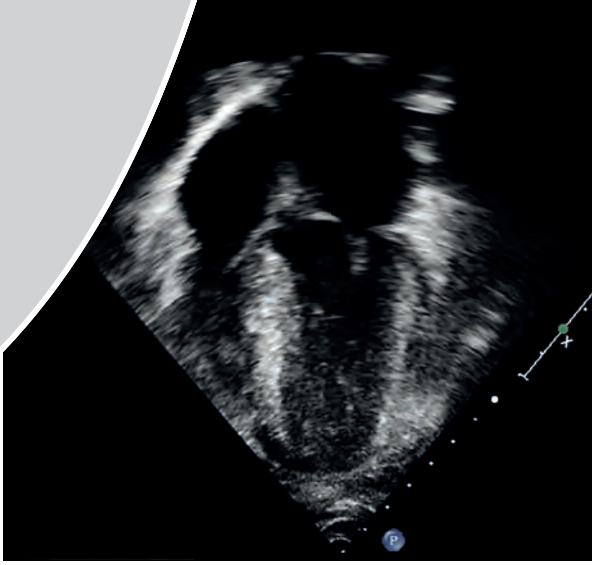
INQUIRY & INVESTIGATION

A Project-Based Biology Unit: Star Athlete Collapses on the Football Field



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Abstract

Students in a high school biology class were introduced to the case of "Marcus" (a pseudonym), a high school football player who collapsed on the football field during a game and was rushed to the emergency room with various symptoms. Throughout the two-week, project-based unit, students worked in cooperative groups to diagnose Marcus, learning about various inherited diseases and heat-related ailments that might impact young athletes. This unit integrates ultrasound technology into the classroom as a teaching and diagnostic technique and introduces students to health science careers. Student groups work to produce a final product that is presented to a public audience (e.g., parents, teachers, coaches) to increase their awareness of the science content underlying the causes of sudden collapses in young athletes. This learning experience ended with students individually writing a letter to Marcus's family explaining his diagnosis and the related biology concepts.

Key Words: *Project-based learning; inquiry; genetics; cell biology.*

○ Introduction

With the adoption of the *Next Generation Science Standards* (NGSS Lead States, 2013) and state implementation of these or similar standards, teachers are having to change their instruction to integrate science content and practices, teaching for in-depth understanding. Project-based learning (PBL) curricula, which engage students in investigating authentic real-world problems through science practices, collaborative discussion, and investigation, align well with this reform vision. Literature reviews of project-based instruction in K–12 environments summarize evidence that when properly enacted this instruction leads to improved student science content knowledge and 21st-century process skills as well as better performance on standardized content assessments (Thomas, 2000; Holm, 2011; Hasni et al., 2016). Literature also shows that these positive effects extend to students of various ethnicities, ages, and academic levels (Thomas, 2000; Moje et al., 2001; Schneider et al., 2002; Larmer et al., 2015; Han et al., 2016).

According to Krajcik and Czerniak (2018), project-based science units are organized around a real-world driving question that gives learning activities a central focus and engages students collaboratively in scientific practices to develop standards-based learning products that address this question. Larmer et al. (2015) described "gold standard" PBL units as having seven key design elements that work together to build student content knowledge and 21st-century skills (critical thinking, communication, collaboration, etc.): (1) a challenging question, (2) sustained inquiry, (3) authentic (real-world) problems, (4) voice and choice, (5) reflection on their own learning and skills, (6) critique and revision, and (7) the production of a public product (p. 34). Table 1 shows how students were engaged in each of the "gold standard" PBL elements during our unit.

○ Unit Overview

During this PBL unit, students in a high school biology class were introduced to the case of "Marcus" (a pseudonym), a high school football player who collapsed on the football field during a game and was rushed to the emergency room with various symptoms. Throughout the unit, students worked in cooperative groups to diagnose Marcus, learning about various inherited diseases and heat-related ailments that might impact young athletes. The teacher acted as a liaison to the hospital, providing updates on Marcus's condition throughout the unit. This learning experience ended with students writing a letter to Marcus's family explaining his diagnosis and the related biology concepts. Student groups also presented information to a public audience (e.g., parents, teachers, coaches) to increase their awareness of the science content underlying the causes of sudden collapses in young athletes. This unit was developed collaboratively with a southern university's college of education, its school of medicine, and teachers who participated in a professional development program.

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Table 1. Alignment of the Marcus unit to "gold standard" project-based learning (PBL) design elements.

"Gold Standard" PBL Element[a]	Unit Features
Key Knowledge and Understandings/Success Skills	Students engage in science practices to learn key genetics, cell biology, and heart anatomy content (for alignment to NGSS, see Table 2).
Challenging Problem/ Question	Entry event: Introduction of the Marcus case through discussion of initial symptoms; students engage in differential diagnosis throughout the unit to determine what happened to Marcus; students work throughout the unit to determine what caused Marcus to collapse and to answer the question "How can we educate others on the serious health risks in young athletes?"
Authenticity	Students connect to similar real-world, sports-related injuries through reading or watching local news stories; they give final presentations to school and community members to help make them aware of health issues associated with sports.
Student Voice and Choice	Students gather evidence to support their final diagnosis, which they present in their letter to Marcus's family; student groups design final presentations based on a rubric and their chosen audience.
Sustained Inquiry	Students research various sports-related diseases (disease jigsaw and final presentation research); students engage in investigative laboratory activities (egg osmosis lab, sickle cell simulation, ultrasound, etc.).
Reflection	Students reflect through daily written protocols (e.g., I used to think . . . , Now I think . . .) and through small-group and whole-class discussion of Marcus's diagnosis.
Critique and Revision	Students participate in a gallery walk and provide feedback on each other's final projects before formal presentation; they use peer critique protocols on initial project ideas (e.g., charrette protocol from www.nsrfharmony.org).
Public Product	Students write a letter to Marcus's family and also present and receive feedback from an audience of parents, coaches, and teachers at a school- or community-based event.

[a]Larmer et al. (2015, p. 34).

This unit is unique in that it integrates ultrasound technology as a teaching and diagnostic technique and introduces students to health science careers. Ultrasound is a safe imaging tool that has advanced significantly in recent years. The machines are now available as portable devices and are laptop- and handheld-sized and include ultrasound probes that plug into smartphones and tablets for imaging (Herper, 2017). These portable devices are very user friendly and produce excellent ultrasound images. Ultrasound has been found to be a great teaching tool for human anatomy and physiology and provides active hands-on learning experiences (Mouratev et al., 2013; Bell et al., 2015; Hoppmann et al., 2015). These handheld ultrasound devices are well on their way to becoming the stethoscopes of the 21st century and are being used by physicians, nurses, sonographers, physician assistants, emergency medicine technicians, and medics.

○ Unit Flexibility

The case of Marcus can be adapted to focus on different diseases and biology content (body systems, genetics, cell biology) depending on the teacher's course standards and students' interests. Although it's presented here as a two-week unit, teachers can shorten the unit and present the case as a review of content at the end of the year. As a review unit, student teams would work more independently to apply their prior biology content understanding to diagnose Marcus. In this article, we describe how a teacher used the unit in an introductory high school biology course. The teacher emphasized standards related to cell transport and cell structure through a study of dehydration, and emphasized standards related to inheritance patterns through a study of various inherited cardiovascular diseases related to Marcus's collapse on the field. Throughout the unit, students worked collaboratively to create a final product to address the driving question: How can we educate others on the serious health risks in young athletes? Specific activities of this unit and their alignments to NGSS dimensions are presented in Table 2.

○ Unit Outline

Entry Event

On the first day of the unit, students were introduced to the case of Marcus (see Handout 1: Marcus Brown Case, Day 1; all handouts are available as Supplemental Material with the online version of this article) through a written description of his case. Students were asked to take on the role of physicians and brainstorm, individually and then in pairs, potential causes of his collapse. After students discussed for a few minutes why he might have collapsed, the teacher recorded their initial diagnoses on a large chart paper. The teacher then assigned students to groups of two or three to research potential health problems that might have caused Marcus's symptoms.

Table 2. Alignment of Marcus unit activities to *Next Generation Science Standards* (NGSS) dimensions (NGSS Lead States, 2013).

NGSS Dimension	Name & NGSS Code	Unit Activity
Science and Engineering Practices	Developing and Using Models Constructing Explanations and Designing Solutions Obtaining, Evaluating, and Communicating Information	Students model homeostasis in a dehydrated cell using a de-shelled egg. Students draw models that explain cell transport processes. Students write a letter to Marcus's family describing his medical diagnosis and the genetics of his disease. In final presentations, students provide an explanation with supporting evidence and recommendations for appropriate care in future athletic activities.
Disciplinary Core Ideas	LS1.A: Structure and Function • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (HS-LS1-1) • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (HS-LS1-3) LS3.A: Inheritance of Traits • Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet-known function. (HS-LS3-1) LS3.B: Variation of Traits • In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. (HS-LS3-2)	Student groups research genetic disorders that might predispose student athletes to exertion-based collapses. Students determine the inheritance patterns associated with select diseases through the cooperative jigsaw activity. Students observe ultrasound images to understand normal and abnormal cardiac functions. Students participate in egg osmosis laboratory and research dehydration in human bodies. Student groups discuss and identify that mutations lead to genetic disorders and variations in populations. Students prepare pedigrees to represent the familial inheritance patterns of potential genetic disorders in Marcus's family.

Table 2. Continued

NGSS Dimension	Name & NGSS Code	Unit Activity
Crosscutting Concept(s)	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.	Students participate in diagnosing Marcus's underlying genetic disorder that led to his collapse while playing sports. Students use medical data and research to refine their predictions and conclude with a final diagnosis.

Students inferred dehydration, sickle cell trait crisis, Marfan syndrome, hypertrophic cardiomyopathy, exertional heat stroke, asthma, and other causes, all of which come up after an initial Internet search. After giving students 15 minutes to do an Internet search for athlete-associated health problems, the teacher asked them to discuss their findings around dehydration and heat stroke. The teacher then used the first two minutes of a news report about a high school athlete who died from a heat-related illness (see Online Resources below) to discuss potential ways that coaches might prevent this fatality. Possible solutions included having water or other drinks available, giving athletes regular breaks, and training for coaches in prevention and treatment of heat stroke. Students were asked which beverages they thought would work best to alleviate dehydration. As directed, they engaged in a laboratory that used a de-shelled egg as a model of a cell (see Handout 2: Egg Lab Summary). Students working in pairs and wearing approved safety gloves, aprons, and goggles placed the raw eggs in vinegar to soak overnight in refrigeration, a process that required two to three days to remove the entire calcium carbonate shells. To connect this common biology laboratory to the PBL case, students were asked to brainstorm a list of sports drinks and other liquids that they wanted to use to rehydrate their eggs (e.g., Gatorade, Powerade, water, Kool-Aid), to determine which drinks might be the best to help with dehydration in athletes.

Days 2–3

At the beginning of Day 2, students received an update on Marcus's condition from the emergency room doctor, via the teacher (see Handout 3: Update on Marcus, Day 2). The teacher led students through a discussion of unfamiliar medical terminology in the test results and addressed additional information they needed to understand Marcus's condition. To make this more student-centered, the teacher divided the test results among groups of three or four students and had each group research and present the meaning of the different tests and how Marcus's results compared to expectations for an average, healthy, 18-year-old male. To help teachers with the interpretation of the medical results, we have provided a description of the laboratory results in a teacher section (not to be shown to students) at the end of Handout 3. After making initial sense of Marcus's health update, students returned to their egg osmosis investigations and recorded the initial mass of their de-shelled eggs before placing the eggs in 90% corn syrup to soak overnight, simulating a dehydrated cell.

Student groups were asked to create a model (drawing and explanation) of what they thought would happen to their egg "cells" in the corn syrup and predict what would happen to the egg after soaking in their group's chosen liquids for 24 hours, serving as a review of homeostasis from a prior unit. The teacher asked students to draw and explain what was happening within their "cells" at the molecular level across time (before, during, and after being placed in the current solution) to encourage students to explain their thinking (Windschitl et al., 2018). As the student groups shared their initial models with the class, the teacher recorded common misconceptions to be addressed later in the investigation through whole-class discussion or mini-lectures (Lawson, 2000; Sanger et al., 2001).

After setting up the eggs to soak in corn syrup on Day 2, the teacher asked students to revisit their list of potential diagnoses. The students considered diagnoses that they could remove from their list, given the new health information. Students usually rule out asthma at this time, as Marcus showed no signs of wheezing. The teacher's questions helped students narrow their focus to inherited diseases that might involve the heart. Students then engaged in a cooperative-learning jigsaw activity (see Handout 4: Expert Group) in which groups of four students became experts on one of the following four diseases: exertional heat stroke, sickle cell trait, Marfan syndrome, and hypertrophic cardiomyopathy. The latter three are inherited diseases that offer the opportunity for discussion of genetics and risk of transmission to offspring. Student experts on each disease taught their peers within their respective home group and filled out Handout 4 describing the symptoms/causes, prevention, genetics, and other factors relevant to each disease. Other diseases can be investigated based on students' initial research findings.

On Day 3, each group recorded the mass of their dehydrated egg, then placed the egg in a plastic cup and covered the egg with the liquid they had brought in to test overnight. The teacher took the mass of a de-shelled egg and placed it back in the 90% corn syrup to serve as a class control group. The students revised their initial models on Day 4 and provided explanations of osmosis and explained when their solution was hypertonic, hypotonic, or isotonic based on their findings. The teacher then led students through a whole-class discussion addressing which liquid (water) was the best to rehydrate the eggs and the importance of hydration to health.

Days 4–5

On Day 4, students finished sharing their jigsaw findings within their home groups and each student completed Handout 4. After this research and sharing was completed, the students received another update on Marcus's condition from the teacher (Handout 5: Update on Marcus and Plea for Help, Day 4). After this update, the teacher led a discussion with students during which they were encouraged to determine what additional information they needed to diagnosis Marcus within their home groups. Their curiosity about Marcus's family medical history provided a great opportunity to introduce them to pedigree analysis. The students created a pedigree for Marcus's family based on the information provided so far in the case (Handout 6: Pedigree). The teacher used this opportunity to review inheritance patterns of Mendelian diseases and to introduce inheritance of non-Mendelian diseases using Punnett squares to help students understand the probability of Marcus's future children inheriting any of the diseases. On Day 5, after a lesson describing pedigree construction and application, student expert groups were asked to find example pedigrees or create pedigrees for individuals with sickle cell trait, Marfan syndrome, and hypertrophic cardiomyopathy. Student groups shared their created pedigrees with the entire class and the teacher clarified the inheritance patterns and further explained the content related to the different inheritance patterns.

Figure 1. High school biology students engaged in ultrasound of a standard patient's heart.

Day 6

On Day 6, a medical school student from the university's ultrasound institute accepted the teacher's invitation to engage the students in ultrasound scanning of a "standard patient" (Figure 1). The students got a chance to ultrasound the patient's heart. We recommend using a "standard patient" and do not recommend engaging in ultrasound on your own students, as the experience should be about seeing the anatomy and understanding the ultrasound technology rather than a diagnosis of student health issues. Because this interaction is not possible for all teachers, we have included video footage of a healthy heart and video footage that might represent Marcus's diseased anatomy (see Figures 2 and 3; the videos are available from the authors). However, the teacher should not show Marcus's videos until the next day. Instead, the teacher can provide the autopsy report from Marcus's uncle, Robert Brown (a pseudonym; see Handout 7: Robert Brown Autopsy Summary), and show a video loop of his heart ultrasound (Figure 2) at the end of this class. This ultrasound loop shows an enlarged diseased heart consistent with hypertrophic cardiomyopathy.

Days 7+

This final Hospitalization Update was provided to students near the end of the unit (before their final presentations) and the teacher showed the students Marcus's heart ultrasound:

> *Hospitalization Update*
>
> Marcus continues to improve. He has been placed on a beta blocker and has been moved out of the ICU. He is eating well, talkative, and walking the halls. His cardiologist has been coming by every day to examine Marcus and help him understand his disease.

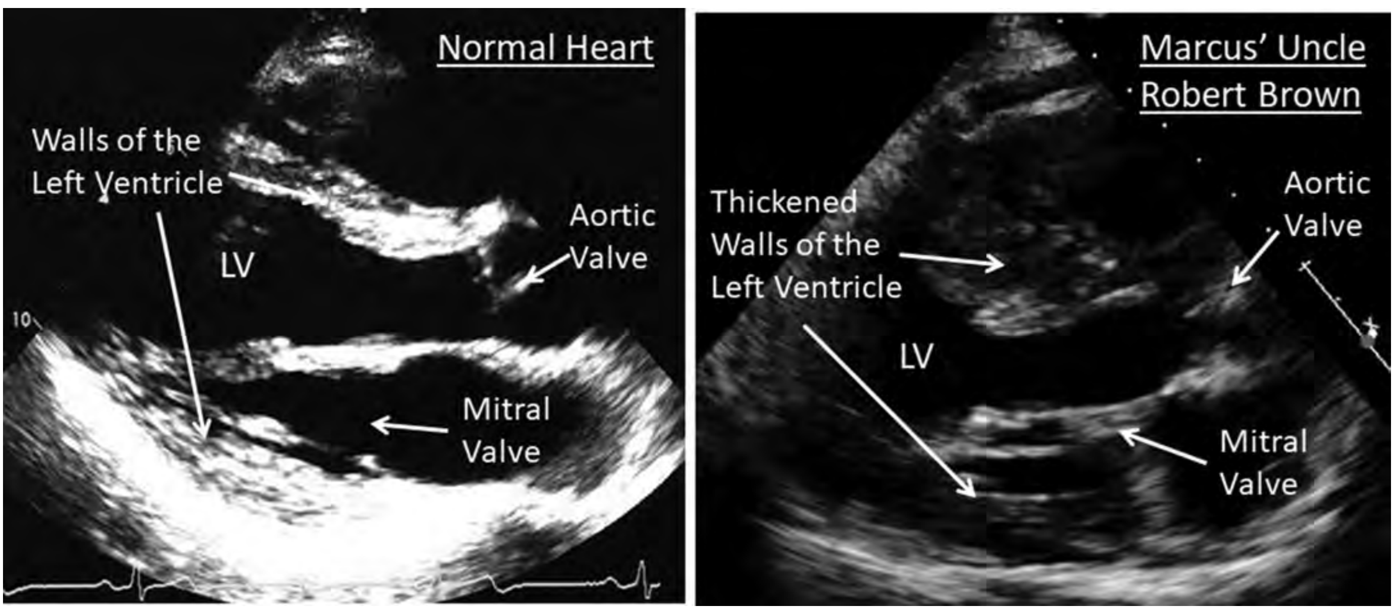

Figure 2. On the left is an ECHO of a normal heart and on the right is an ECHO of Robert Brown's heart. Note the thickened walls of the left ventricle of Brown's heart and the small volume of blood in the ventricle (LV).

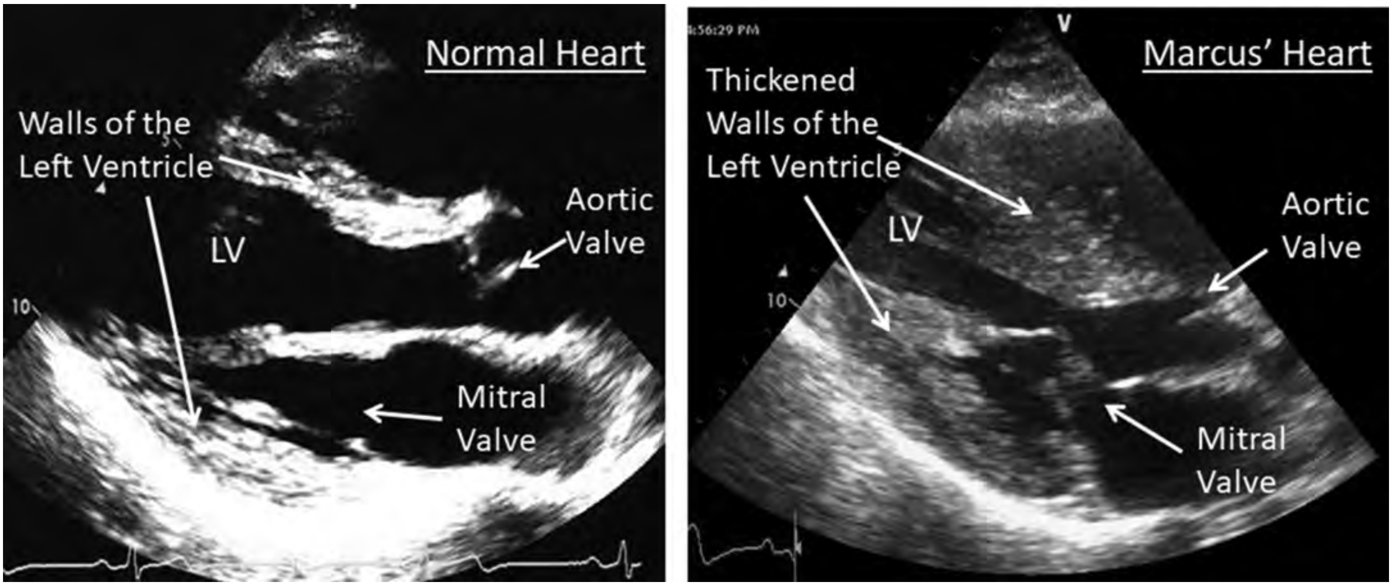

Figure 3. Diagram of normal heart and hypertrophic cardiomyopathy.

The teacher led a discussion with the students to interpret the ultrasound videos and helped them understand the effects of hypertrophic cardiomyopathy on heart muscles and function (see Figure 3). The rest of the unit involved student project groups coming to a consensus on Marcus's final diagnosis and students engaging in additional research to create a product educating a target audience (which could be chosen by the students) on the risks and prevention of sudden collapse or death in athletes. For this implementation, the teacher invited the school's coaches and administration to listen to each group's final presentation. Students might create various products (i.e., PowerPoint presentations, informational videos, short skits, brochures) that align with the needs of their target audience.

After students created a draft of their final projects, they engaged in a gallery walk during which they showed their products to their peers and received critical feedback on ways they could improve their products using the provided rubric (Handout 8: Final Product Rubric) before presenting to their external audience. During the gallery walk, students wrote at least one strength and one area that needed additional work on sticky notes that they placed on each other's initial products. Given this feedback, students spent the next day revising their products before they were shown to the external audience.

As a final individual summative assessment, students wrote a letter to Marcus's family that described his disease and the genetics and cell biology content associated with the disease. In this letter, students offered recommendations to Marcus's family for future treatment and reproductive decisions (Handout 9: Letter to Marcus's Family). Whether taught in a middle or high school classroom, we have found that Marcus's case and the use of ultrasound technology motivate students to learn the genetics and cell biology content needed to diagnose Marcus. With final presentations to an external audience, students feel they are making a difference in educating their peers and others about potential sports-related health issues.

○ Online Resource

- CBS news video of coach on trial for the death of a high school football player, Max Gilpin, who died from heat-related illness: https://www.youtube.com/watch?v=4cUddZEom0k (we suggest that the teacher show first two minutes)

○ Suggested Online Resources for Students' Initial Research

- https://www.mayoclinic.org/diseases-conditions/sudden-cardiac-arrest/in-depth/sudden-death/ART-20047571?p=1
- https://medlineplus.gov/ency/article/000192.htm
- https://www.safekids.org/sites/default/files/documents/sports/DEHYDRATION%20SAFETY%20TIP%20SHEET%202013.pdf
- https://www.cdc.gov/ncbddd/sicklecell/traits.html

○ Online Supplemental Material

- Handout 1: Marcus Brown Case, Day 1
- Handout 2: Egg Lab Summary
- Handout 3: Update on Marcus, Day 2
- Handout 4: Expert Group
- Handout 5: Update on Marcus and Plea for Help, Day 4
- Handout 6: Pedigree
- Handout 7: Robert Brown Autopsy Summary
- Handout 8: Final Product Rubric
- Handout 9: Letter to Marcus's Family

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