How to Build a Human Chapter 12:
If I Only Had a Brain

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This curriculum unit is recommended for Students who are in Grades 10-12 and Have an Interest in Biology or Human Physiology

Keywords: developmental biology, fetal, brain, neural tube, defect, brain, cognitive, degenerative, synaptic, fertilization, zygote

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit. (Insert a hyperlink to Appendix 1 where you've stated your unit's main standards. For directions on how to insert a hyperlink, see Fellows Handbook, p. 24.)

Synopsis: This unit is designed to explore developmental biology, particularly brain development in the human. Arguably the human body's most important organ, the brain sends and receives messages from all other parts of the body to keep the body functioning properly, and to address any problems that may develop. A study into how the human develops from a single fertilized egg to the beginnings of a nervous system in a manner of weeks can help students truly appreciate the many complicated and scientific phenomena that contributed to their current identity. Students will take traditional notes, research case studies in brain development, and write two papers, one on whether they agree or disagree that the incomplete brain development during adolescence leads to the erratic and unpredictable behavior of teenagers and another paper of a brain trauma, such as a disease or traumatic brain injury. Students will also view live development of vertebrate animals and dissect and a brain to better understand the complexity of the process. This unit will take 5-7 weeks to teach as a supplement to a class, or on a weekly basis for a yearlong course as a special topics class.

I plan to teach this unit during the coming year to 25 *students in Biology I classes grades 10-12.*

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Introduction

In human embryonic development, the brain is perhaps the most important. With a complex organism such as a human, a fully developed central (and peripheral) nervous system is paramount to the success of the organism. A dully developed brain keeps the heart beating, the lungs breathing, the eyes blinking, and all other essential functions of the body. The brain is command central, instructing every part of the body, voluntary or involuntary, to do their job. It is also the center of learning, the senses, emotions, and rational thought. Brain function also determines quality of life. Often if there has been a traumatic injury to the brain and the person is considered "Brain Dead". According to scientists and medical professionals "Brain death is defined as the irreversible loss of all functions of the brain, including the brainstem. The three essential findings in brain death are coma, absence of brainstem reflexes, and apnea. ... A patient determined to be brain dead is legally and clinically dead."[1] When a person is brain dead, often life support is terminated because there is no quality of life. The person cannot eat, drink, breathe, talk, think or any other functions without the help of a machine. But how and when does this most critical organ develop? Is it fully developed at birth, or even before? How does a human go from one cell to trillions, with 100 billion being reserved for this crucial command center of the human body?

Rationale

Some high school students, whether through a psychology class or anatomy and physiology, may learn about the brain and its parts, occipital lobe-vision, cerebellum-balance and coordination, etc. Almost none of those students will learn *how* these lobes develop and when. Developmental biology is a topic that is all but skipped in a general biology class. All you get is that a sperm fertilizes an egg and forms a zygote. Then, sometime layer, a human, or bird, or fish, or frog is hatched or born. Biology majors get a course of developmental biology in most curriculum at most universities, but in my developmental biology course I do not remember much on brain and nervous system development. It could be because I took the class over 20 years ago and found it very boring (the professor was ancient and had a very soft voice with black and white slides; I struggled to stay awake!).

School Demographics

The school at which I teach, Phillip O. Berry Academy of Technology is located on West Charlotte. POB is a magnet school, which means we draw from a student pool all over Mecklenburg County. Out of a total of 1818 students, approximately 65% are Black or African American, 22% are Hispanic or Latino, 6% are Asian, 4% are White, and 3% are multiracial or of other ethnicities. Our school is totally immersed into STEM (Science Technology Engineering Mathematics). In addition to the core classes (social studies, English, science, PE, and math), we have three 'academies' where students focus their studies, Engineering, Health Science, and IT. I teach in either the Health Science Academy or Biology as a core course. We also have a small arts department that offers band, orchestra, and visual art. I think the best characteristic of our

school is the open mindedness of our students. I love seeing the blue hair, graphic novels, and the other ways in which our students express themselves.

Course Research

In human embryology, the brain begins to develop around 4 weeks. The reason I have penned the brain development as Chapter 12 is based on the Carnegie system of human development. The Carnegie stages are named for the Institute that began collecting and categorizing human embryos[2]. Some of the images are pictured below. One of the major contributors of the Carnegie Collection is Franklin P. Mall (1862-1917) who has done extensive work at both the Carnegie Institute in Washington and Johns-Hopkins University.

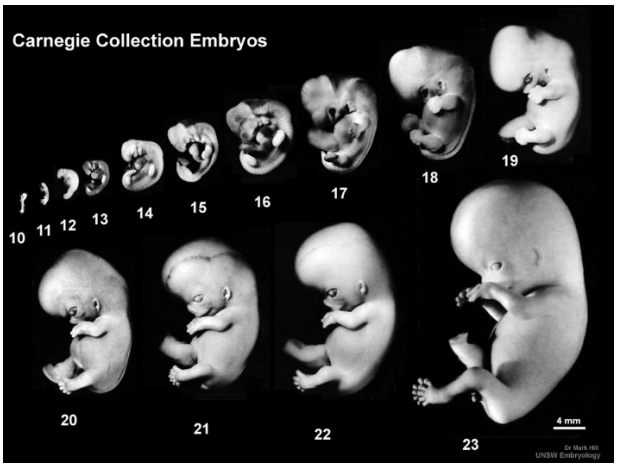


Figure 1. Carnegie Stages of development. Human forebrain

significantly developed at stages 12-13. Images from Carnegie

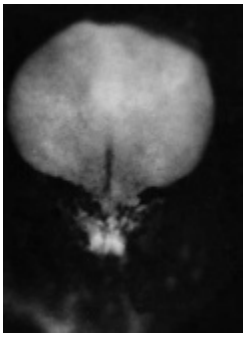
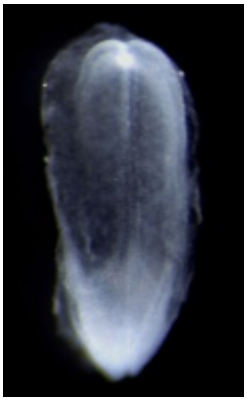
Collection©.

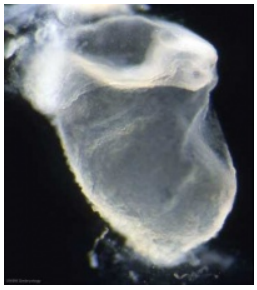
Before delving into the detail of brain and central nervous system development, one must first study the development of the human as a whole. For the purposes of this work, we will state the story of a human development begins at fertilization. Merriam-Webster dictionary defines fertilization as "the process of union of two gametes whereby the somatic chromosome number is restored and the development of a new individual is initiated"[3]. There are two important words in this definition – gamete and somatic. A *gamete* a sperm for males and an egg or ovum for females. When two different gametes of the same species are joined, fertilization occurs. *Somatic* number refers to two full sets of chromosomes (2n) which is required for a viable organism. In humans, 2n=46. Each gamete contains only 23 chromosomes, 22 somatic (non-sex) chromosomes and usually two sex chromosomes XX for females and XY for males, although some chromosome disorders allow for humans to have a more or less chromosomes present. Each viable (able to produce an offspring) ova contains 22 somatic chromosomes and an X chromosome, and sperm contain 22 chromosomes and either an X or a Y chromosome; therefore, sex determination is carried within the sperm cell. When sperm are released, they must swim up the vagina, through the cervix and uterus to the fallopian tube, where an egg located, waiting to be fertilized. It takes many sperm to break down the zona pellucida (outer membrane) of the egg, and they do so with enzymes. Even though it takes hundreds (maybe thousands) of sperm to break down the zona pellucida, only

ONE sperm will enter the egg and fertilize it. Afterward, a cortical barrier is formed so that no more sperm can penetrate the egg[4]. At this point, the fertilized egg is called a zygote.

Week 1 after fertilization covers Carnegie stages 1-4. Carnegie stage 1 lasts for 1-2 days. The zygote has not yet formed its own nucleus, and the polar bodies (non-viable ova produced during meiosis) are still present. The zygote is small but visible, about .15 mm in size. During Carnegie Stage 2 mitosis begins, culminating with the formation of a morula, a solid ball of cells. This stage last for 2 days, going to three days past fertilization. During stage 3, a blastocyst (hollow ball of cells filled with fluid in the middle). The blastocyst has migrated from the fallopian tube to the uterus, it then "breaks free" of the zona pellucida, and attaches to the uterine wall. After the egg attaches to the uterine wall, the woman is considered to be "pregnant"[5]. Stage 4 consists of further implantation into the uterine lining, and an increase in the hormone hCG, of which levels are used in pregnancy test. We 2 consists of stages 5 and 6, in which further implantation, a "hatching" and a yolk sac are formed.

Week 3 consists of Carnegie stages 7-9. In stage 7 critical events occur, including gastrulation. The blastula, still a single layer of cells, reorganizes at this points into three distinct layers in a process called gastrulation. The three layers formed are called the ectoderm, mesoderm, and endoderm. From the ectoderm, the nervous system neural tube (spinal cord), neural crest, and epidermis are formed. The neural tube and neural folds begin to form during stage 8. The mesoderm gives rise to muscle and connective tissue (blood, bone, adipose), and many of the major organs such as the gonads and kidneys. The endoderm gives rise to the dermis, respiratory and gastrointestinal tract, including the liver and pancreas early development of these systems begins in stage 9.



Figures 2-5. Stages 7, early and advanced stages 8 and stage 9 respectively Two stages of 8 clearly shows neural tube and neural folds. All images from the Carnegie collection ©.

Week 4 (stages 10-13) sees critical development in the body systems, including the brain and nervous system. Stage 10 sees the neural crest forming the spinal cord and neural folds beginning the hemispheres of the brain. The neural crest also forms the bilateral halves of the body, culminating in paired organs such as the lungs and kidneys. During stage 11 the endocrine system begins development with the thyroid gland. Stage 12 sees the "brain" begin to shape and the neural tube begins to close. It is at this critical point between stages 12-13

that open neural tube defects such as spinal bifida and anencephaly can occur. During stage 13 the neural tube closes, ensuring that the nervous system will develop fully. Also the senses, such as smell, begin to develop. The development of senses indicates increased development of the brain as the parietal, temporal, and occipital lobe play critical roles in the senses. The peripheral nervous system buds from the spinal cord also form.[9]

Maternal Health and Brain Development

Maternal health is important to fetal brain and nervous system development. Nutrition is key to the healthy development of a fetus without any defects. Mothers are encouraged to take prenatal vitamins, particularly folic acid, to discourage major defects of the baby's brain (anencephaly) and spine (spinal bifida). The main issue that can arise from lack of folic acid is open neural tube defects. During stages 12-13 of Carnegie development, the neural tube closes, which is key to a fully developed, undamaged nervous system and brain. If the neural tube doesn't close completely. Serious defects that will affect the child for the rest of its life. Stages 12-13 occur at about 4 weeks of pregnancy; in which many women don't yet realize they are pregnant. If the baby is planned for, the mother can begin taking prenatal vitamins and extra folic acid before conception to be sure for healthy brain development.

Illness, just like lack of nutrition, can lead to devastating developmental defects of a fetus. The Zika virus, causes a condition called microcephaly in pregnant women to the fetus. The Zika virus is spread through the bite of a mosquito.[10] The highest risk is in tropical to subtropical areas where mosquito-borne illnesses are prevalent. This includes the southwestern United States, Florida, Mexico and south America, Sub-Saharan Africa and Southeast Asia. There is no vaccine or cure for Zika, treatment consist of rest and ruling other conditions like Dengue. Microcephaly occurs when a baby is born with a head (and brain) much smaller than normal. Conditions that affect the baby motor skill development, intellectual disabilities, and problems with hearing and vision. These conditions are chronic and irreversible.

Fetal alcohol syndrome is a condition in a child that results from alcohol exposure during the mother's pregnancy. Fetal alcohol syndrome causes brain damage and growth problems.[11] The problems caused by fetal alcohol syndrome vary from child to child, but defects caused by fetal alcohol syndrome are not reversible. There is no amount of alcohol that's known to be safe to consume during pregnancy. The severity of fetal alcohol syndrome symptoms varies, with some children experiencing them to a far greater degree than others. Signs and symptoms of fetal alcohol syndrome may include any mix of physical defects, intellectual or cognitive disabilities, and problems functioning and coping with daily life.[12]

Brain Development After Birth

At birth, the average baby's brain is about a quarter of the size of the average adult brain. Incredibly, it doubles in size in the first year. It keeps growing to about 80% of adult size by age 3 and 90% – nearly full grown – by age 5. A baby is born with all the neurons they will ever have, but lacking the synaptic connections. The synaptic connections help us move, think, feel, and do just about everything we do in life. The baby's exposure to constant stimuli is what builds synaptic connections and increases brain development. It is also why educations, doctors, and child development specialists urge parents and caregivers to read to babies and young children.

The early childhood years are crucial for making these connections. At least one million new neural connections (synapses) are made every second, more than at any other time in life. Different areas of the brain are responsible for different abilities, like movement, language and emotion, and develop at different rates. Brain development builds on itself, as connections eventually link with each other in more complex ways. This enables the child to move and speak and think in more complex ways.

Until recently, early childhood received the most attention and was the most research stage of development. However, recent (within past 8-10 years) studies suggest that the adolescent years play a crucial role in brain development and can explain some of the erratic behavior of adolescents. A study done in Germany states that "The brain of the adolescent goes through a new phase of plasticity in which environmental factors can have major, lasting effects on cortical circuitry. This opens up new opportunities for education. For example, for the very reason that adolescents are so readily influenced by emotions, they stand to profit from learning experiences taking place in a positive emotional context that are intentionally designed to train emotional regulation. Given that risky behavior in adolescence has a neurobiological basis, attempts to suppress such behavior completely seem bound to fail. It would be more reasonable to enable adolescents to have emotional experiences in a safe environment, and to increase the social rewards associated with non-risky behaviors."[6]

Brain Anatomy

The Brain can be divided into three main parts, the Cerebrum, the cerebellum, and the brain stem. The cerebrum is divided into two hemispheres, and four lobes. The frontal lobe is responsible for problem solving, personality, reasoning, and some motor function. The parietal lobe is responsible for sensations such as touch, pain, hot and cold, and handwriting. The temporal loves are involved with memory and hearing. And the occipital lobe is responsible for processing vision. The cerebellum, just below the cerebrum, is responsible for balance and coordination. The brainstem handles involuntary functions such as heartbeat, breathing, blinking and reflexes.

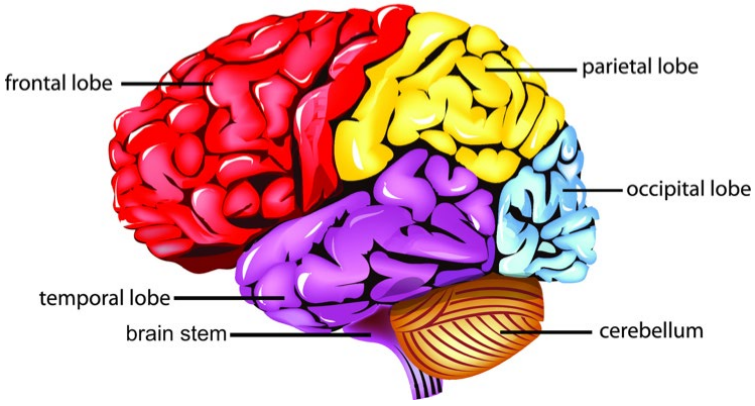


Figure 6. Diagram of the brain, showing lobes of the cerebrum and cerebellum and brain stem. Photo courtesy of National Brain Tumor Society.

Brain Injury/Trauma

There are several ways the brain can be injured throughout life. Concussions can be anywhere from mild to severe, with symptoms ranging from headaches and dizziness to loss of memory, coordination, and concentration. A concussion is a brain injury caused by a blow to the head. In most cases, the symptoms are temporary and with rest, the brain will heal. However, frequent concussions and other brain injuries can lead to CTE, or chronic traumatic encephalopathy. This is a neurodegenerative disease caused by repeated head injuries. Symptoms of this disease occurs in stages. Stage 1 involves frequent headaches that don't respond to medication, loss of attention and concentration. Stage II involves depression, severe mood swings, violent outbursts of temper, and short term memory loss. A condition known as executive dysfunction between stages II and III. This includes failing in certain "higher order thinking and organization skills" such as planning, time management, remembering details, switching focus to another topic, multitasking, and acting and speaking appropriately. Stage III sees stage II symptoms such as violent outbursts and mood swings worsen, and the ability to control oneself is diminished. Stage IV is characterized by severe memory loss and dementia. The violence and outburst continues.[7] Concussions and CTE is frequently caused by contact sports such as football and boxing. Aaron Hernandez, a former NFL player for the New England Patriots, murdered at least two people (he was only convicted for one murder) and was convicted in 2013. After conviction he committed suicide by hanging himself in his prison cell with a bed sheet. According to researchers at Boston University, Hernandez suffered from the 'most severe case of chronic traumatic encephalopathy (CTE) ever discovered in a person his age (27 years)'.[8]

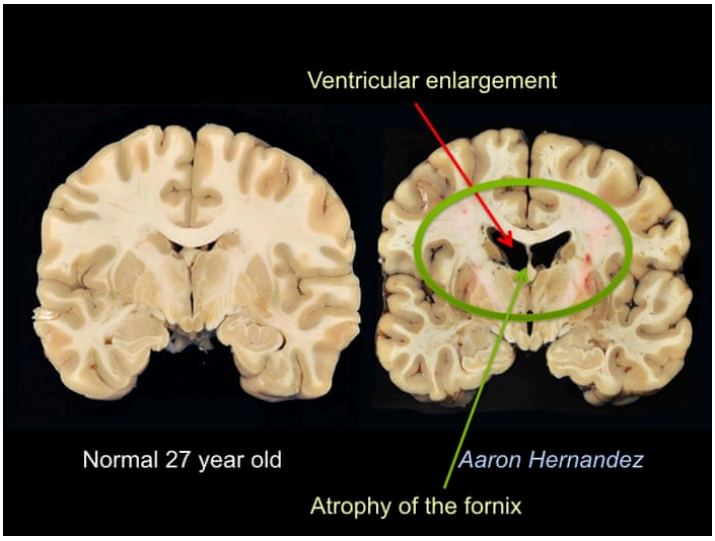


Figure 7. Cross Section of Brain of Aaron Hernandez versus a normal 27-year-old mail. Photo courtesy of *The Guardian*.

"Brain Death"

Often on TV and frequently in real life, you will come across someone who has profound brain trauma, either due to an accident, gunshot wound, stroke, or other condition. The doctors advise the next of kin that the patient is 'brain dead' and that its "time to turn off life support'. What does being brain dead mean? A definition of brain dead was given earlier in the unit here. The debate becomes whether the patient should continue to be supported by machines if they cannot do anything for themselves and, unlike a coma, cannot breathe on their own. Some will argue that their quality of life has completely diminished since they cannot interact with their environment, dream, communicate or even breath on their own. These are in favor of terminating life support. On a practical side, it is very expensive to keep someone on life support. Many people also have a living will or a DNR (Do Not Resuscitate) order with specific instruction on what do in case the quality of their life is diminished.

Instructional Implementation

Teaching Strategies

I think the best way to teach brain development to high school students is to include as much visual stimulation as possible. Even though some students can and do enjoy learning by reading and taking notes, many students are visual learners. Videos and images will be the key to hooking the students interest. The students, will, however, also need to take detailed notes with many drawings. They will also have to keep a detailed vocabulary list, which will also be included in the appendices of this publication. Giving each student a topic to research will help as well. Developmental biology is not normally covered in either general or AP biology, but some schools (like mine) teach a special topics class call neurobiology, which focuses on the nervous system. I want to focus more on the central nervous system, particularly the brain and its significance.

The course will have to begin with teaching about the brain, its parts, and its significance to the functioning of the entire human body. The class will be organized into 4 or 5 units. Basic anatomy of the brain, such as the lobes, cerebellum and brainstem will compromise the first unit. The second unit will focus on the embryonic development of the brain. This unit may end up being two, since this is most of the focus of the class. I may choose to divide this into early development and late development (embryonic). I think this part will be the most challenging and most difficult for the students to master. The terminology and complex course matter (which will include general human development and the Carnegie stages) will require the most. If this course will be a separate class on a semester basis I predict this will take 6-8 weeks to cover, master, and assess. The next unit will consist of later development of the brain, through infancy, early childhood, adolescence, early and late adulthood, and late life. The last unit will consist of issues with the brain in three parts, during embryonic development, traumatic injuries and degenerative disorders such as Alzheimer's, and dementia. Students will have a final project in which they have to pick a disorder or injury that affects the brain. Students will have to do a research paper on the topic, and a presentation that includes a real case study.

Lessons and Activities

During the first unit, students will not only learn the lobes and functions of the different parts of the brain, but they will dissect a sheep's brain and build their own brain model of a human brain out of clay, plaster, or any materials we have available in class. They will study the case of Phineas Gage, a rail worker who in the late 19th century suffered a traumatic brain injury to when a 43 in long ((1.25 in diameter) rail bar entered his skull at the lower right cheek and exited through the top of his head during an explosion. Even though his brain was able to physically recover somewhat, the damage to his frontal lobe permanently altered his personality. Assessment in this unit will primarily be in scenarios, in which a brain injury is suffered and certain functions have been affected, students must be able to identify which part of the brain is being affected by the symptoms; or predict which body functions would be affected if a certain part of the brain was injured.

The second unit will consist of embryonic development of the brain. The main focus would be the embryonic development of the brain. Students will take notes on and research the process of fertilization, the Carnegie stages and fetal development of the brain. In lab, students will observe the embryonic development of the Casper Fish ™ to better visualize the process. Students will research the research the Carnegie stages in which brain development occurs, and when during fetal development the fetus can start to process high level brain function like the hearing, smell, taste, touch and respond to stimuli. Assessment will focus mainly what brain development happens when and how this affects the overall fetal development. Sample lesson plan and assessment will be included from this unit in the appendices.

The third unit will consist of a series of case studies on adolescent brain development. I am hoping this topic will particularly draw the interest of the students, considering this is their age range. The brain is still not fully developed, and the intersection between unbalanced hormones and the incomplete synaptic connections in the front lobe contribute the emotional and erratic behavior of adolescents. I will have students write an opinion essay on whether they believe the research is substantiated or not. They will have to cite evidence to support their position from research and current publications. This will serve as their assessment for this unit. The appendix will have a rubric for the essay.

The fourth and final unit will consist of what happens to the brain in a time of crisis. We will deal with injuries during all stages of life. During embryonic stages, we will study open neural tube defects and the link to folic acid and fetal alcohol syndrome which will be a case study. Next we will discuss concussions and traumatic brain injury due to accidents or lack of oxygen. Concussions are particularly important to discuss with students at this age who may be athletes or learning to drive, which increases their chances of getting a concussion. Case Studies of Aaron Hernandez, whose frequent head trauma led to chronic traumatic encephalopathy (CTE) and Muhammad Ali, whose career in boxing may or may not have contributed to his development of Parkinson's Disease; will be analyzed, including comparing and contrasting the two conditions (CTE vs Parkinson's) and what (if any) prevention methods can be taken. We will also attempt to answer the question, *what does it mean to be brain dead?* Which will include a Socratic seminar on when it is appropriate (or is it ever) to take someone off life support because they are "brain dead". See appendix for rubric for Socratic seminar.

Final Project

As a culmination of the class and for students to apply what they learned, students will do a final project. The Final project will bring the purpose of the class back to the forefront: The recognize the significance of the brain and what happens if there is an injury or condition that diminishes brain function. Students will have a list of brain injuries of diseases to choose from. Some examples include CTE, Alzheimer's, Parkinson's Disease, Brain Tumors, etc. The students will write a well-researched paper on the condition, they must also cite at least one case study or example of a person with the condition. In addition to the paper, students must also prepare a presentation. The presentation can be a slideshow, video, poster, or pamphlet. A rubric with a checklist of everything that must be included with the presentation must be given to the student. The research paper will count for 40 percent of the final grade, the product of the presentation will be 40 percent and the presentation itself will be 20 percent.

Appendix 1: Standards

Biology (North Carolina Essential Standards)

Bio 1.2.2: Analyze how cells grow and reproduce in terms of interphase, mitosis, and cytokinesis.

Bio 1.1.3: Explain how instructions in DNA lead to cell differentiation and result in cells specialized to perform specific functions in multicellular organisms.

Bio 3.2.1: Explain the role of meiosis and fertilization in sexual reproduction and genetic variation.

Human Body Systems (PLTW)

HBS 2.1 The structure and function of the brain, and the consequences of miscommunication in the human body**.**

KS6.2.1 Model the structures of the central nervous system.

KS6.2.4 Match regions of the brain with their primary function in the human body.

Appendix 2: List of Materials

- Modeling Clay (I recommend the clay from Anatomy in Clay, it doesn't dry out and is very durable) for the model of the brain.
- Sheep's Brain for Dissection (can be purchased from Carolina Biological)
- Casper Fish Eggs (can be purchased from Carolina Biological) to observe embryological development
- Dissection Kits for Dissecting the sheep's brain. A basic dissection kit should be enough.
- 10 Gallon Aquarium (for Casper Eggs to develop into fish)
- Brain Models- To give the students an idea of what the brain looks like.
- Models of human development- To give students a visual of the size of the stages of development.
- Dissection trays
- Nitrile Gloves-Gloves should always be work when dissecting. Nitrile gloves are thicker than latex and do not carry the risk of allergies.
- Goggles-Eye protection is key when dissecting a material
- Aprons or Lab Coat-To protect clothing from dissection preservation fluid.
- Stereo Microscope (for observing egg development)
- Hand lens (for observing egg development)

Teacher Resources

Site for the Carnegie Developmental Stages
https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_Stages
This site illustrates and describes all of the Carnegie stages of development. Student and teachers will find this very useful.

Video on Phineas Gage
https://www.youtube.com/watch?v=aw0zbyQVCEc
This video reenacts the injury of Phineas Gage and explain his injury.

Article on Aaron Hernandez's Case of CTE
https://www.washingtonpost.com/sports/aaron-hernandez-suffered-from-most-severe-cte-ever-found-in-a-person-his-age/2017/11/09/fa7cd204-c57b-11e7-afe9-4f60b5a6c4a0_story.html
This article discuses former NFL player Aaron Hernandez's brain injury and how they may have contributed to his behavior.

Conducting a Socratic Seminar
https://www.facinghistory.org/resource-library/teaching-strategies/socratic-seminar
Outlines the basics in conducting a Socratic Seminar in class.

Sample Lesson Plan
http://bit.ly/37ehK2j
A generic lesson plan developed for the first or second day of the class, including modeling the brain.

Rubric for Final Project
http://bit.ly/2O0PkBE
A description of the final project and rubrics for the paper and presentation. These are sample rubrics and can be altered are replaced altogether.

Student Resources

Site for the Carnegie Developmental Stages
https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_Stages
This site illustrates and describes all of the Carnegie stages of development. Student and teachers will find this very useful.

Crash Course: The Central Nervous System
https://youtu.be/q8NtmDrb_qo
This video outlines and introduces the brain and spinal cord.

Article on Aaron Hernandez's Case of CTE
https://www.washingtonpost.com/sports/aaron-hernandez-suffered-from-most-severe-cte-ever-found-in-a-person-his-age/2017/11/09/fa7cd204-c57b-11e7-afe9-4f60b5a6c4a0_story.html
This article discuses former NFL player Aaron Hernandez's brain injury and how they may have contributed to his behavior.

Site for Brain Conditions
http://www.snmmi.org/AboutSNMMI/Content.aspx?ItemNumber=1781
A site listing and briefly describing some of the major conditions of the brain.

NIH-The Brain Initiative
https://braininitiative.nih.gov/
A resource center by the National Institutes of Health about the brain and nervous system.

NINDS-NIH
https://www.ninds.nih.gov/
National Institute of Neurological Disorders and Stroke. Government based research on the brain and nervous system, journal articles and research studies.

Endnotes

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