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A Cell's Story - From Growth to Mitosis

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Introduction

St. Georges Technical High School is one of four vocational-technical high schools in New Castle County, Delaware. The 1,119 students enrolled at St. Georges, represent a diverse community – urban Wilmington, suburban Newark, and rural Middletown. Students apply to St. Georges for a variety of reasons: learn a family trade, learn in a safer school environment when compared with a feeder high school, or earn a certification to join the workforce instead of continuing to a post-secondary school. Approximately fifty percent of the graduating class directly joins the workforce, an apprenticeship, or trade school. The remaining fifty percent continue on to college/university, or a branch of the military.

The technical school environment offers students a unique high school experience. Each student earns a certificate or license in their field of study upon graduation. The trades offered to our students are as diverse as the students themselves; ranging from nursing to carpentry, web design to culinary, automotive technology to early childhood education, and a dozen other options. In the school year 2016-2017, out of 802 upperclassmen, 20% study a trade in the Public/Consumer Services cluster, 23% study a Construction trade, 35% study in the Health Career cluster, and 23% study in the Business and Technology cluster.

Although St. Georges is a technical trade school, it is considered a branch of the public school system. Therefore, students have access to their career classes in addition to the academic courses offered within St. Georges. I am one of the science instructors within the building; teaching biology to sophomores, integrated science (earth and space) to juniors, and environmental science to seniors. This unit has been developed for the biology course mandated by the state of Delaware for graduation. All sophomores will take biology, regardless of their trade, however the classes are typically tracked based upon career area. Construction trades students take classes separately from health care trades due to scheduling.

As a fully-inclusive school, students of all ability levels study in the same classroom and therefore it becomes important to differentiate each lesson. Following the blended learning educational model, this unit provides students with several choices in how they learn, express knowledge acquired, the pace at which they learn, and utilize technology to enhance the overall learning experience. Within the blended model, the teacher becomes a facilitator while the student becomes the gatherer and organizer of information. My role as a facilitator is to provide students with appropriate resources to extract information and scaffold the lesson. It is essential that the teacher carefully identifies a limited set of videos, articles, and simulations to provide the

students with a choice in gathering information.

The state of Delaware has adopted the Next Generation Science Standards (NGSS) and is currently implementing them into the high schools. The standards are still being shifted between grade levels and therefore, standards once taught in high schools have been moved to middle school. This makes it challenging to assume a level of prior knowledge in order to effectively complete the high school standards. To best meet the new NGSS, the New Castle County Vo-Tech School District has adopted the Science and Global Issues (SGI) textbook and activity kits as the curriculum for the Biology course. This unit is designed to enhance and supplement current topics discussed in the text while creating a greater interactive curriculum.

Rationale

This unit on biology of the mammalian cell is designed to integrate science concepts with the school-wide focus on literacy. The literacy initiative includes reading, writing, speaking, and listening in order to improve scores on the SAT, which is currently used as a benchmark to measure proficiency in Delaware schools. All content areas, including the technical trades, are responsible for incorporating literacy strategies into lessons per administrative request. Examples include, analysis in a writing assignment, a “KWL” (know, want to know, learned) reading strategy, and “PVLEGS” (poise, voice, life, eye contact, gestures, speed) speaking/listening strategy. Each component of the unit will involve one aspect of literacy to support the school’s vision and ultimately support the increase in SAT literacy scores. The literacy standards are also addressed in the Common Core State Standards and will create a cross-curricular unit plan.

My main concern with the current structure of the cell biology lessons is the order of presentation, which appears to be disjointed. The disorganization causes students to struggle in making connections between molecular topics. Students study cell biology and genetics topics in the following order: functions of proteins, cell cycle, mitosis, DNA structure, meiosis, genes and chromosomes, protein synthesis, and stem cell differentiation. The students’ textbook covers each topic at a superficial level with the expectation that one topic is covered per day. The activities provided by the book are somewhat engaging to students but lack connectivity.

The goal of my unit is to create a coherent map of cell biology allowing students to make connections between previously disorganized topics. As a result, students will understand the cell cycle to be more than just a few phases that occur sequentially, but rather understand that protein synthesis, DNA replication, regulation, and cellular reproduction are occurring during the cycle for proper cellular function and gene expression. My goal is to add content-specific details and engaging hands-on experiences both of which will enhance understanding and create scaffolds as students’ progress through the unit. Each component will build on the prior component (which does not currently happen). In accordance with the school’s literacy focus, students are expected to gather notes in an organizer by reading text, listening to videos, having group discussions, and completing at least one writing assessment with associated rubric.

The unit is designed in the format of the cell cycle story and is divided into five major sections. (1) Students study the basic structure of DNA through an experiment and structural model. Students review DNA replication, which is taught at the middle school level in Delaware. Students isolate DNA from either strawberries, kiwis, or spinach depending on availability. Students build a class-sized model of a DNA double

helix. After understanding the structure of DNA, (2) students investigate how cells build a protein molecule through the process of transcription and translation. Students study the importance of protein structure and folding. Units two and three provide students an explanation of what occurs in G1 and G2 phases and review DNA replication in S phase. (3) Chromosomes and genes are discussed in conjunction with mitosis. According to the Next Generation Science Standards, students simply must know that the process creates two identical daughter cells. (4) Students study the importance of regulation in cell cycle and complete an exercise to identify other times regulation takes place. (5) Students complete a culminating drawing and writing assignment encompassing the entire cell cycle and stem cell differentiation. The group drawing is used as evidence within the writing assignment. These papers will be graded on a rubric provided to students ahead of writing.

As a result of completing the curriculum unit, students will be able to explain all stages of the cell cycle and their individual importance to a cell and organism, including the processes of protein synthesis and mitosis. Students will be able to explain DNA's significance in the production of proteins and chromosomal distribution in daughter cells. This curriculum unit on the cell cycle provides the groundwork for students to understand the causes of cancer, gene expression, and meiosis covered in later units.

Student Prior Knowledge

It is expected that students have a working knowledge of cell types, fundamental structures, and DNA replication. Students have a basic understanding of the differences between prokaryotic and eukaryotic cells to the extent that prokaryotes house their DNA within the cytoplasm rather than in the enclosed nucleus. Students study the differences between bacterial, plant, and animal cells; identifying the differences in structures and functions present in each. Relevant structures covered include: cytoplasm, ribosomes, nucleus, cell membrane, and cell wall. The eighth grade curriculum covers DNA replication and therefore is only revisited during the unit and not explicitly taught.

Students must understand that double-stranded DNA is systematically split apart by the enzyme DNA polymerase in order to produce two new complement strands. DNA polymerase "reads" the nucleotides on the template strands and incorporates base pairs onto the new growing strands.[1] DNA is always read moving from the 5' to 3' end. This creates a leading strand and a lagging strand. On the leading strand, the new strand of DNA is synthesized in the same direction that the replication fork is traveling; on the lagging strand, the new strand is produced in the opposite direction by creating short DNA fragments, Okazaki fragments, which must be fused together by ligase to form a continuous strand.[2] DNA replication takes place at multiple locations along a single strand of DNA. Replication is initiated at numerous points of origin based upon specific sequences of DNA and catalyzed by DNA polymerase and other proteins.[3] This process yields two identical copies of DNA that remain joined at the centromere within the nucleus until mitosis, at which time the two copies are split apart.

Teacher Prior Knowledge

Cell Cycle

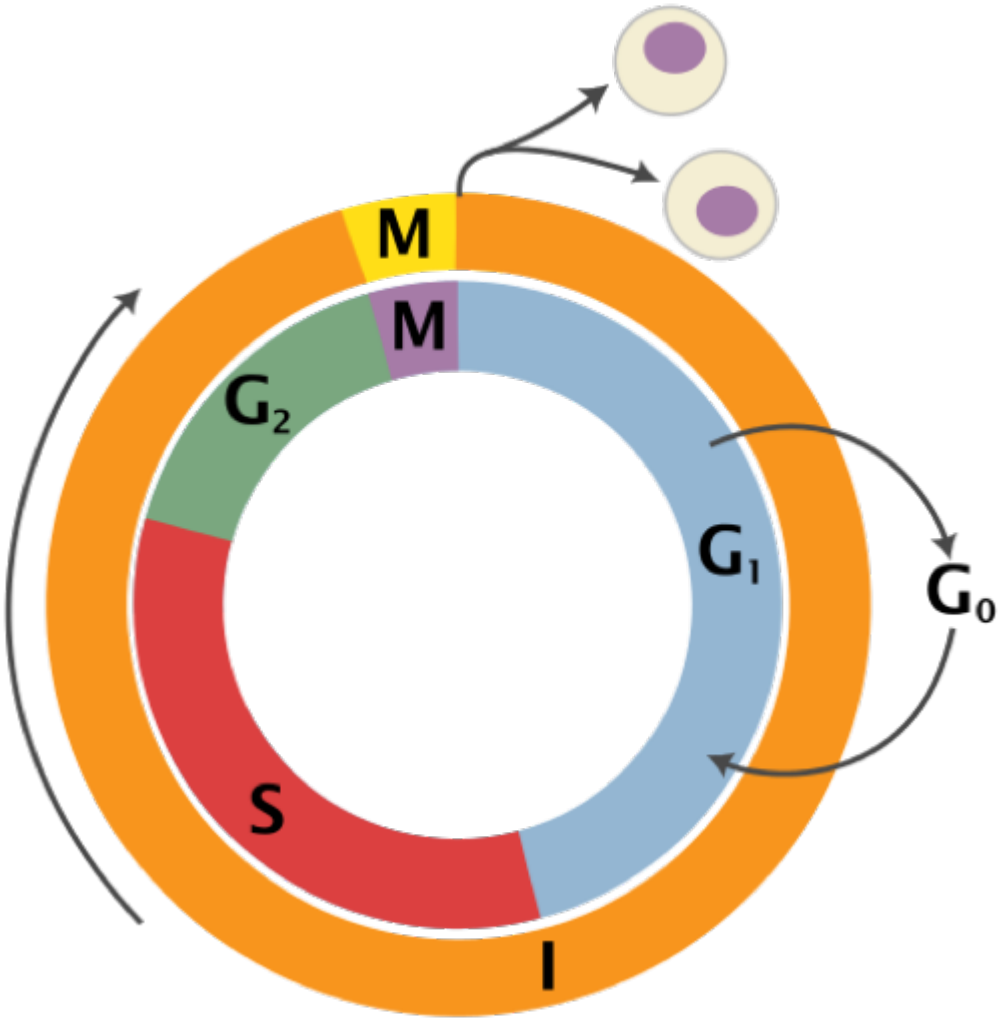

Figure 1. A basic representation of the cell cycle. Reproduced from Richard Wheeler (Zephyris) 2006.

The cell cycle is comprised of four main phases: G1, S, G2, and mitosis (Figure 1). During the G1 and G2 phases a cell's growth and maintenance of homeostasis takes place. The S, or synthesis phase, encompasses the process of DNA replication. Mitosis is the cell's process for cell division into two identical daughter cells. The length of time spent in each phase varies. The length of G1 can fluctuate greatly depending upon the cell but generally lasts for ten hours; S phase is consistently nine hours in length; G2 is approximately four hours, and mitosis approximately one hour.[4] The majority of a cell's life is comprised in G1, S, and G2 phases, collectively known as interphase. This accounts for 90% of a cell's life at which time DNA, RNA, proteins, and other biological molecules are synthesized.[5] Not all cells move through the cell cycle at the same time and rate; cells grow and divide asynchronously. In a given population of mammalian cells, 40% are in G1 phase, 40% in S phase, and 20% in G2 and mitosis phases (these are typical fractions).[6] Cell division encompasses only a small fraction of the entire cell cycle.

Signal checkpoints are encountered prior to a cell progressing from one stage to the next. However, not all cells travel along the traditional cell cycle pathway; some move from G1 to G0 where they exit the cell cycle and do not divide (refer to Figure 1). The decision to either commit a cell towards a mitotic pathway or to an alternative arrested G0 stage is made in the G1 phase of the cell cycle.[7] It is at the restriction point, or start location, that cells must evaluate both external environmental signals, such as available nutrients, and internal signals, such as cell size, to determine whether to commit to mitosis, differentiation, or stationary phase.[8] If the conditions are favorable, the cell will continue through the remainder of the cell cycle, otherwise the cell will either temporarily or permanently exit the cell cycle. In unfavorable conditions—such as depletion of growth factors, lack of nutrients, or cell crowding—cells may enter G0 phase, a state of quiescence.[9] Some cells remain quiescent for a short period of time while others such as nerve and muscle cells are permanently quiescent.[10] These cells can be activated to proliferate if nutrients such as sugars, salts, vitamins, and essential amino acids needed for their growth become available.[11] Temporary quiescence generally occurs between two successive cell cycles due to mitosis having depleted necessary requirements, such as size, for cells to immediately begin another cycle.

Cells exposed to appropriate conditions are permitted to begin the cell cycle. It is in the G1, or Gap 1, phase that the cell begins to grow and complete normal cellular functions. Cell growth requires the synthesis of new proteins, controlled by signaling pathways in response to hormones, available nutrients, and extracellular growth factors.[12] Checkpoints prohibit cells from continuing through the cell cycle if an appropriate size is not met. Cells almost double in size prior to mitosis, producing “balanced cell growth”.[13] The cell cycle process will be halted at a specific checkpoint within G1 if the cell has not reached the critical minimum size.[14] This is important because cells must create enough cytoplasm, proteins, organelles, and genetic material to create two viable daughter cells. This stage culminates when DNA synthesis is initiated by growth factors involved in a signal cascade.[15]

Following the first growth phase, cells enter into the synthesis, or S, phase. This stage is representative of DNA replication. It is imperative that the entry into S phase only occurs in cells that are committed to undergoing the entire cell division process.[16] The replication of the entire genome is important in order for the cell to complete mitosis at the end of the cell cycle and ensure that each daughter cell receives one complete copy of the genetic code. DNA replication occurs when the complementary strands are disassociated by DNA polymerase, read at multiple replication forks, eventually creating two identical strands of DNA. For more information, please refer to “Student Prior Knowledge” section.

G2 phase is the second stage of growth in the cell cycle. This stage occurs for a relatively short time period between DNA synthesis and the beginning of mitosis. It is presumed that this time is used to produce the machinery required for the cell to complete mitosis.[17] After cells depart from this stage, they will enter cell division. Mitosis is discussed in a later section.

Cell Cycle Regulation

Regulation of the cell cycle is designed around a series of signal checkpoints. The role of each checkpoint is to detect the failure of an early event, generate a signal, amplify and transmit the signal to another location, and inhibit the machinery of subsequent events.[18] Prior to moving between phases, signals must determine whether a cell has reached a specific benchmark. These checkpoints monitor potential DNA damage and have the ability to arrest cells in G1 phase and G2 phase.[19] The completion of DNA synthesis in S phase signals the process of mitosis to begin. Regulation of chromosomal alignment in metaphase of mitosis ensures that

genetic material is evenly distributed between the two forming daughter cells. A checkpoint at the completion of mitosis monitors cells before entering into another round of the cell cycle and replicating the DNA again. Cyclin-dependent kinases are a class of proteins that are responsible for the signal regulations.[20]

Checkpoints are a way for the cell to periodically self-assess. For example, a cell's ability to proliferate is determined in G1 by assessing available growth conditions. Cells that experience damage to the DNA in G1 will not be permitted to enter S phase until repairs have been made.[21] However, if regulation control fails, apoptosis, programmed cell death, or genetic instability can result.[22] Cancer is a potential outcome if a cell progresses through the cell cycle after regulation has failed. As stated in a previous section, the restriction point allows a cell to continue in G1 phase. Initiation at replication sites must be regulated to ensure that all of the chromosomal DNA is completely replicated, yet nothing is copied more than once.[23] Cells that have not completed DNA replication or have experienced some type of damage to DNA during replication can become delayed in G2 because mitosis will only proceed once replication has been completed and damage has been repaired.[24] It is evident that multiple checkpoints ensure DNA is copied correctly and the proper mechanisms are produced that would otherwise prevent the onset of cell division.

DNA structure

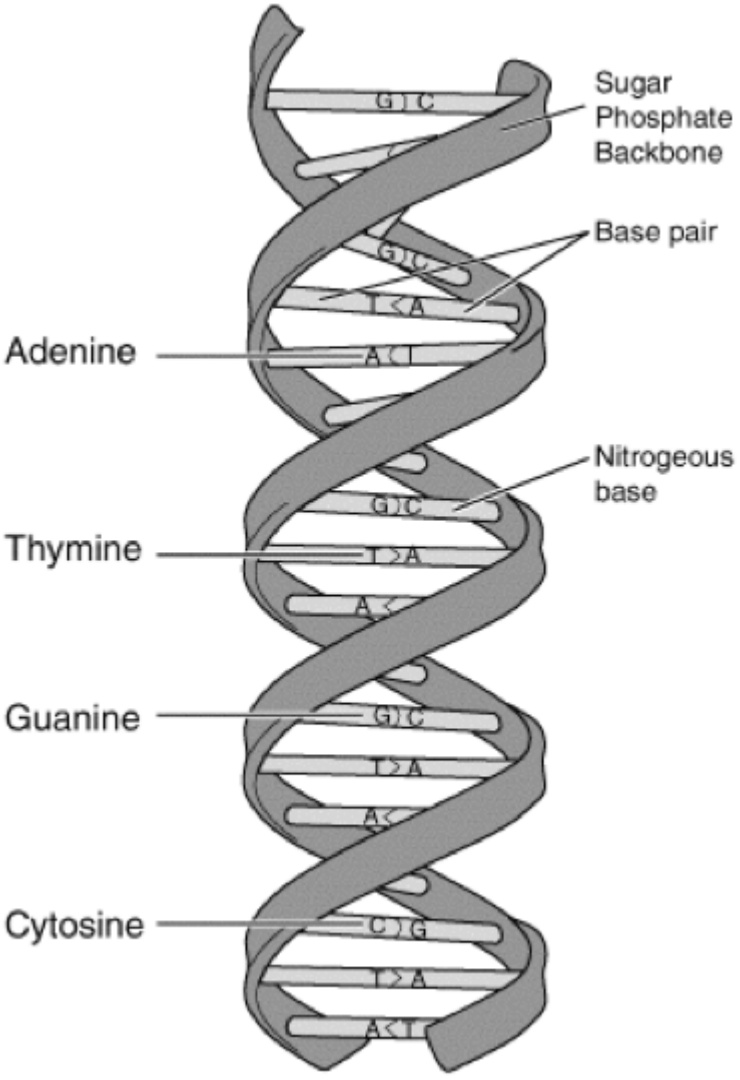

Figure 2. The structure of DNA. Courtesy of: http://www.genome.gov/Pages/Hyperion//DIR/VIP/Glossary/Illustration/base_pair.shtmlhttp://www.genome.gov/Pages/Hyperion//DIR/VIP/Glossary/Illustration/Images/dna.gif

Many of the molecular characteristics of DNA were discovered by Rosalind Franklin, but James Watson and Francis Crick were the first to describe its double helical structure. DNA is the genetic material encoding all living organisms. The molecule's structure is that of a double helix, where two complementary strands are linked together by hydrogen bonds. It is a polymer, made up of a sequence of nucleotides, which are the monomers. Each nucleotide is comprised of a negatively charged phosphate, deoxyribose sugar, and nitrogenous base. There are four potential bases attached to the sugar-phosphate backbone: adenine, thymine, guanine, or cytosine. Guanine and adenine are both purines, while thymine and cytosine are pyrimidines. Purines bond with pyrimidines in a predictable fashion; adenine always bonds with thymine and guanine always bonds with cytosine.

Protein Synthesis

Cell growth during G1 and G2 stages consumes a large amount of energy, because it requires substantial protein synthesis, which is the most energy-consuming process in the cell.[25] Every DNA molecule contains sections that code for proteins, regulatory molecules, and other expressed traits. These regions are known as genes. Less than two percent of a human's entire genome encodes for proteins and the remainder is involved in gene regulation.[26] It is not a simple process to build proteins from DNA. A segment of DNA must be transcribed, or rewritten, into RNA, transferred out of the nucleus, and translated into a protein. The protein must then be folded properly in order to complete its function. The central dogma of biology states that DNA is converted into RNA and then transformed into a protein.

DNA and RNA molecules share similarities in structure, yet possess key differences in their codes, influencing the necessity of both molecules in protein synthesis. DNA is a double-stranded molecule forming a helical structure, while RNA is often single stranded. The DNA code, as stated previously, is comprised of adenine, thymine, guanine, and cytosine nitrogenous bases. Each having a specific complement. RNA base pairs also contain adenine, guanine, and cytosine; yet DNA's thymine is replaced by RNA's uracil. This variance requires adenine to bond with uracil when transcribing from DNA to RNA. The sugar located in the backbone of these molecules also differs; DNA is made of deoxyribose, while RNA is made of ribose.

The process of biological transcription involves the conversion of the DNA sequence—stably stored in the double helix—into a transient RNA sequence. Complementary DNA strands must be temporarily separated in order to produce a messenger mRNA molecule. Genomic DNA is unable to travel outside of the nucleus; therefore, in order for the genetic information to travel to a ribosome in the cytoplasm to be expressed, the message on genomic DNA is copied into RNA. RNA polymerase is an enzyme that copies genes on a DNA strand. It recognizes a "promoter region" as the "start" signal for reading a gene.[27] Initiation sites begin at the 5' end of a DNA strand so replication forks are able to travel in the same direction as RNA polymerase, which is the protein responsible for copying the genes.[28] When RNA polymerase reaches the end of the gene, a terminator region signals for the RNA polymerase to stop transcribing.[29] The RNA molecule detaches from the DNA strand and the complementary DNA strands are reunited.

The single-stranded RNA molecule freely moves from the nucleus into the cell's cytoplasm. The cell processes the RNA strand by excising the introns, adding a cap, and attaching a poly-A tail, which make the mRNA suitable for translation in the ribosome.[30] This is in order to protect the genetic code when entering the

cytoplasm from the nucleus. Introns are not needed because they do not code for the specific protein in question; the exon sections are spliced together to form the correct and continuous instructions for protein synthesis (Figure 3).

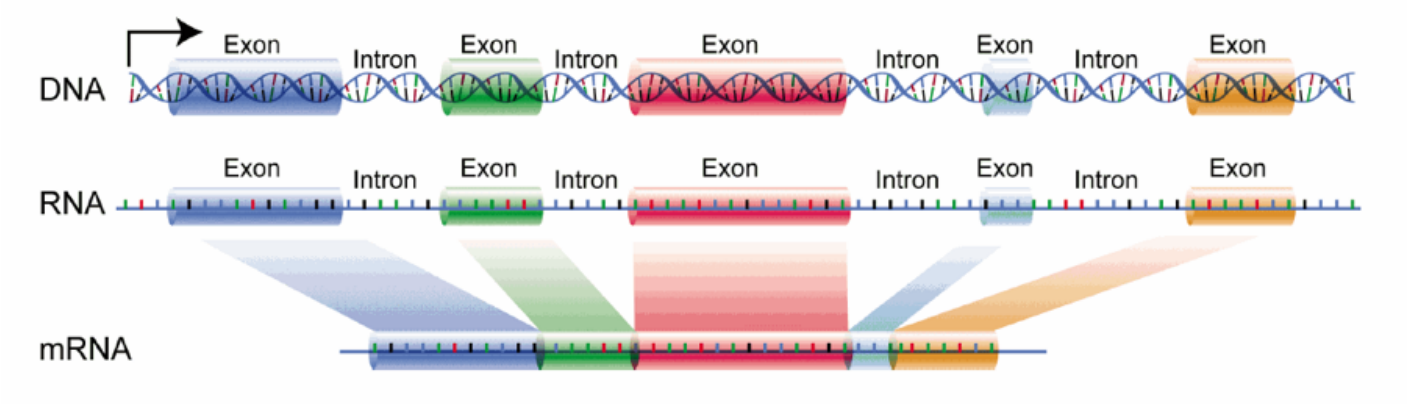

Figure 3. Excising introns from DNA/RNA and splicing exons in mRNA. Courtesy of: https://upload.wikimedia.org/wikipedia/commons/1/12/DNA_exons_introns.gif

Ribosomal production directly correlates to protein synthesis rates in most cells.[31] This is explained by an increase in protein synthesis requiring more ribosomal sites. When messenger RNA binds to a ribosome, the sequence of nucleotides is used to direct the synthesis of a sequence of amino acids. This process is called translation – converting the genetic sequence into a functional amino acid sequence. The translational initiation pathway requires the binding and subsequent dissociation from the 40S and 60S ribosomal subunits, facilitated by initiation factors.[32] The ribosome reads mRNA three nucleotides at a time, called a codon. There are sixty-one codons for twenty amino acids in addition to three stop codons making up the genetic code.[33] The small ribosomal subunit identifies the first AUG, or start codon, and releases initiation factors for the large ribosomal subunit to join, creating an initiation complex.[34] A tRNA molecule contains the complementary RNA sequence on one side, an anticodon, and the corresponding amino acid on the other. The tRNA is transferred to the ribosome and the new amino acid is added to the carboxyl end of the previous amino acid to form a peptide bond.[35] As amino acids are continuously brought to the ribosome, a peptide bond forms between them and the tRNA molecule is then released and able to bring another amino acid to the ribosome. When the ribosome encounters a termination sequence, or stop codon, a release factor recognizes the codon that mimics tRNA.[36] The amino acids bonded together by peptide bonds creates a polypeptide, which is also known as a protein once it has been fully formed and folded. Hundreds of thousands of different proteins exist in living organisms and are unique based upon the arrangement and length of amino acids.[37]

The structure and specific folding of a protein determines the function of the molecule. There are multiple types of proteins described by Tropp: catalytic proteins, structural proteins, transport proteins, receptor proteins, toxic proteins, and regulatory proteins which are pertinent to this unit because they are able to speed up or slow down biological processes such as cell cycle checkpoints.[38]

Gene Expression

Most cells in the human body, with the exception of red blood cells, contain the same genetic information, yet only specific genes are expressed by each type of cell.[39] From the point of fertilization, stem cells differentiate to eventually make all of the cells within the body. As stem cells differentiate, many genes are “turned off”

and specialized genes are “turned on”.[40] Gene expression is regulated by either allowing or prohibiting transcription factors from binding to the DNA strand when producing messenger RNA.[41]

Mitosis

During the two growth periods and S phase, DNA remains uncoiled, in the form known as chromatin. The genetic material is copied by DNA replication in S phase. After interphase—which is comprised of G1, S, and G2 phase—is complete, the DNA double helix coils up around histone proteins, creating a condensed structure called a chromosome. The coiling of the replicated DNA will develop the iconic X-shaped structure. The centromere is the central region holding the sister chromatids together. During mitosis, the replicated DNA are separated to create two identical daughter cells.

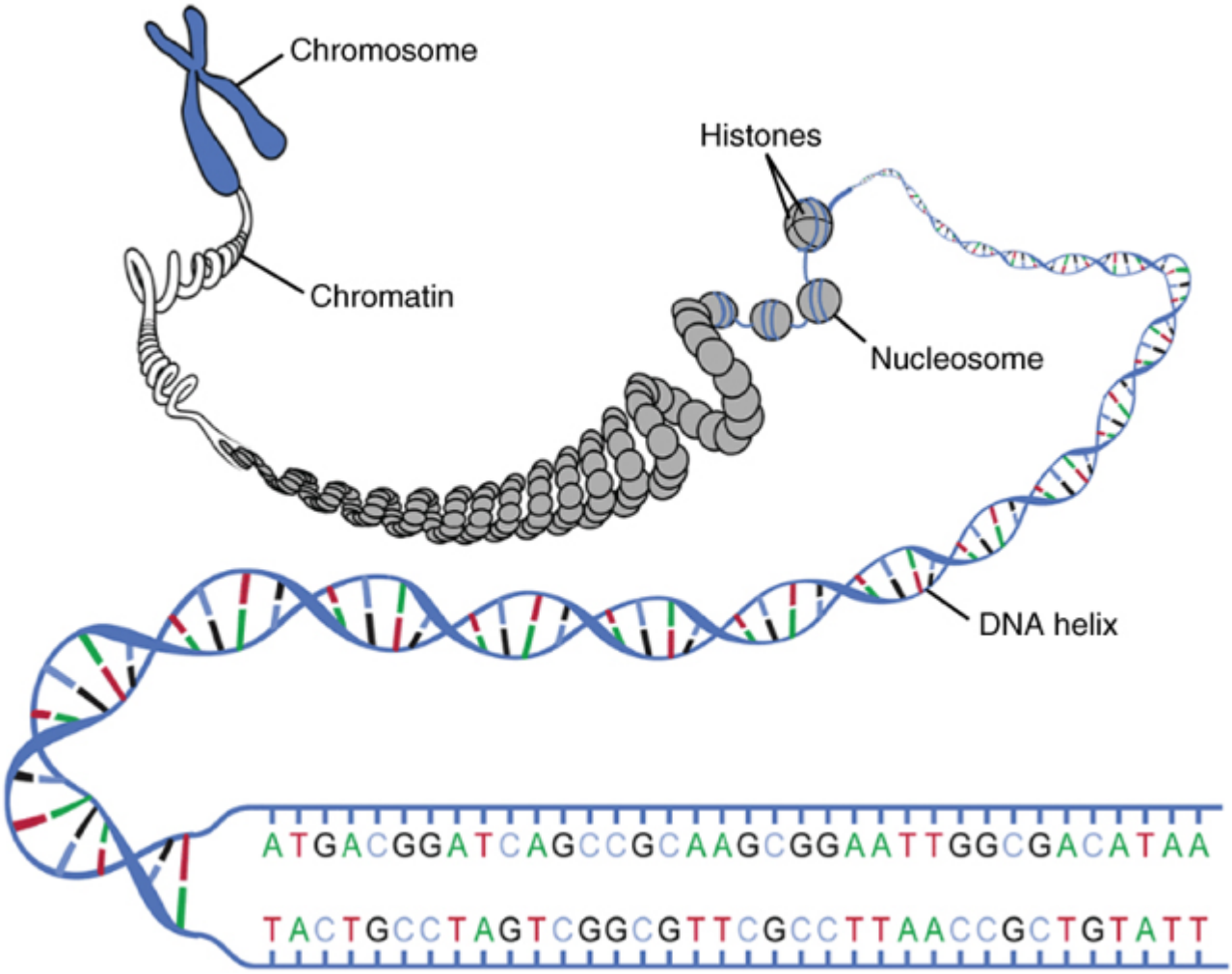

Figure 4. Replicated chromosome structure uncoiled to make individual nitrogenous bases visible. Courtesy of OpenStax https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface

The chromosomes become visible as the nuclear envelope, surrounding the nucleus, begins to break down and DNA has condensed. Prophase is described as the beginning stage of mitosis. Evidence suggests that chromosomes begin condensing in S phase and reach complete condensation during anaphase.[42] After the spindles have formed and begun to move to opposite sides of the cell and the nuclear envelope has disappeared, the chromosomes arrange themselves along the metaphase plate, located relatively on the central plane of the cell. Once the chromosomes are aligned in the middle and the spindle fibers are attached

to the centromere, the cell is considered to be in metaphase, where meta- indicates the middle. A mitotic checkpoint ensures that segregation occurs correctly by delaying the completion of mitosis until all chromosomes have been properly attached to the mitotic spindle.[43] The spindle fibers carefully pull, by shortening their length, the replicated chromosomes to opposite sides of the cell to ensure that each daughter cell receives only one copy of the chromosome. As chromosomes move towards opposing poles, the cell is said to have entered anaphase. Ana- is a prefix to indicate something that is “anti” or “against” and in this case the chromosomes are moving away from each other. As the chromosomes have segregated, the cell membrane begins to create a cleavage furrow and begins to pinch together. The nuclear envelope begins to redevelop around two separate nuclei. Telophase is the process by which the cell membrane pinches together and the nuclear envelop reforms. The last stage of mitosis, and the completion of the cell cycle, occurs when the two daughter cells have completely separated from each other, the nuclear envelope is intact, the chromosomes uncoil and are no longer are visible behind the membrane. Ideally two identical daughter cells have formed. There are incidences where the chromosomes do not separate properly during anaphase and create daughter cells with improper chromosome numbers.

Teaching Strategies

This unit is designed to incorporate the school’s literacy focus and create a scientific story for students to understand the many intricacies of the cell cycle. The literacy initiative requires students to read, write, speak, and listen at a proficient level in accordance with PSAT and SAT scores. Tenth grade biology students participating in this unit will be assessed on their content knowledge by a district-mandated unit assessment and their literacy skills by the PSAT. These results will then be used to measure the effectiveness of teachers. To comply with the school-wide implementation to improve literacy, the unit contains multiple reading, writing, listening, and speaking opportunities for students. The unit scaffolds from the basics of DNA structure and building to protein synthesis, mitosis, and cycle regulation in order to apply the knowledge to the entire cell cycle. Students will produce a written response based upon our class model, explaining how each of the various cell processes relate to the cell cycle as a culminating activity.

Schoology is the learning management system used by the entire school district for teacher collaboration, student learning, and professional development. All three courses I teach—biology, integrated science, and environmental science—utilize Schoology on a daily basis for students to access course resources, assignments, and assessments. This biology unit will be structured electronically with “completion rules” requiring students to move through the unit in a specific manner. This enables students to scaffold their learning with periodic checkpoints and instructor feedback throughout the unit. Students will not be free to explore all content simultaneously due to the completion rules. Too much information can create unintentional confusion. The intention of the rules is for students to be walked through the lessons in a systematic approach where one topic will build upon the next without the direct instruction from the teacher. All of the courses I teach are designed to be self-paced with strict deadlines for students to practice time management – an important 21st century skill.

Blended learning focuses on the integration of technology to create a personalized learning experience for students. The teacher provides a set of resources, in this case resources will consist of videos, simulations, articles, and hands-on experiences, and students have a choice in the time, path, place, and pace of their

learning. This means that students are able to complete lessons both in and out of the classroom utilizing resources that best fit their learning style, while moving at a pace comfortable to the individual. This type of learning experience allows students to practice various 21st century skills: extracting pertinent content from resources, using technology as a source of information, obeying deadlines, organizing and applying found information, and self-assessment. In this unit, students study DNA structure, protein synthesis, mitosis, and cell cycle regulation by extracting information from pre-selected resources in order to complete a graphic organizer. The graphic organizer will be used as a vehicle for students to collect and organize information and the instructor to review content and identify connections.

Although students will be working primarily at their own pace, there is ample time for peer collaboration. Groups of students will conduct a laboratory experiment to extract DNA from strawberries and kiwis. Analysis questions will be answered as a group to encourage discussion. While working individually, students will be free to work around peers to promote the discussion of content. The class will participate in a protein synthesis relay race where students must work together to convert a DNA sequence into an amino acid chain.

The Next Generation Science Standards ask students to construct an explanation based upon evidence and use a model to illustrate a process. This unit requires students to explain the structure of DNA, the process of protein synthesis, and the functions of proteins. Although initially these written responses will be collected as informal assessments for the instructor to gauge student progress, this knowledge will eventually be incorporated into the culminating writing assignment. All written responses will be graded on a rubric that students have access to prior to writing highlighting expectations. The class will create a life-sized model of the cell cycle to illustrate the stages and processes a cell moves through during its time towards reproduction. Students will also use this model to explain when some cells differentiate and why regulation of the stages is necessary.

Classroom Activities

DNA Structure

Understanding the structure of DNA is a visual experience for students. This portion of the unit is divided into two sections – a laboratory experiment and a modeling exercise. The process of inquiry is fundamental in the Next Generation Science Standards; therefore, the unit begins with a DNA extraction lab for students to continuously reference. Pairs of students (or groups of three depending on class size and resources) extract DNA from strawberries, kiwis, and bananas. In preparation for the laboratory experiment, the instructor is to review lab safety rules with students, prepare a buffer solution, and gather all required materials. Each pair or group of students will need some fruit in a Ziploc bag with all of the air removed, a funnel, cheese cloth or coffee filter, two test tubes, buffer solution, and isopropyl alcohol. Both the buffer solution and isopropyl alcohol might remain in the teacher’s possession until it is time to incorporate each one. Depending on the group of students, you may choose to have the chemicals pre-measured or have the students measure the solutions themselves. The goal of this experiment is for students to observe DNA at a macroscopic level. Students observe the similarities in appearance of DNA from various organisms in addition to the differing quantities of DNA in each fruit. Students understand all living organisms contain different amounts of DNA in their cells.

Modeling coupled with inquiry are important skills outlined in the Next Generation Science Standards. Individual students construct a three-dimensional model out of paper, representing the structure of a double helix molecule. Students identify the structure at the open end of adenine corresponds to the open end of thymine on a separate strand and the same holds true for cytosine and guanine. As students connect the appropriate purine and pyrimidine combinations from two pieces of paper, the structure will begin to fold into a helical shape. Without any formal instruction, students observe the complementary base pairings, the helical shape, and the 5' end aligning with the 3' end. Individuals connect their DNA structure to a peer's model and so on and so forth. The final structure produces one long helical shape incorporating the entire class's genetic code. A class discussion takes place to highlight student observations and further explain the complementary base pairings. The paper model is referenced in a later activity to show that DNA is able to condense when transitioning into mitosis.

Protein Synthesis

Prior to beginning this activity, the instructor should create a short set, one to five questions, of DNA replication review questions before permitting students to move to the content section on protein synthesis. On Schoology, the teacher is able to create a completion rule requiring a score of 100% before unlocking the next folder.

Students utilize teacher-selected resources on Schoology to understand the basic processes of transcription and translation – creating protein from DNA. Sample resources made available to students are located within the "Student Resources" section and include videos, text, and simulations. Within my classroom, various forms of graphic organizers are frequently used providing students with a plethora of possibilities when given the option to choose their own organizer. Students may choose any of the provided resources to gather information. To ensure correct information is collected and the students are focused on key concepts, the instructor provides the headings to be found on the organizer. Suggestions for this unit's headings include: DNA à RNA, RNA à Amino Acid, Amino Acid à Protein. It is at this point in time that the majority of notes are taken by the student. The instructor may choose to review the organizer once students have been given the opportunity to assemble their own knowledge.

To review the notes of protein synthesis, students are divided into teams of four in preparation for a relay race. Prior to playing, the teacher must create multiple DNA codons, complementary mRNA codons, tRNA anti-codons, and amino acids on individual cards. A codon chart must be provided for student use. The relay race can be set up in many ways depending upon available classroom space. The first student of each team picks up a single DNA card and transcribes it into mRNA. The same student "runs" or communicates to the next student the mRNA card that they are looking to find. Once the second team member locates the appropriate card, they must translate it into the complementary tRNA code. This code is communicated to the third student on the team. The third student must identify the appropriate amino acid corresponding with the given tRNA anti-codon. At this time, the third student communicates the amino acid that the fourth teammate should locate. The fourth student locates the amino acid card and either posts it or places it near the "finish line". They then choose the next DNA card and transcribe it into mRNA and continue the process until all team members have had a chance to participate in each role. The team who completes their four amino acid polypeptide correctly first, wins the game. If there are mistakes amongst any of the groups, they should be addressed at this time as a class learning experience. Teams are continuously re-grouped until every team in the round, regardless of place, correctly builds a protein.

Mitosis

Resources such as videos, simulations, readings, and a hands-on model are accessible to students to gather information that is entered into a graphic organizer. It is, again, up to the student's to decide which resources they use to gather information. As the instructor, do not overwhelm the students with too many resources but provide at least one option for each type of learner – kinesthetic, auditory, reading/writing and visual. At the completion of the graphic organizer, pop-beads will be used to depict the stages of mitosis. Students may choose to document their models as individual images or create all of the stages prior to documentation. Images should be taken either with a cell phone camera or computer camera and uploaded to an assignment page on Schoology. A brief description of each stage created is included with the uploaded images. The identified images and corresponding explanation will be graded as a formative assessment to assess student progress and understanding of cell division.

Cell Cycle and its Regulation

Students gather information based upon teacher-provided resources in a way that they feel comfortable organizing information. It is imperative that knowledge from previous activities is referenced because this is the final activity of the unit before completing the culminating activity. Students identify which locations in the cell cycle regulation occurs and why it is important at these times. As a formative check, students post to a discussion board documenting times in everyday life they encounter regulation and explain why it is important in the scenario. One example that can be used to model the assignment with students is that of traffic signals. Students should be able to identify the importance of traffic signals as regulating the flow of traffic to avoid vehicle accidents and for the safety of pedestrians. Students should relate these familiar modes of regulation, to regulation in the cell cycle. To emphasize the importance of these regulations in health, students read a case study on cancer and the role cell regulation plays and answer summarizing questions on Schoology.

Culminating Assignment

Students are placed in groups of two to four for the first section of this activity. The instructor should ensure that each time groups are assembled for any section of this curriculum unit, student combinations are varied. Each group will construct an illustrative model of the cell cycle and all of the discussed cellular functions within the image. The teacher is able to circulate the room and ask probing questions to the groups but should not be providing answers. The completed image should identify the major stages of the cell cycle, phases of mitosis and the movement of chromosomes, signal checkpoints throughout the cycle, and protein synthesis explained in G1 and G2 phases. Once the final image is created, the groups dissolve and individuals formulate a written response describing the cell cycle and all of its intricacies. The written response is graded on a rubric requiring students to address major content objectives as well as provide specific evidence based upon their group drawing. The rubric grades students on their ability to explain the steps of protein synthesis and the importance of its occurrence during G1 and G2 phases, significance of S phase in regards to mitosis, and the locations and impact of cell regulation throughout the cell cycle. It is up to the teacher's discretion whether grammar and spelling are graded components of the students' writing.

Student Resources

The following resources are organized in an order that the instructor might access them.

Video: DNA Structure and Function

https://www.youtube.com/watch?v=_POdWsii7AI

This Amoeba sisters video is to be used as student resource on DNA structure and function.

Simulation: DNA the Double Helix

https://www.nobelprize.org/educational/medicine/dna_double_helix/dnahelix.html

This interactive website to be used as student review of DNA replication.

Video: Protein Synthesis and the Lean, Mean Ribosome Machine

https://www.youtube.com/watch?v=h5mJbP23Buo

This Amoeba Sisters video is an excellent resource for students studying protein synthesis.

Article: DNA, RNA, Protein

https://www.nobelprize.org/educational/medicine/dna/index.html

This interactive electronic article is to be used as student text resource in the DNA replication section as well as protein synthesis.

Simulation: Mitosis and Cytokinesis

http://highered.mheducation.com/sites/0072495855/student_view0/chapter2/animation__mitosis_and_cytokinesis.html

This simulation explains the intricacies of mitosis for the students. It can be added to their resources.

Video: Mitosis: The Amazing Cell Process that Uses Division to Multiply!

https://www.youtube.com/watch?v=f-ldPgEfAHI

This Amoeba sisters video is a student resource for mitosis.

Appendix A

Next Generation Science Standards

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

Students study the structure of DNA and the process of protein synthesis. Students create a model to explain the structure of DNA and simulate how the genetic code is transcribed and translated into proteins. Functional proteins discussed include those involved in regulation.

HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

This standard is displayed by students building and uploading models of the cell division stages to Schoology for feedback. Students incorporate knowledge of the cell cycle to explain when differentiation occurs.

Common Core Literacy Standards

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

Students answering lab analysis questions are written as informative and explanatory text. As the culminating activity, students write informative text on the intricacies of the cell cycle supported by a visual model.

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Students experience all information as digital media in which they must interpret and organize the information to enhance understanding. Students implement this standard through the submission of the mitosis activity as digital media to present their understanding of the process.

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Notes

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