have passed the gene to your unborn child, but you don't have the disease and wonder if you should even worry.

Redirect Questions:

1. What is an enzyme?
2. What could lead to a mutated huntingtin protein on chromosome 4?
3. How is it possible that the huntingtin gene is found in cells all over the body?
4. Why would mutant huntingtin have an effect on the cell when it binds to GAPDH?

Questions to Ponder:

1. Why is the counselor's explanation that brain cells rely mostly on glucose for energy relevant to your question about why these brain cells are most affected by huntingtin?
2. Should you be concerned about getting Huntington's or about passing the gene on to your child? Why or why not?
3. Considering that afflicted people eventually die from the disease, why do about 30,000 people have it? Why has the gene not been removed from the population?

Part 3 – To Test or Not to Test

For genetic testing a blood sample is taken from an adult and for an unborn child, the doctor must perform an amniocentesis or chorionic villi sampling to get a sample of the fetus' cells. DNA is extracted and amplified to the desired amount and then cut with enzymes for specific lengths. The DNA pieces of different sizes are then separated by size and stained so their pattern can be seen when separated.

People of different genotypes (Hh or hh) for Huntington's produce different fragment patterns. The different patterns are called restriction fragment length polymorphisms or RFLP. RFLP determines if an individual has the genotype Hh or hh. The genetic counselor says, "each one of you can be tested or not. The choice is yours and yours alone." You feel overwhelmed by the conflicting opinions you have about testing and you know that this will not be an easy decision

Redirect Questions?

1. What is an amniocentesis? Chorionic villi sampling?
2. What are the risks of genetic testing?
3. How is it possible that an enzyme that cuts DNA recognizes some DNA nucleotides but not others?
4. Why does someone with Huntington's disease have a different RFLP than a normal person?

Questions to Ponder:

1. Suppose the test came out positive and you find that you are heterozygous for Huntington's disease. Complete the pedigree you drew on Day 1.
 - a. What are the benefits and pitfalls of having this knowledge?
 - b. How would this be different from learning that you are heterozygous for cystic fibrosis, another genetic disorder?