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Middle School Science: Using Conceptual Models to Develop Molecular Genetics Concepts

Katie Berry
University of Wyoming

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By

Katie Berry

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Masters Committee:

Dr. Ana Houseal, Chair
Sylvia Parker
Dr. Diana Wiig

Abstract

The purpose of this project was to review aspects related to teaching molecular genetics at the middle school level. Literature on molecular genetics was used to determine benefits and challenges of using conceptual models and effective ways of applying conceptual models to learn. Additional information on the Next Generation Science Standards (NGSS) was used to identify ways that conceptual models might fit into the scientific practices of Making and Using Models. Understanding gained from the literature was applied to develop a National Board Certification entry. The NBC entry focused on progressing students' conceptual understanding of the structural relationship among DNA, genes and chromosomes and the functional relationship between genes and traits. Conclusions and recommendations from the literature and NBC process are made. Both findings from the literature and my NBC unit designs suggest that middle school students develop deeper understanding of molecular genetics through the effective use of models. As students practice using and developing conceptual models, they develop their scientific practices, as identified in the NGSS.

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Chapter 1

Introduction

Each year, genetic advances are made in the areas of health (medications and disease prevention), agriculture (food production), and reproduction. For example, in 2013 Sir John B. Gurdon and Shinya Yamanaka were awarded the Nobel Prize for discovering that mature cells could become pluripotent cells. These pluripotent cells have the ability to turn into any cell in the body. This discovery will eventually be used to develop treatments for diseases (Shinya yamanaka-facts, 2013).

In addition to news reports of genetic advances, the general public is also exposed to genetics concepts and topics through pop culture television series, books and movies (Shaw, VanHorne, Zhang, Boughman, 2008). Programs, like *Crime Scene Investigators (CSI)*, depict investigators using genetic technologies to solve crimes. Genetic applications have been depicted as being either beneficial or harmful. Benefits might include the cure for specific diseases or the tools used to solve crimes. Others may claim that these advances could bring an end to society as we know it, by causing unknown and terrible consequences. Genetically modified organisms (GMO), also known as genetically engineered foods, continue to be depicted as both beneficial and harmful by the media.

In 2013, Napa Valley residents protested the planting of Monsanto's GMOs due to fear of the creation of "super weeds" and foods that are not healthy for human consumption (Todorov, 2013). At the same time, poppy growers in Tasmania were considering suing the government for not allowing them to grow genetically modified poppies ("Legal Challenge Threat," 2013). How do we know what to believe? How do we know whether the genetic information we receive is legitimate and trustworthy? The continual role of genetics in our society makes it important that everyone have a general understanding of genetics (Shaw, et. al, 2010) and to develop skills that allow them to make good decisions about scientific topics (Boujemma, et al., 2010). Yet, students are not graduating with an understanding of molecular genetics adequate enough to become informed citizens (Duncan, Freidenreich, Chinn, & Bausch, 2011).

Problem

Neoclassical, molecular, or modern genetics deal with the concepts of gene sequences of DNA, which are coding for proteins. These concepts are referred to as the *central dogma* of genetics. They require students to understand both the chemical and the physical aspects, including the processes and functions of DNA at a molecular level (Duncan et. al, 2011). In middle school, students learn about genes and chromosomes, with little emphasis on DNA or the processes of gene expression. As students move into high school biology, the genetic concepts learned in middle school are built upon to develop deeper understanding. At this level, students learn about the structure of DNA and the processes involved in the central dogma.

This research seeks to identify ways to help middle school students develop a conceptual understanding of molecular genetics and thereby provide a better basis for continued conceptual development in high school. Most of the literature on molecular genetics has focused on secondary and post-secondary education, where the majority of the concepts are taught. Few studies concentrated specifically on middle school students. Since secondary school students have had more exposure and experience with genetic concepts, I have inferred in this paper that the struggles experienced by middle school students are similar to those experienced by high school students.

The literature has identified various reasons high school students struggle with molecular genetics. One reason is the complex nature of genetics. Students in genetics courses are required to deal with factors and processes that are unfamiliar (Lewis & Katterman, 2004; Marbach-Ad & Stavy, 2000) and cannot be seen with the naked eye (Duncan, Rogat, Yarden, 2009). Students are also challenged with understanding and navigating between various levels of biological organization. For example, genetic material is discussed as chromosomes, which are double strands of coiled DNA, but are also referred to as a gene, which is a small section of DNA. Both of these organizational units have different functions. Students have difficulty understanding the different levels of organization, while at the same time differentiating their structural and functional similarities and differences (Freidenreich, Duncan, & Shea, 2011; Duncan et al., 2011; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000).

In addition to complex content, there is inappropriate coverage and inadequate teaching of modern genetic concepts in high schools. For example, often students learn how to predict offspring probabilities from punnett squares without understanding the processes that encompass molecular genetics (Duncan, et al., 2009). The molecular topics that are covered tend to be deterministic and incomplete (Boujemma et al., 2010). This treatment of genetics content produces limited connections between the concepts and processes of classic and molecular genetics (Marbach-Ad, 2001) and has become an obstacle to developing an overarching and complete concept of genetics (Boujemaa, et al., 2010; Duncan, et al., 2009).

Another problem highlighted in the literature is the need for teachers to overcome misconceptions that can be barriers to student understanding. Shaw et al. (2008) identified seven general areas of misconception found in high school genetics students. The nature of genes and genetic material is one of the topics basis to the understanding of molecular genetics. Students have difficulty differentiating between terminologies used to identify genetic material: genes, alleles and chromosomes (Boujemma et al., 2010; Shaw et al, 2008). Students tend to view genes as informational units instead of productive instructions that are expressed in various ways throughout the life of an organism (Duncan et al, 2011). This leads to misunderstanding of the connection between a gene’s expression and the chemical processes that influence the expression (Boujemma et al., 2010; Lewis & Kattmann, 2004).

To improve student understanding, Shaw et al. (2008) recommended having students think deeply and critically about the content. Students need to be able to differentiate between, and link together, the structural and functional aspects of genetic molecules (Duncan et al, 2009; Freidenreich et al., 2011; Venville & Treagust, 1998). The literacy and critical-thinking skills thus developed allow students to successfully navigate between various levels of organization (Duncan, et al., 2009) and to apply their knowledge (Shaw et al, 2008). Being able to explain the processes that link genes to traits decreases the likelihood of students’ developing a deterministic view of genes. At the same time, it increases students’ ability to reconstruct their understanding of the concept. Without this understanding, genetic phenomena and technology can seem, to students, more like science fiction than reality (Duncan, et al., 2009).

Using scientific models can link students’ conceptions of reality and genetic concepts (Rotbain, Marbach-Ad, & Stavy, 2006). Models are a representation of a concept, idea or understanding (Ornek, 2008) that show specific characteristics or concepts (Churchill, 2013). Most models used by teachers use analogies to help students understand abstract and unfamiliar concepts (Rotbain et al., 2006). Churchill (2013) identified models as being useful for students in communicating, experimenting and describing systems or concepts. Rotbain et al. (2006)

found models to be useful for solving problems, building arguments and explaining abstract concepts.

Lewis and Kattmann (2004) identified students' preconceptions as an "essential starting point" for developing students' thinking in genetics. One way to identify these preconceptions is to use mental models. Mental models are representations of concepts that are created in the students' minds based on previous knowledge (Greca & Moreira, 2000). Instructional tools that allow teachers to understand students' mental models can help teachers identify students' misconceptions. Models can be used to help students develop and revise their conceptual models of genetics (Duncan, et al., 2011). Both mental and conceptual models are simplified, incomplete versions of the actual concept (Jonassen, Strobel & Gottdenker, 2005; Grecca & Moreira, 2000; Grobert & Buckley, 2000). Teachers can use active questioning to identify similarities and differences between mental models, conceptual models and the scientific concept, in order to develop the critical thinking skills of students.

The curriculum's focus on Mendelian genetics, compartmentalized content, varying levels of organization and misconceptions make genetics a conceptual and "linguistically" difficult content for high school students (Tsui & Treagust, 2007). Using tools that incorporate critical-thinking skills and help identify misconceptions can help students develop deeper conceptual understanding of molecular genetics.

Purpose

The purpose of this literature review is to focus on identifying research that would help middle school students comprehend the differences between genes, DNA, and chromosomes.

Developing a conceptual understanding of genes, DNA and chromosomes in middle school students will give students the required foundation for high school genetics.

Research Questions

The questions that guided this literature review are:

1. What are the benefits and challenges of using conceptual models to teach the relationship of DNA, genes and chromosomes to middle school students?
2. What are ways that conceptual models can be used to teach the relationship of DNA, genes, and chromosomes?
3. In what ways might these conceptual models fit into the Scientific Practice (Making and Using Models) identified by the newly released Next Generation Science Standards?

Methods

To answer these questions, I identified literature that deals with the topics of genetics, conceptual models, and mental models. The University of Wyoming online journal database was used along with key term searches of *modeling, gene, middle school, conceptual models*, and *genetics*. The Next Generation Science Standards (NGSS) (Achieve, 2013) were also be used to determine the role conceptual models play in future science standards.

The information gathered from these searches was used to guide my National Boards Certification portfolio for entry number one. The connections realized through this process will be discussed in the final section of this paper.

Chapter 2

Literature Review

Genetic Content

Genetics is an extensive area of study, encompassing a broad range of concepts and terminology. Genetic concepts are grouped into three broad categories: Mendelian, molecular, and meiotic (Freidenreich et al., 2011; Boujemma et al., 2010; Stewart, Cartier & Passmore, 2005).

Mendelian or classical genetics focuses on the concept of genes coding for a trait or characteristic. Gregor Mendel's understandings and outcomes from his experiments with pea plants are the primary source used in these lessons. Instruction is focused on determining offspring probabilities of genotypes and phenotypes using punnett squares. Inheritance patterns of simple, one gene traits are observed and identified from punnett squares. Students develop an understanding of the relationship of dominant and recessive alleles or forms of a gene, through the instruction of classical genetics.

Molecular, also known as neoclassical or modern, genetics is centered on the processes that produce proteins from the DNA code or genes and the result of changes at the gene level (Duncan & Tseng, 2010). This is known as the central dogma of genetics. Genes direct the order of amino acids that bond together to create a protein. The protein itself has a particular shape as a result of its folding and the interactions of the various amino acids in the protein, which in turn determines a cell's structure and function. When a protein is altered, due to genetic changes, the protein's structure and function can be inhibited or inactivated (Duncan & Tseng, 2010). Understanding these concepts requires students to comprehend both the chemical and physical aspects of genetic processes and factors at a molecular level (Duncan et. al, 2009). These processes are not visible to the naked eye. This area of genetics has become increasingly important as new discoveries have influenced biomedical sciences and given rise to bioethical debates, such as cloning and genetic modification (Tsui & Treagust, 2007).

Meiotic or cellular genetics focuses on understanding the process of meiosis as a means of producing reproductive cells, sex cells or gametes. Autosomal or body cells contain two copies of each chromosome. Gametes on the other hand have only one copy of each chromosome. The random assortment of chromosomes in the gametes, along with the combination of chromosomes from two unrelated gametes produces variation from one generation to the next. Meiosis helps students understand the variation seen in each population. To be proficient in genetics, students must be able to explain physical traits (Mendelian genetics) in relation to both molecular and cellular genetics (Duncan, et al., 2009).

Challenges in Genetic Instruction

Several challenges have been identified in the literature that impedes students' conceptual understanding of genetic concepts and their ability to navigate between these three models. The complex nature of genetics makes content challenging for students. In order to understand modern genetics, students at middle school, high school and post secondary levels are required to navigate between both genetic and molecular models (Duncan et. al, 2009). As students navigate between these models, they find it difficult to deal with factors and processes that are unfamiliar (Lewis & Katterman, 2004; Marbach-Ad & Stavy, 2000) and cannot be seen or experienced (Duncan, et al, 2009). Students can only see DNA when several strands are bunched together. Likewise, processes, such as transcription, deal with a single strand of DNA and cannot be viewed or experienced directly in its microscopic state. As a result, current instruction is focused more on memorization of terms and processes than on understanding core ideas and mechanisms (Duncan & Tseng, 2010)

Students are also challenged with understanding and navigating between the various levels of biological organization. Each level builds on the previous organizational level (Duncan & Tseng, 2010). The genetic molecule is referred to as *DNA* when discussing its molecular make-up, as *chromosomes* when it is bundled together and visible, and as *genes* when discussing a specific section or segment of DNA. In addition to the structural levels of organization, each of these levels has a different functional emphasis. DNA's function is to carry the genetic information. Chromosomes pass the genetic information from generation to generation and genes determine traits (Miller & Levine, 2006). The physical traits that are observed at the organism level are the result of interactions at the gene level of organization (Duncan & Tseng, 2010).

Marbach-Ad and Stavy (2000) found that ninth-grade students had difficulty explaining the molecular reasoning for the phenotypic or organism level phenomena. The twelfth-grade students fared better in being able to explain the relationship of the different levels, but they were unable to connect the intermediate levels of organization together, or make very meaningful connections. Duncan, et al., (2009) also found that both middle and high school students have limited understanding of the levels of organization. As a result, students are unable to make the connection between the influence of molecular changes and phenotypic changes (Duncan & Tseng, 2010).

In addition to the levels of organization, students have difficulty understanding the similarities and differences of the factors involved (Freidenreich, et al., 2011; Duncan, et al., 2011; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000). These functional and structural levels of organization are necessary for understanding genetic phenomena (Duncan & Tseng, 2010).

In addition to the complex content, there is often inappropriate coverage and teaching of modern genetics concepts in high schools (Duncan, et al., 2009). Genetic concepts for both Mendelian and molecular genetics are taught as separate chunks of information (Boujemaa, et al., 2010). Students learn how to predict offspring probabilities and determine inheritance patterns from punnett squares without understanding the processes that produce the outcomes (Duncan, et al., 2009). Since inheritance patterns are a result of gene interactions at the molecular level, students are limited in their understanding of these patterns (Freidenreich, et al., 2011). In this way, the molecular link between genes and traits remains hidden to students (Duncan, et al., 2009; Lewis & Katterman 2004; Venville & Treagust, 1998) and leaves them with an incomplete understanding of Mendelian genetics.

A complete understanding of molecular genetics remains hidden to students as well. Molecular topics that are covered in secondary curriculum materials tend to promote a deterministic viewpoint of genes expression. Genes are shown as having a linear relationship from gene to protein to trait, without making explicit effects that the environment can have on a gene's expression (Boujemma, et al., 2010). Students usually learn about the historical studies of Mendel, which focus on one gene leading to one specific trait, such as plant height in isolation. However, the environment plays a role on gene expression and activation. For example, in plants, the gene for pigment production can be regulated by temperature changes in autumn. A change in the temperature causes an inhibition of green pigment production. Due to the lack of green pigment, other pigment colors present in the leaves become visible, causing some trees' leaves to change color. This continued focus on Mendelian genetics is a contributing reason that secondary students are confused regarding gene expression (Shaw, et al., 2008). Genetic content taught in this way provides insufficient connections among the concepts and processes of classic and molecular genetics (Marbach-Ad, 2001) and has become an obstacle to students' development of an overarching and complete concept of genetics (Boujemaa, et al., 2010; Duncan, et al., 2009).

Similar to high school genetics curriculum, the concepts taught in middle level grades (6-8) are also not fully developed (Duncan, et al., 2011). Materials generally focus on the rules and patterns of inheritance of Mendelian genetics (Lewis & Katterman, 2004). Due to the challenging nature of molecular genetics, most of those concepts are reserved for secondary and post-secondary classrooms (Duncan, et al., 2009), even though understanding of genetics through kinship (genetic inheritance of traits) begins in early elementary students, those as young as four to five years old (Venville, Gribble, & Donovan, 2005; Springer & Keil, 1989).

Role of Next Generation Science Standards (NGSS)

Due to a concern that in most areas of study United States students are not graduating prepared for post-secondary science, a group headed by the National Academy of Sciences developed a framework (Achieve, 2013) based on research that would provide a basis for the development of standards designed to increase the rigor of science education for K-12 students. From there, Achieve headed the development of standards with a group that included twenty-six states and forty writers. In April 2013, the Next Generation Science Standards (NGSS) were released. These standards contain performance expectations identified for every grade band, which were designed to integrate scientific and engineering practices, cross-cutting concepts, and content together to provide more authentic science experience s, while helping students develop a deeper understanding of essential concepts (Achieve, 2013).

Each standard has three dimensions. The first dimension focuses on the practices used by scientists and engineers. The eight practices are identified as (1) asking questions and defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (4) using mathematics and computational thinking, (5) constructing explanations and designing solutions, (6) engaging in argument from evidence, (7) obtaining, evaluating and communicating information (Achieve, 2013).

The second dimension is the cross-cutting concepts. These are similar to the unifying concepts and process or themes from previous state science standards, content standard number one. The seven cross-cutting concepts are identified as (1) patterns, (2) cause and effect, (3) scale, proportion, and quantity, (4) systems and system models, (5) energy and matter, (6) structure and function, (7) stability and change (Achieve, 2013).

Dimension three covers the disciplinary core ideas (DCI). These are not all of the content related to a concept, but rather the most central ideas required for an understanding of the concept. By understanding these core concepts, students should be equipped to reason out and comprehend new knowledge within that content area as it is discovered (Achieve, 2013).

The NGSS placed importance on genetics as a core idea for life sciences. Two middle school performance standards for Heredity are linked directly to students' understanding of molecular genetics: MS-LS3-1 and, MS-LS3-2. These standards and the high school performance standards that middle school students will be progressing towards are shown in Table 1 (Achieve, 2013).

Table 1: NGSS Heredity: Inheritance and Variation of Traits Performance Expectations of the Standards

	Middle School
MS-LS3-1.	Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. [Clarification Statement: Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [*Assessment Boundary: Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.*]
MS-LS3-2.	Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. [Clarification Statement: Emphasis is on using models such as Punnett squares, diagrams, and simulations to describe the cause and effect relationship of gene transmission from parent(s) to offspring and resulting genetic variation.]
	High School
HS-LS3-1.	Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]
HS-LS3-2	Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

MS-LS3-1(*Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial or neutral effects to the structure and function of the organism*) is designed to demonstrate students' understanding of the core ideas of the central dogma of molecular genetics. Students must be able to understand how genes that are found on the chromosome code for proteins, and can affect the organisms' traits. Some genes can be altered, which may affect the proteins of the organism and consequently the traits. These changes could be good, bad, or indifferent. By understanding these concepts, students will develop the cross-cutting concept of structure and function. They will develop an understanding of how structure influences the function of proteins and thereby also traits. These core ideas require a firm understanding of the structural difference between genes and chromosomes and the functional relationship between genes and proteins (Achieve, 2013).

The second performance standard, MS-LS3-2 (*Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation*), is designed to demonstrate students' understanding of chromosome inheritance. The core idea is that any offspring has two copies of each chromosome in its cell. The variation between parents and offspring is a result of one allele being inherited from their mother and the other allele from their father. Parents may pass on either of their alleles to their offspring, even ones that have been altered through mutations. The concept that some of the variation in life is the result of random allele inheritance develops the cross-cutting concept of cause and effect between alleles and traits. Although these concepts are part of meiotic genetics, the understanding of genes as coding sequences on DNA through molecular genetics is beneficial for conceptual understanding (Achieve, 2013).

Both of the heredity performance standards incorporate use of the science and engineering practice of *developing and using models*. Students are expected to develop and use models to help describe the phenomena observed as a result of the core ideas of heredity (Achieve, 2013). Models are a mode or tool to facilitate conceptual understanding of heredity.

Models

Importance of Models

Models can be used as a tool to develop an understanding of the natural world. They can aid in decision making as people try to understand cause and effect relationships of complex ideas (Schwarz, et al., 2009). For example, Earth's climate is a complex system involving feedback loops and multiple, interconnected molecules that influence one another and the climate. Models for climate have to take into account such factors as carbon dioxide's effect on global temperatures as it traps infrared radiation; or the melting of ice that results in less reflection of sunlight back into the atmosphere, which can lead to temperature increases. The predictions made from climate models influence how natural resources are managed and used to maintain a sustainable planet (Pallant, Lee & Pryputniewicz, 2012; Ruebusch, Sulikowski & North, 2009). The skills and knowledge needed to use models as decision-making tools begins in K-12 education. Teachers can use models to inform and instruct students about important concepts both through the interpretation and creation of models (Tsui & Treagust, 2007; Michaels, Shouse & Schweingruber, 2007). Through the use of models, students develop an understanding of the concepts and processes of science and become more informed citizens (National Research Council, 2007).

Types of Models

There are two basic types of models used in teaching: mental and conceptual (National Research Council, 2012). Mental models are developed internally from a person's experiences and perceptions (Greca & Moreira, 2000). Mental models may be used in making predictions about everyday situations and phenomena (NRC, 2012; Greca & Moreira, 2000). For example, students often create mental models of how traits are passed on from parent to offspring.

Students may think that because they more closely resemble one parent over the other, they received more genes from one parent. Even though this is an incorrect model, they will make predictions on genetic inheritance based on their mental model of inheritance. For example, when using this type of mental model of inheritance, they may expect that all boys receive more traits from their fathers than their mothers.

Conceptual models are the outward manifestation of mental models (NRC, 2012). They are defined as representations of a concept, idea, object, process, event or understanding that depict specific characteristics or relationships (Churchill, 2013; Schwarz, et al., 2009; Ornek, 2008; Rotbain et al., 2006). As specific characteristics are emphasized, other features are simplified, incompletely shown or completely removed (Michaels, et al., 2007). For example, most models of DNA show a simple twisted ladder with different colors representing the four unique bases. This model is missing several of the features of DNA, such as the hydrogen bonds between each of the bases, and the specific molecular structure of the bases. The simplified ladder model represents the arrangement of base pairs and the double-helix structure of DNA. Including all of the features of DNA would complicate the structure and inhibit the understanding of the specific ideas displayed in the model. As such, conceptual models are not replicas, but representations, which are used to understand a specific idea or concept. Due to their focus on specific core ideas, conceptual models are a part of the scientific and engineering practices and cross-cutting concepts in the NGSS (NRC, 2012).

Forms of Models

Conceptual models can be represented in a variety of ways, including graphs, tables, diagrams, mathematical equations, simulations and replicas (NRC, 2012, Michaels, et al., 2007). The format ranges from formal to informal. Formal examples include mathematical models, such as the equations and graphs for population growth; and software models, such as NetLogo simulations predicting a factor's effect on deer populations. Informal examples include sketches, such as hand drawn models of water movement during osmosis and handmade objects, such as a DNA double helix made from beads (Bell, Urhahne, Schanze & Ploetzner, 2010; Michaels, et al., 2007; Rotbain et al., 2005).

Benefits of Model Use

Skill Development

Models are useful in developing students' scientific skills (NRC, 2012, Schwarz, et al., 2009). Like scientists, students use models for a variety of purposes and in a variety of ways. They can build and test their own models or they can use preexisting conceptual models to depict their understanding of a system or phenomena (NRC, 2007). This understanding can be tested and trends can be identified allowing students to make predictions in relation to new factors (NRC, 2007; Rotbain et al., 2006; Treagust, Chittleborough,& Mamiala, 2002). Models play a vital role in the development of students' skills, enabling them to develop, construct, experiment, communicate, predict and describe a phenomenon (NRC, 2012; Churchill, 2013; Schwarz, et al., 2009; Kenyon, Schwarz & Hug, 2008; Michaels, et al., 2007). For example, students use punnett squares as a mathematical model to determine the outcome of genetic crosses. As students become familiar with the trends associated with simple inheritance patterns, they can use punnett squares to determine outcomes of similar or more complex genetic crosses of living populations such as fruit flies or fast growing plants.

Reasoning Skills

Models have also been found to develop reasoning skills of critiquing, evaluating, and analyzing (Duncan & Tseng, 2010; Chang & Chang, 2012; Tsui & Treagust, 2007). Students use these skills as they create analogous representations of a system or phenomena based on a specific structure or function (NRC, 2012; Rotbain et al., 2006). These thinking skills are not easily developed without guidance and instruction (NRC, 2007; Michaels, et al., 2007). In order for this to happen, students need content that is complex and requires high levels of thinking.

The interrelated, varied levels of organization and varying functional levels (Duncan & Tseng, 2010) of molecular genetics make it a complex content that requires students to reason and problem solve (Jensen, Kummer & Banjoko, 2013; Tsui & Treagust, 2007).

Molecular genetics is rife with structures that are too small to see with the naked-eye. They can be organizationally complex, and include both structural and functional levels of organization. Studying them allows students to be able to develop fundamental concepts. Students can visualize and comprehend the differences and similarities between molecules' functions and structures (Duncan, et al, 2009; Freidenreich et al., 2011; Venville & Treagust, 1998). For example, researchers used a project-based unit to help high school students understand the connection between genes, proteins and physical traits. The students created "toobers" models of lactase, using bendable, foam tubes, that they used to develop the understanding of how changes in this protein affect the ability of a person to breakdown lactose. Students used their understanding to make predictions about changes in other proteins in the body (Alozie, Ekland, Rogat & Krajcik, 2010). As students develop understanding of the link between genes and proteins, it gives students the ability to solve and understand genetic phenomena that may be encountered outside of the classroom (Duncan & Tseng, 2010).

Scientific Literacy

Modeling is at the very core of scientific literacy and is a challenging goal of science education (Duncan & Tseng, 2010). Scientific reasoning requires students to be able to critically think and logically reason (Shaw, et al., 2008). As students use models, it allows them to develop a deeper scientific understanding and scientific literacy; thereby making them better at doing and learning science (NRC, 2007). Through continued practice, students will think more critically (Kenyon, et al., 2008), build arguments, solve problems, propose explanations (Rotbain et al., 2006) and develop more sophisticated higher quality models (NRC, 2012).

Student Engagement

In addition to the development of scientific skills, reasoning skills and literacy, models are also excellent tools for engagement. Models provide a mode for students to be actively engaged (Orneck, 2008) through the processes of designing, describing, building, testing and revising models (Duncan, et al., 2011; Orneck, 2008). As students are engaged in a challenging task, conceptual change can occur (Churchill, 2013). Venville and Treagust (1998) identified engagement as a factor affecting high school students' development of the concept of genes. Since instruction did not include the use of genetic phenomena that would require an understanding of molecular genetics, these researchers found that students thought of genes as a passive molecule and saw the molecular details as uninteresting and unimportant. By using appropriate connections to molecular phenomena and engaging students through modeling practices, students were able to develop an understanding of the process of science as well as content understanding (Duncan, et al., 2011; Venville & Treagust, 1998).

Conceptual Understanding

Models are used by students in the classroom to develop scientific understanding, skills and reasoning. The primary focus has been to develop students' conceptual understanding of specific science content by targeting the misconceptions found in students' mental models (Lewis & Katterman, 2004). Misconceptions are the misaligned understanding students have of a concept versus the true understanding of the concept. Due to the complex nature of genetics, several misconceptions rely heavily on an understanding of classical (gene determines character trait) gene models (Boujemaa et al., 2010), with little understanding of modern gene conceptions (Shaw et al., 2008). To develop students' concepts of genes, teachers need to begin with the students' experiences of genetic phenomenon (Lewis & Kattmann, 2004), and make connections to students' mental models of genes (Lewis & Kattmann, 2004; Venville & Treagust, 1998). As students revise and improve their mental models, they can more accurately understand concepts and develop their reasoning (NRC, 2012).

Shaw et al. (2008) identified seven major topics of misconceptions in high school students: (a) genetic technologies, (b) deterministic nature of genes, (c) patterns of inheritance, (d) nature of genes and genetic material, (e) genetic disease, research and (f) reproductive technologies. Of particular interest to the focus of this paper are (b) the deterministic nature of genes, (d) the nature of genes and genetic materials, and their impact on students' understanding of molecular genetics.

Students tend to develop the idea that one gene codes for one trait (Shaw et al., 2008). Most instructional materials use the analogy of blueprints to help students understand the general function of DNA. As students progress through formal education years, this basic and simplified understanding persists. Duncan, et al., (2009) found that most high school students still tend to use the analogy of genes as blueprints. This misunderstanding creates a belief that genes cannot be influenced by other factors, but are predetermined and cannot alter in their expression. Genes are often influenced by other factors in the body and their expression can be regulated or inhibited. The blueprint deterministic analogy, although helpful at a rudimentary level, is not complete or functional. It inhibits students' understanding of traits that are caused from multiple genes (polygenic) or are influenced by environmental factors, as well as polygenic diseases and the environmental influence. This leads to misunderstandings about the connection between a gene's expression and the chemical processes that influence the expression (Boujemma et al., 2010; Lewis & Kattmann, 2004).

Another common misconception is found in students' ideas related to the nature of genes and genetic material (Shaw et al., 2008). This misconception also inhibits their understanding of the influence of various factors on gene expression. Students have difficulty differentiating between terms used to identify genetic material: genes, alleles and chromosomes (Boujemma et al., 2010; Shaw et al, 2008). Since each of these terms describes a different structural level of organization for DNA, students fail to realize that they serve the same functions (Marbach-Ad, 2001). Genes are a specific segment of DNA that codes for a specific protein. Chromosomes are DNA that has been wound up and organized into a specific rod shape. Although we differentiate gene, DNA and chromosome based on their structure, they all contain genetic information and code for specific proteins. Generally, students falsely distinguish them by both structure and function (Marbach-Ad, 2001). Understanding the molecular structures and functions will also benefit students' abilities to comprehend the process occurring in those structures (Duncan, et al., 2009). Being able to explain the processes that link genes to traits help students conceptually understand genes and genetic material (DNA and chromosomes), while decreasing the chance of creating a deterministic or simplistic view of genes (Duncan, et al., 2009).

Models help address misconceptions by activating students' mental models (Churchill, 2013). The internal thinking or mental model is displayed as students reason, construct and manipulate conceptual models (NRC, 2007; Rotbain et al., 2006). As students use their model to explain genetic phenomena, they are able to reconstruct their understanding of the concept (Duncan, et al., 2009).

Challenges of Models

Misconceptions

Despite their beneficial attributes, models can also be challenging for students to use as they develop conceptual understanding. The presence of students' misconceptions, limited understanding of the attributes of models and the lack of formal reasoning skills are factors limiting students' conceptual growth. Students do not always perceive what teachers expect they will from models (Treagust, et al., 2002). They may make connections to life experiences based on features or observations from a model that could result in the formation of misconceptions (Jensen, et al., 2013). Once a misconception is created, it can be difficult to undo. Students often find their own prior conceptions more appealing, even if they are not correct. A study conducted by Jensen, et al. (2007) found that non-biology majors, with low prior knowledge showed a higher knowledge gain than those biology majors with high prior knowledge. Those with less knowledge may have had fewer misconception and the misconceptions those with higher prior knowledge may have encumber those students' abilities to learn (Churchill, 2013).

It can also lead teachers to make incorrect assumptions of student understanding (Treagust, et al., 2002).

Features of Models

Students' limited understanding of the features as well as the use and function of models is an obstacle to effectively using models and understanding the nature of science (Ruebusch, et al., 2009). Grosslight, Unger, Jay and Smith (1991) investigated middle and high school students' understanding of the nature of models. They identified three levels of understanding. At Level 1, students view models as copies that were created from data. Level 2 students view models as incomplete or simplified, but not as replicas. By Level 3, students understood that models could be used to explain and predict phenomena. Students also realized that models are constantly revised based on new data. Most of the middle school and high school students tested by Grosslight et al. (1991) were at a Level 1 for understanding the use and structure of models. More recent studies find middle school students still hindered by the idea that models are replicas, instead of just representations (Gustafson & Mahaffy, 2011; Ruebusch, et al., 2009). Students' comprehension can be hindered by using models when they do not also have a good depth of understanding (Treagust, et al., 2002).

The above discussion demonstrated how research has shown that high school students have a difficult time grasping the concepts of molecular genetics. Major misconceptions of molecular genetics focused on in this paper are those related to the deterministic view of genes and the misunderstanding of the structural and functional similarities and differences of genes, DNA and chromosomes. Using conceptual models can be a beneficial instructional tool. The discussion above has demonstrated that models provide a means for developing students' scientific skills, reasoning, scientific literacy and content while engaging students in the process of learning. At the same time, teachers must be aware that students can be challenged by not understanding the role and use of a model, and its use can cause the development of new misconceptions. Since most molecular genetics content is reserved for the high school classroom, limited research has been conducted on middle school students. However, the literature I found demonstrated that middle school students hold similar misconceptions to high school students and are capable of making sophisticated connections to the basic concepts relating to molecular genetics through the use of models (Friedenreich, et al., 2011; Duncan, et al., 2011; Duncan & Tseng, 2010). The final chapter in this paper discusses the conclusions drawn from this research on how to more effectively use models for molecular genetics instruction at the middle school level.

Chapter 3

National Board Certification

National Board Certification (NBC) is a professional development program designed by the Nation Board for Professional Teaching Standards to improve the quality and standard of student education through the development of professional teaching standards. It provides a process for certification of teachers who aspire to meet the standards. This process is developed around five core propositions that represent the skills, knowledge and beliefs held by accomplished teachers. Teachers are evaluated through six assessment prompts and four portfolio entries (National Board for Professional Teaching Standards, 2014).

The assessment prompts are computer tests that focus on assessing teachers' knowledge of data analysis, understanding of the interrelationship of content ideas, unifying concepts between contents, identifying and targeting student misconceptions and the effective use of technology. The portfolio entries are a combination of student work, written explanation, and reflections on specific topics. They focus on understanding a teacher's ability to design instruction, probe student understanding, provide understanding through inquiry and document teacher accomplishments (NBPTS, 2014).

Portfolio entry number one focuses on teachers' design of instruction to develop a specific concept in students. In this entry, three different activities are selected that show how each activity builds on understandings from the previous activities to develop a student's conceptual understanding. A written commentary, sample work from two students and instructional materials are used to demonstrate how conceptual understanding was supported and progressed through the unit (NBPTS, 2014).

Entry two focuses on demonstrating how the teacher probes for student understanding. This entry includes a written commentary and a twenty-minute video recording of a class discussion that depicts a teacher using discussion and questioning to probe for students' understanding at the beginning of a unit or a new concept (NBPTS, 2014).

In entry three, teachers demonstrate their use of inquiry methods to develop understanding of a concept. This entry includes a written commentary and a twenty-minute video recording of a class discussion demonstrating how students use evidence to draw conclusions and develop understanding. The written commentaries for both entry two and three focused on describing and analyzing the effectiveness of the discussion and resulting conceptual understanding (NBPTS, 2014).

The final entry focuses on demonstrating the relationship of the teacher with the community and other professionals. This entry includes a written description and documentation of accomplishments in these areas and how they impact student learning. Both the assessment prompts and the portfolio entries are scored using a four point rubric. There are 400 points possible and candidates with a score of 275 or above are recognized as a National Board Certified Teacher. It is a difficult and rigorous process and the national and state wide passing rate is 50% (NBPTS, 2014).

Entry One

Instructional Design

This literature review focused on the concept used for portfolio entry one, which highlights the development of an important scientific concept. Using three different activities from a unit on genetics, I demonstrated how each activity built on the previous activity to develop student understanding of the concept. The core concept of this entry was determined after researching middle school and high school students' misconceptions in genetics.

Supporting Research

Middle school students have difficulty comprehending the behavior of molecules and have a limited understanding of molecules (Duncan & Tseng, 2010). As a result, middle school textbooks contain little emphasis on molecular topics, such as molecular genetics. Few research studies have focused on middle school students' abilities to understand the concepts of molecular genetics. Three studies, highlighted below, provided evidence that although not all molecular genetics concepts are appropriate, middle school students can comprehend molecular genetics.

Duncan and Tseng (2010) conducted a study on a five-week unit that was designed to help students develop a better understanding of the structures and processes involved in genetics. One ninth-grade and three eighth-grade classes followed a process of inquiry cycles starting at the macroscopic, organism level and worked down (in scale) to the microscopic level. Duncan and Tseng found that students were able to comprehend the central role that proteins play and the effect gene changes have on the structure and function of proteins, and that students were motivated to learn as well.

The second study was conducted by Duncan, et al. (2011) and looked at the ability of seventh grade middle school students to understand the link between genes and traits and the effect changes in genes have on traits. They implemented a two-week inquiry unit based on models created from the study of genetic phenomena, such as lactose intolerance and genetically modified crops. Through a process of creating and revising models, students developed an understanding of the link between genes and traits. At the end of the study, Duncan, et al. found that middle school students could demonstrate understanding of the role proteins play in producing traits and the effect that genetic changes have on proteins.

The third study that focused on middle school students was conducted by Friedenreich, et al. (2011) to determine the effectiveness of explanatory models in building connections between the three categories of genetics: classical, molecular and meiotic. The models were designed to cover several levels of organization, while also connecting microscopic and macroscopic organization levels of phenotype to genes and their processes. Friedenreich et al. studied mixed classes of 234 sixth through eighth grade low-performing students for two years. Modeling, computer animations and lectures were used to help students understand the concepts. Prior to this experiment, 4% of the students were able to independently make connection to genes and proteins. After instruction 55% of the students provided this explanation without prompting. As a result of this instruction, students showed a shift in their explanations of genes from being non-informational to informational. Data suggested that middle school students are capable of reasoning about and developing a molecular understanding of genetics as it relates to genes and proteins.

Research also suggests that by working with models, students may be able to overcome their misconceptions about genes, chromosomes, and DNA, and their deterministic viewpoint of genes by understanding that changes at the gene level can impact the structure and function of proteins (Duncan & Tseng, 2010). These findings influenced the decisions that I made when designing instruction for entry one. The instruction for the lesson sequence was designed to target student misconceptions relating to the relationship between genes, chromosomes and DNA. Research has shown that high school and middle school students have a hard time discerning between these structurally distinct levels of organization (Duncan & Tseng, 2010;

Duncan, et al., 2009). The other targeted misconception was the idea that one gene always codes for one trait (deterministic viewpoint).

Student-learning goals through the unit are summarized in the four sequential targets below.

1. Distinguish between genes, DNA and chromosomes
2. Construct a model of the relationship between genes, DNA and chromosomes
3. Determine traits represented by genotypes
4. Apply gene and trait knowledge to build model organisms

Computer Animations/Simulations of DNA and Chromosomes

At the beginning of this unit sequence, students were asked to make a drawing or a diagram showing genes, chromosomes and DNA. Following this, the class watched and recorded information from six short, 3-D video animations related to DNA make-up, organization, and replication. Following each animation, students summarized their ideas and also participated in both table-partner and whole group class discussions. Class discussions were particularly effective in engaging students and helping them to comprehend and identify the key points in the videos. The information gained in these videos was used by students to reconstruct or alter their models of DNA, genes, and chromosomes constructed at the beginning of the unit. The animations helped students examined the structure of DNA and see how DNA coiled to form chromosomes. By using these dynamic videos, my objective was to start building students' understanding of the structural and functional similarities and differences between DNA and chromosomes. Students were assessed formatively through questions, discussions and drawings.

Genes as Coding Units

As students developed a better concept of the relationship between DNA and chromosomes, they were ready to develop their understanding of a gene as a unit that codes for traits. Activities were used that helped students develop a concept of gene symbols, dominant and recessive relationships, and heredity predictions through the use of a punnett squares. Students were given guided practice using punnett squares to predict the offspring of a given cross. Students developed their understanding of how a gene carries a single unit of information that codes for a trait and that a gamete (reproductive cell) carries a single copy (allele) of each gene. This introductory activity involving inheritance patterns and predictions was followed up with labs that linked the concepts of genes on DNA and genes as a genetic trait through the crossing and creation of smiley faces and genetic dogs. For example, in the genetic dog activity, students linked the ideas of specific code (symbols) on chromosomes (strips of paper) coding for a trait, thus linking the idea that genes are found on chromosomes and that a specific sequence of code creates a specific traits. This basic knowledge was used to develop further understanding about genes, DNA and trait inheritance patterns in future labs. Teacher -student discussions were used to help students interpret this model, uncover current misconceptions, and provide feedback to students.

Assessing Progress of Conceptual Understanding

Students completed two question sets, designed to probe students' understanding of the relationship between DNA, genes, and chromosomes and their understanding of the inheritance of traits as a formative assessment near the end of the genetics unit. This was designed to uncover lingering misconceptions and determine students' progression on their understanding of the relationships among these structures. Once the learning goals had been met, students continued to develop their understanding of the relationship the environment plays on a gene's expression and the control of traits by multiple genes.

The first question (assessment) probe asked students to read through five different students' responses to a specific question. In this probe, four friends were talking about human DNA, genes, and chromosomes. They each had different ideas about where these structures were found. "*Whom do you agree with the most? Explain why you agree*." were the prompts used and the students were to determine which person they agreed with. Then they explained why they believed this statement to be true and what information they had relied on to make their decision. Students engaged in discussions with table partners and whole group class discussion after recording their responses. As a class, we narrowed the responses to two possible ideas and then used notes and the book to try to decide which statement was true. During this discussion phase, my job as the teacher was to facilitate classroom discussion, strive to clarify any statements students made and to pose additional questions to the class.

The second prompt was handled in the same fashion using a think-pair-share followed by a whole group class discussion. This prompt required students to apply their understanding of gene expression to determine the likelihood of two blue-eyed parents producing a brown-eyed child. This probe was designed to uncover whether or not students understood the complex nature of gene expression. Based on student responses to both prompts, lingering misconceptions were uncovered and addressed through end-of-unit and test-preparation activities.

Chapter 4
Discussion

Before beginning the NBC process, I explored literature on the misconceptions related to teaching genetics and the benefits associated with understanding molecular genetics concepts. One of the major misconceptions that stood out was the structural and functional relationship among DNA, genes and chromosomes, which became the focus of my portfolio entry one. Reflection on the unit and student responses showed areas of strength and weakness in my instructional design. The following sections highlight those areas and give recommendations for future instruction as well as conclusions drawn based on the literature.

Conceptual Understanding from Molecular Genetics Unit

Structural Relationship among DNA, Genes, and Chromosomes

At the beginning of the unit students watched simulations and produced models (illustrations and three-dimensional objects) to develop their understanding of structural relationships among DNA, genes and chromosome. Lessons developed the concept of a chromosome as a bundled and condensed form of DNA (genetic molecule) and *genes* as a specific section or segment of DNA. An assessment probe was administered to determine the progress of students' conceptual understanding. In the probe, students analyzed four friends' statements about the relationships among DNA, genes and chromosomes. The class discussion showed that students easily recognized the incorrect statements about chromosomes and genes but had difficulty recognizing the incorrect statements regarding the relationship between genes and DNA. Although a majority of the students were able to identify the correct response, they used a process of elimination to determine the correct statement, instead of understanding the relationship directly.

Functional Relationship between Genes and Traits

After completing the structural activities, student learning was focused on the functional connection between genes and traits. Activities incorporated students' knowledge of inheritance patterns (punnett squares) and gene symbols to produce model organisms, like the genetic smiley faces and genetic dogs. A final assessment probe checked for students' conceptual understanding. The probe asked students to explain the likelihood that two blue-eyed parents would have a brown-eyed child. Students correctly explained the simplistic relationship that certain gene combinations produce specific traits. Students did not discuss more complex relationships such as variation in the expression of the gene from environmental factors, despite exposure to these ideas through class discussion.

Model Purpose and Critiquing

To help students use models effectively, I included instruction on the process of developing and critiquing models. Students started the unit by illustrating their understanding of the relationship between DNA, genes and chromosomes. Following activities and class discussions, students altered their illustrations. For example, students used information from the DNA simulations to modify their previous drawings of the relationship between DNA, genes and chromosomes. After making three-dimensional models of chromosomes, they altered their models again. In this way, students developed more complex models to depict their conceptual understanding.

In addition to developing models, students also critiqued models. In their critiques, students looked for similarities and differences between the model and the actual structure. For example, after students drew their genetic dogs from the code found on DNA (paper strips with symbols), we discussed the similarities and differences between the strips of paper with symbols and the real DNA with genes. As the unit progressed, students developed their model critiquing skills.

Reflections and Recommendations for Future Lessons

Structural Relationship of DNA to Genes

At the end of the unit, there were two main concepts that were not sufficiently developed. The first was the concept of the relationship that DNA has to genes and chromosomes. The activities taught during this section focused on the molecular structure of DNA. Students were frustrated and did not connect the molecular structure of DNA with the structure of chromosomes. This inhibited students' ability to understand how DNA was structurally related to genes and chromosomes.

Future Conceptual Development

Research has shown that middle school students have a limited understanding of the nature of molecules, and instruction should not focus on minute molecular structures (Duncan, et al., 2009). This was validated by the high levels of frustration exhibited by my students. For middle school instruction, the relationship between DNA and chromosomes should focus on DNA's role as the structural building material for chromosomes, and not on DNA's molecular structure. The specific molecular relationship between genes and DNA will be developed in high school biology. From these concepts, students can understand the structural relationship among DNA, genes and chromosomes, without focusing on the difficult molecular aspects.

Functional Relationship of Genes and Traits to Proteins

The second concept was the understanding of the functional role that proteins play in the relationship between genes and traits. Students demonstrated a Mendelian gene to trait relationship but not a molecular relationship. Students used the basic rules of inheritance to explain why blue-eyed parents could not have a browned-eyed child, even though eye color is the result of multiple genes. With this limited understanding, students cannot accurately reason out the causes and effects of molecular phenomenon, which impacts their ability to gain a deeper understanding of genetics (Freidenreich et al., 2011; Duncan & Tseng, 2010; Marbach-Ad & Stavy, 2000; Venville & Treagust, 1998).

Future Conceptual Development

In order to develop conceptual understanding of the relationship between genes and proteins, instruction should include the study of genetic phenomena, like sickle cell anemia or lactose intolerance (Freidenreich et al., 2011; Duncan et al., 2011; Duncan & Tseng, 2010; Lewis & Kattmann, 2004; Marbach-Ad & Stavy, 2000). By using genetic phenomena to model molecular genetics concepts, students can learn about the effects of gene changes on proteins and physical traits, identify cause and affect relationships, and apply their understanding to other genetic phenomena. As students increase their understanding of the link among genes, proteins and traits, they minimize their chance of developing a simplistic, deterministic misconception of genes (Duncan, et al., 2009).

Understanding of Models Development

Providing instruction on models during the unit helped to develop my students' ability to critique models. As we progressed, they developed a greater ability to identify the similarities and differences between models and the actual structures of DNA, genes and chromosomes. Students progressed from a replica (level one) to a representation (level two) understanding of models. However, it is important to note that during this unit, none of my students displayed a level three understanding by using models to explain and predict phenomena (Grosslight et al., 1991).

Future Development of Model Use

According to the NGSS practices matrix, middle school students should be able to evaluate models as well as develop and use them to help make predictions and describe observable and unobservable phenomena by the end of eighth grade. In order for students to progress, specific strategies need to be incorporated into the lesson design. Two groups of researchers provided specific ideas for developing students' use of models.

Gustafson & Mahaffy (2011) developed a strategy for teaching and supporting their fifth-grade science students in interpreting, critiquing and developing models. They identified key questions for students to answer when critiquing a model. The questions focused on students identifying the similarities and differences between the real item and the model and identifying the concepts and misconceptions that could be construed from the model. The researchers found that students were able to more effectively use models for conceptual understanding. Incorporating these questions into my genetics unit would have helped students develop their understanding and use of models.

The second group of researchers, Windschitl and Thompson (2013) identified five strategies for using models: small group models, class consensus models, sticky notes and sentence frames, explanatory checklists and summary tables. For my genetics unit, the use of explanation checklists and summary tables seems most applicable. In the summary tables strategy, a large class data table is used to summarize the patterns, evidence and understanding received from each activity completed in the unit. The information from the summary table can be used to create the explanation checklist. This checklist contains the elements that students will include in their final model (Windschitl and Thompson, 2013). Both tools help students make connections between the various activities and provide feedback on their conceptual development. As students continue to use models, they will develop the skills to used models more effectively from year to year (Michaels, et al., 2007; Treagus et al., 2002).

Conclusion

Genetics is a complex content area and students are not graduating from high school with an appropriate understanding of genetics. It is challenging for students to learn and comprehend due to concept complexity, curriculum design, and student preconceptions. Research has suggested that one solution is to begin teaching the concepts of molecular genetics in middle school, instead of waiting until high school. Middle school students are capable of understanding the structural relationship between genes and chromosomes and the functional link among genes, proteins and traits. The purpose of this literature review and national boards certification project was to determine the benefits and challenges of conceptual models and the ways that conceptual models could be used to teach the relationship among DNA, genes and chromosomes. With the release of the NGSS, I also was able to determine how conceptual models fit into the scientific and engineering practice of NGSS. The follow conclusions were made in relation to these questions.

Benefits and Challenges of Conceptual Models

Models are vital tools for scientists and students. The NGSS identify models as an important scientific and engineering practice that spans all the content areas of science. Models develop students' scientific literacy, reasoning and skills as they develop, test, revise and apply their models. Such application requires high levels of reasoning about a concept as students modify their models based on evidence and data. Conceptual understanding is deepened and scientific practices are developed through the use of models.

In addition to the benefits of using models, there are challenges concerning their effective use. Students lack understanding about the purpose and use of models, seeing them as exact replicas of the real phenomenon or factor. This lack of understanding can cause students to make incorrect connections, which can lead to the development of misconceptions. Students need specific help understanding the purpose and effective use of models to limit the impact of the challenges.

Ways to Use Conceptual Models

Students tend to hold on to their Mendelian understanding of genetics and need a purpose for incorporating molecular genetics concepts into their schema. To effectively use models in genetics, teachers should target specific concepts, apply the concepts through models and provide support for students. Activities should be designed to focus on the structural relationship among DNA, genes, chromosomes and the functional link among genes, proteins, and traits. Studying genetic phenomena, such as lactose intolerance, provides a model for understanding these relationships. As specific strategies are used to support students' understanding and use of models, they will develop a deeper understanding of molecular genetics concepts that can be applied in high school science.

Conceptual Models and Scientific Practices of NGSS

Conceptual models are listed as the science and engineering practices dimensions; of the framework from which the NGSS were developed. To meet the scientific and engineering practices of NGSS, middle school students need to be able to understand the purpose of models. They must then develop models and use them to make predictions and describe observable and unobservable phenomena. Students need to receive explicit instruction on ways to analyze and develop models. Teachers can support students through a variety of methods, such as key analysis questions, summary tables and explanation checklists. As students are supported in their use, development and analysis of models, they develop the ability to use models effectively for conceptual understanding and will master the components of modeling.

References

Achieve. (2013). Next generation science standards. Retrieved from http://www.nextgenscience.org/

Alozie, N., Eklund, J., Rogat, A., & Krajcik, J. (2010). Genetics in the 21st century: The benefits & challenges of incorporating a project-based genetics unit in biology classrooms. *The American Biology Teacher, 72*(4), 225-230.

Boujemaa, A., Pierre, C., Sabah, S., Salaheddine, K., Jamal, C., & Abdellatif, C. (2010). University students' conceptions about the concept of gene: Interest of historical approach. *US-China Education Review,* 7(2), 9-1.

Brenda Gustafson, & Peter Mahaffy. (2011). The concept of a model. *Science and Children,* 49(1), 73-77.

Chang, H., & Chang, H. (2013). Scaffolding students' online critiquing of expert-and peer-generated molecular models of chemical reactions. *International Journal of Science Education, 35*(12), 2028-2056.

Churchill, D. (2013). Conceptual model design and learning uses. *Interactive Learning Environments, 21*(1), 54-67. doi:10.1080/10494820.2010.547203

Duncan, R. G., & Tseng, K. A. (2011). Designing project-based instruction to foster generative and mechanistic understandings in genetics. *Science Education, 95*(1), 21-56.

Duncan, R. G., Freidenreich, H. B., Chinn, C. A., & Bausch, A. (2011). *Promoting middle school students' understandings of molecular genetics*. Dordrecht: Springer Netherlands. doi:10.1007/s11165-009-9150-0

Duncan, R., Rogat, A., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th-10th grades. *Journal of Research in Science Teaching, 46*(6), 655-674. doi:10.1002/tea.20312

Freidenreich, H. B., Duncan, R. G., & Shea, N. (2011). Exploring middle school students' understanding of three conceptual models in genetics. *International Journal of Science Education, 33*(17), 2323-2349. doi:10.1080/09500693.2010.536997

Gobert, J., & Buckley, B. (2000). Introduction to model-based teaching and learning in science education. *International Journal of Science Education, 22*(9), 891-894. doi:10.1080/095006900416839

Greca, I. M., & Moreira, M. A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education, 22*(1), 1-11. doi:10.1080/095006900289976

Grosslight, L., Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science - conceptions of middle and high-school-students and experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Jensen, J., Kummer, T., & Banjoko, A. (2013). Assessing the effects of prior conceptions on learning gene expression. *Journal of College Science Teaching, 42*(4), 82-91.

Jonassen, D., Strobel, J., & Gottdenker, J. (2005). Model building for conceptual change. *Interactive Learning Environments, 13*(1-2), 15-37. doi:10.1080/10494820500173292

Kenyon, L., Schwarz, C., & Hug, B. (2008). The benefits of scientific modeling. *Science and Children, 46*(2), 40-44.

Legal challenge threat over GMO moratorium. (2013, Oct 13). Retrieved from http://www.abc.net.au/news/

Lewis, E., & Kattmann, U. (2004). Traits, genes, particles and information: Re-visiting students' understandings of genetics. *International Journal of Science Education, 26*(2), 195-206. doi:10.1080/0950069032000072782

Marbach-Ad, G. (2001). Attempting to break the code in student comprehension of genetic concepts. *Journal of Biological Education, 35*(4), 183-189. doi:10.1080/00219266.2001.9655775

Marbach-Ad, G., & Stavy, R. (2000). Students' cellular and molecular explanations of genetic phenomena. *Journal of Biological Education, 34*(4), 200-205. doi:10.1080/00219266.2000.9655718

Michaels, S., Shouse, A.W., Schweingruber, H. A., National Research Council (U.S.). Board on Science Education, & ebrary, I. (2008). *Ready, set, science: Putting research to work in K-8 science classrooms* National Academies Press.

Miller, K., & Levine, J. (2006). *Biology* (First ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

National board for professional teaching standards. (2014). Who we are. Retrieved from http://www.nbpts.org/

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K8.* Washington, D.C.: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Ornek, F. (2008). Models in science education: Applications of models in learning and teaching science. *International Journal of Environmental and Science Education, 3*(2), 35-45.

Pallant, A., Lee, H., & Pryputniewicz, S. (2012). Modeling earth's climate. *Science Teacher, 79*(7), 38.

Passmore, C., Stewart, J., & Cartier, J. (2009). Model-based inquiry and school science: Creating connections. *School Science and Mathematics, 109*(7), 394-402. doi:10.1111/j.1949-8594.2009.tb17870.x

Rotbain, Y., Marbach-Ad, G., & Stavy, R. (2006). Effect of bead and illustrations models on high school students' achievement in molecular genetics. *Journal of Research in Science Teaching, 43*(5), 500-529. doi:10.1002/tea.20144

Ruebush, L., Sulikowski, M., & North, S. (2009). A simple exercise reveals the way students think about scientific modeling. *Journal of College Science Teaching, 38*(3), 18.

Schwarz, C., Reiser, B., Davis, E., Kenyon, L., Acher, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654. doi:10.1002/tea.20311

Shaw, K. R. M., Van Horne, K., Zhang, H., & Boughman, J. (2008). Essay contest reveals misconceptions of high school students in genetics content. *Genetics, 178*(3), 1157-1168. doi:10.1534/genetics.107.084194

Shinya yamanaka-facts. (2013). Retrieved from http://www.nobelprize.org/nobel_prizes/medicine/laureates/2012/yamanaka-facts.html

Todorov, K. (2013, 10/12/13). Napa marchers protest Monsanto, GMO foods. *Napa Valley Register*

Treagust, D., Chittleborough, G., & Mamiala, T. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4), 357-368. doi:10.1080/09500690110066485

Tsui, C., & Treagust, D. F. (2007). Understanding genetics: Analysis of secondary students' conceptual status. *Journal of Research in Science Teaching, 44*(2), 205-235. doi:10.1002/tea.20116

Venville, G., & Treagust, D. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching, 35*(9), 1031-1055. doi:10.1002/(SICI)1098-2736(199811)35:9<1031::AID-TEA5>3.0.CO;2-E

Venville, G., Gribble, S. J., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives. *Science Education, 89*(4), 614-633. doi:10.1002/sce.20061

Windschitl, M., & Thompson, J. J. (2013). The modeling toolkit. *The Science Teacher, 80*(6), 63.