Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2019 Volume III: Human Centered Design of Biotechnology

Vaccinations: Combating Disease, Death, Disability, and Child Mortality Worldwide

Curriculum Unit 19.03.03
by Somi Akella

Introduction and Rationale

I teach 10th-grade Biology and Human Physiology at an inner-city comprehensive high school. The school is considered a neighborhood high school and it draws students not only from the surrounding neighborhoods but also from surrounding towns. We have a revolving door policy, serve a transient student population, and take in students throughout the year. This makes teaching especially challenging as students that move into the neighborhood throughout the school year. The student population is culturally diverse and is at different levels of the learning process.

My high school utilizes a block schedule wherein students have four classes per day, each running for about 90 minutes. Students have eight classes total and any given class meets either 2 or 3 times per week. This presents challenges for teachers concerning homework and turn-around time for feedback because of long gaps between class meetings. What the block schedule does offer is a longer class period wherein lab experiments could be carried out with ease. The biology classes are predominantly designed for 10th graders. Whereas the human physiology, which is an elective, is designed for upperclassmen, that are planning to pursue health fields such as nursing after. Biology is a mandatory class for all students and is a graduation requirement. This unit is designed with the 9-12 grade students in mind. This unit could be applied to students who are enrolled in biology, Human Physiology, Public Health, and Science and Research classes.

The target audiences for this unit are the biology students. The unit was designed with the Next Generation Science Standards (NGSS) in mind. The State of Connecticut adopted the NGSS in November 2015. The main objectives of these standards are to engage learners in meaningful and exciting science learning. This approach teaches K-12th-grade students to learn science in their own way while collaborating with others. Some of the major features of the NGSS that are incorporated in this unit are the three-dimensional learning that encompasses the science and engineering practices, using science to explain the real-world phenomenon, and lastly the engineering design. The school district recently adopted the NGSS and is currently in the process of aligning the K-12 science curricula with these standards. For example, the current 10th-grade curriculum expects that the students to identify differences between genetic disorders and infectious diseases, understand how bacterial and viral infectious diseases are transmitted, explain the roles of sanitation, vaccinations, and antibiotic medications in the prevention and treatment of infectious diseases.

However, it fails to expose the students to the science of vaccinations, their role in developing immunity and preventing and eradicating infectious diseases worldwide. This absence of this information in the current curriculum is the main inspiration behind the development of this unit.

Hence this unit helps fill in the gaps in the current curriculum such that students will have solid background knowledge about vaccinations and their role in combating infectious diseases among children worldwide. [1] The current unit dives into the history of infectious diseases and vaccinations, different types of immunity and how they are acquired, and [2] a brief overview of how vaccinations help produce antibodies that combat disease-causing agents and briefly discuss the vaccination delivery systems that are currently used worldwide. Lastly, this unit will introduce educators to the concept of Design Thinking as a methodology for problem solving. It will give them an opportunity to challenge their students to utilize the design thinking methodology to work collaboratively to solve problems. As a culminating activity, the students are challenged to design a [3] “kid-friendly, needle-free” vaccine delivery system. Lastly, the students will be introduced the Design Thinking methodology that will expose them to empathy, work collaboratively with others, understand why they are creating solutions, who they are planning to help, and how their design could improve health outcomes.

This topic has tremendous potential to introduce problem-solving skills through the Design Thinking process and challenges students to create solutions. This unit will also incorporate the [4] NGSS practices of asking questions and designing solutions, developing models, conducting research, constructing explanations, obtaining, evaluating, and communicating information. The unit will address the following national, state and district standards: NGSS-HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

A Brief History of Vaccinations

[5] Vaccinations date back to the 1500s, where smallpox inoculation was practiced in China and India[6] . The method that was used involved grinding the smallpox scabs and blowing them into the nostrils as well as scratching the matter from smallpox sore into the skin. Sadly, in 1585, the smallpox epidemic was responsible for the death of 8000 children in India. The first case of variolation or inoculation was documented in the year 1706; the method included injecting the disease material directly into the veins of subjects. At this point, the rich seem to be taking advantage of the advances in medicine where the poor died from the disease. The results of variolation were devastating, two out of the three people variolated died from smallpox.

In 1770, Edward Jenner discovered that previous exposure to a disease called cowpox could prevent a person from later becoming ill with smallpox. He noticed that milkmaids who caught cowpox from infected milking cows were not affected by smallpox. In 1796, Dr. Edward Jenner proved that a person who was initially infected with the cowpox disease material acquired immunity to the smallpox disease. Hence vaccination with the cowpox pustule prevented future smallpox infection. Benjamin Waterhouse performed the first vaccination of children in the US in the 1800s.

In 1803, Edward Jenner coined the term vaccination; from the Latin word “Vacca” which means cow. The US Congress and James Madison established the US Vaccine Agency in 1813 and its main objective was to ensure that the smallpox vaccine was delivered to the US citizens for free by the US Postal Office. Thus the death rate due to smallpox was reduced. Another milestone was laid in 1857 when Louis Pasteur highlighted the importance of heating in order to prevent the growth of microorganisms. This lead to the ideas of pasteurization for the preservation of food as well as the importance of following safety protocols during surgical procedures. His experiments further solidified the idea that living organisms are created from other living organisms and hence disapproved the idea of Spontaneous Generations, which insisted that life could arise from non-living materials such as mud. In 1939, the whooping cough vaccine was created. The first DTP (diphtheria, tetanus, and pertussis) vaccines were available in the U.S. In 1965, hepatitis B antigen was isolated. By 1974, various childhood diseases disappeared from the developed world, though they took many lives in poorer countries. In 1977, the meningococcal vaccine was created and the first Haemophilus influenzae type b (Hib) disease was licensed in the United States.

To summarize, **Vaccines** are substances that consist of weakened, dead, or incomplete portions of pathogens or antigens. The major types of vaccines licensed for use in humans include:

1. Live, attenuated organisms for example smallpox, influenza, tuberculosis, and chickenpox.
2. Inactivated or killed pathogens, such as typhoid, whooping cough, hepatitis A, and rabies.
3. Purified or recombinant subunit, for example, diphtheria, tetanus, and anthrax.
4. Recombinant protein vaccines, for example, hepatitis B.

The Immune System

The immune system helps protect organisms from pathogens in their environment. It also does an important job of recognizing the microorganisms as well as the organs received through transplantation as foreign, creates **antibodies** that are specific to **antigens** (a foreign material that causes an immune response). This process helps protect organisms from pathogens such as disease-causing viruses, parasitic bacteria and fungi, and other infectious agents. Some defenses prevent these foreign invaders from entering the body, others help remove them, and yet others help fight the invaders.

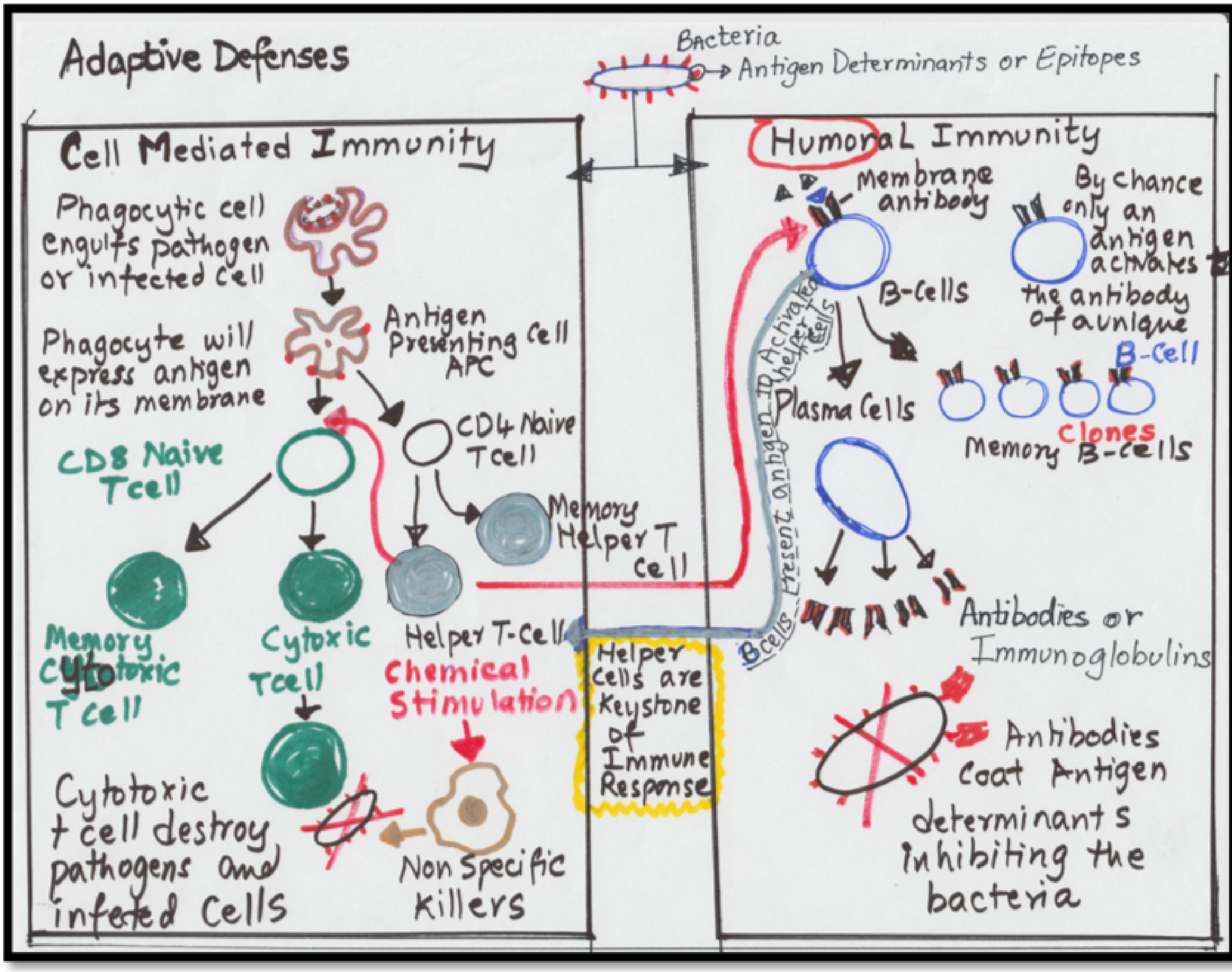

Figure 1: Adaptive Defenses: Interactions in Specific Immune Response*Adapted from Anjelica Gonzelez, Yale-New Haven Teachers Institute*

The immune system is comprised of the **Non-Specific defenses** and **Specific defenses**. [7] Non-Specific defenses (innate immunity) provide the first line of defense against pathogens. They include physical barriers such as the skin, defense mechanisms such as mucous membrane, tears, and sweat and low pH of the stomach acid and general immune responses such as fever and inflammation. Fever helps raise body temperature, which interrupts the reproduction of viruses and other pathogens. Inflammation allows the phagocytic cells such as macrophages and leukocytes to leak into the damaged tissue and helps engulf and destroy pathogens through a process called phagocytosis. The cells of the immune system include the phagocytes, macrophages, mast cells, neutrophils, eosinophils, basophils, natural killer cells, and dendritic cells. Their main job is to locate, identify, incapacitate, and kill the invaders.

[8] **Specific defenses (adaptive immunity)** are provided by the two types of lymphocytes, B cells, and T cells. T cells develop in the thymus and the B cells develop in the bone marrow of the long bones. B cells have membrane-bound antibodies on their surface. When they encounter a pathogen that fits or matches the antibodies on their surface, they quickly divide into a memory B cells and plasma cells. This process is called the antibody-mediated immune response. The plasma cells produce the same antibodies as the parent B cell

and these antibodies circulate throughout the body searching for antigens but the memory B cells have the same membrane-bound antibodies as the parent B cell. Immunity is achieved through antibodies present in a person's body. Antibodies are proteins produced by the body to destroy toxins or disease-causing organisms (antigens). Antigens are disease-specific. Antibody molecules have two important jobs: binds to the specific antigen and activate specific defenses such as phagocytes that destroy the antigen.

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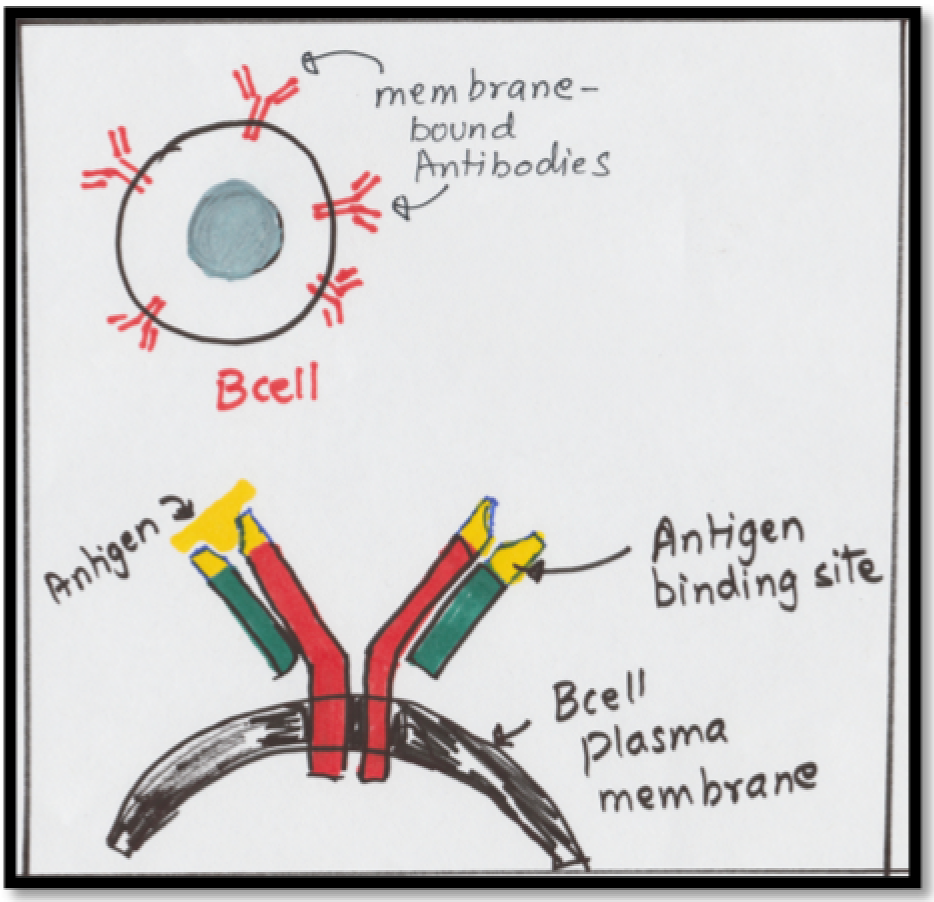

Figure 2: B cell and the Antigen-Antibody Complex*Adapted from Khan Academy*

On the other hand, the T cells do not produce antibodies. There are two types of T cells: cytotoxic T lymphocytes and helper T cells, which play a major role in the cell-mediated immune response. The surface of the T cells is covered with proteins called T cell receptors. These T cell receptors only recognize only the surface proteins bound to the major histocompatibility complex (MHC) of macrophages and dendritic cells. As explained in the figure: 1, during phagocytosis cells such as macrophages ingest the pathogen, digest it, and then display portions of the pathogen’s proteins bound to their MHC proteins on their surface. The T cells, in turn, recognize the protein bound to the MHC proteins and then alert the cytotoxic T cells to orchestrate apoptosis (programmed cell death), which helps limit the spread of infection. Hence T cells play a vital role in distinguishing the MHC that belong to the organism's own cells from that of foreign cells.

Immunity:

Immunity keeps us safe from being sick. There are several types of immunity: **passive, active, and community immunity**. In **passive immunity**, the antibodies are generated in another host. It could be **natural**, from mother to an unborn baby or to a newborn baby through breast milk or **artificial**, where antibodies could be injected into the body. This type of protection is immediate but lasts for a few weeks or months. However, **active immunity** includes **natural immunity** which could be acquired through exposure to the disease or **vaccine-induced immunity** which involves exposure to killed or weakened form of the disease-causing organisms. However, **herd immunity** applies to situations where enough people in the community are exposed to the pathogen and this, in turn, slows down the spread of the pathogen. This type of immunity is indirect and is one of the least reliable.

How do vaccinations help produce immunity?

Vaccines help prevent diseases and are one of the most important achievements of mankind. Research shows that vaccines help prevent a million deaths per year worldwide, increase average life span, and help eradicate smallpox, which is an infectious disease. The United Nations created several sustainable development goals to ensure a sustainable future for all. One of these goals focuses on good health and well being at all ages. According to the UN, this goal highlights increasing life expectancy, decrease child and maternal mortality, and working towards achieving the target of "less than 70 maternal deaths per 100,000 live births by 2030" and vaccinations play a vital role in decreasing communicable diseases.

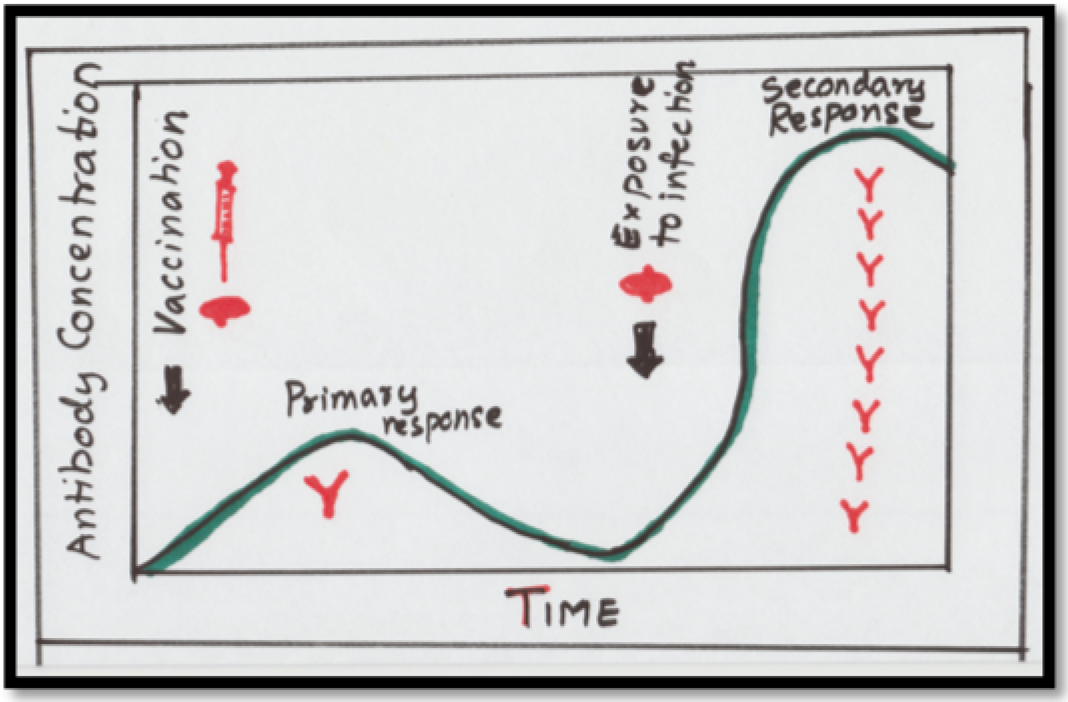

Figure 3: Explanation about the Primary and Secondary Antibody Responses*Adapted from myDr.com.au (Public Domain)*

The B-lymphocytes in the body detect these antigens on bacteria and start multiplying. These cloned B cells either become plasma cells or memory cells. The plasma cells secrete antibodies, which are trained to immobilize the bacteria or virus the person is vaccinated against. [9] So, during the primary antibody response, the antibody concentration rises gradually and peaks about 2 weeks after vaccination. During the secondary response, one is exposed to an infective organism. Then the memory B cells that have lain dormant in the body instantly recognize the organism. The memory B cells multiply rapidly and then develop into plasma cells. The plasma cells produce a large number of antibodies, which are able to quickly bind and inactivate the infecting organism. So, during the secondary antibody response, the antibody concentration rises quickly, and the response is more intense. The antibody concentration remains higher for a longer period of time.

Seven childhood diseases that could be prevented through immunizations are Diphtheria, Tetanus (lockjaw), Pertussis (whooping cough), Hib (Haemophilus influenzae), Hepatitis B, Polio, and Pneumococcal disease. Currently, children’s vaccinations are administered through the following methods: orally, nasal, intramuscular (IM), subcutaneous (SQ), and intradermally (ID). The oral vaccinations, for example, Oral Poliovirus Vaccine (OPV) and Rotavirus are administered through drops and a live attenuated virus is used to administer flu vaccine nasally. When administering the IM vaccinations such as DTaP (Diphtheria, Tetanus, and Pertussis), one needs to pay attention to the needle length and ensure that the needle is inserted at a 90-degree angle and quickly. However, while administering the SQ such as Measles vaccine, tissue needs to be pinched and the needle should be inserted at a 45-degree angle. Lastly, the intradermal (ID) injections such as the BCG are administered in the topmost layer of the skin. There are several other protocols one needs to follow during administering the vaccinations. It is also crucial the personnel are sufficiently trained to minimize errors and to ensure that the personnel is aware of the needle length, the angle at which it needs to be inserted, and the suggested injection sites are followed. Hence the current research is leaning towards creating needle-free delivery systems.

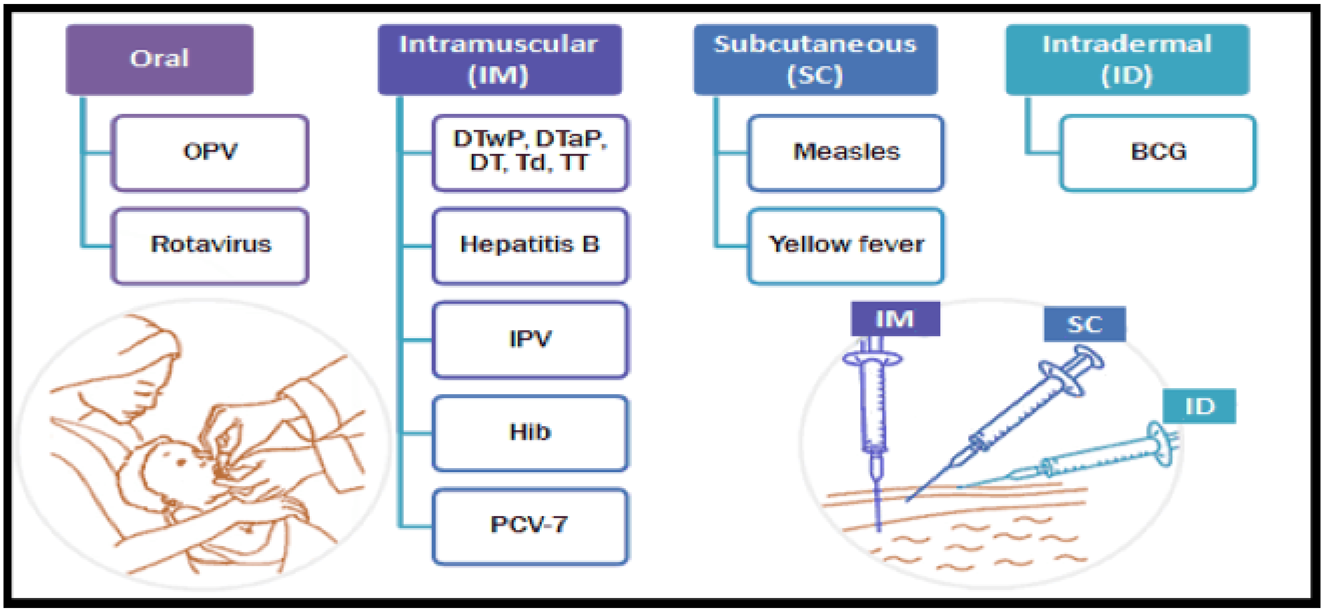

Figure: 4 Children's Vaccination Administration Systems*Image source WHO (public domain), https://vaccine-safety-training.org/route-of-administration.html*

The needle-free systems do not pose a safety risk to patients, providers, and the community. Out of the 12 billion injections administered to humans per year worldwide, 1 million are childhood vaccines. Next, the issue of compliance- too many vaccinations and needle-phobia and 20% of children experience serious distress. One must take it into consideration the discomfort- reduced pain and soreness at the injection site. Most economical reason would be the increased ease and less training of vaccinators, and decreased costs. The current material cost per vaccination is $0.06 but the societal cost is $26.75 per injection. Another important factor is the speed of delivery. Lastly, Cold Chain is not needed and delivery to remote areas is possible allowing vaccinating 10 million more children. The needle-free systems could easily avoid the problems involved in the cold chain, which provides challenges to the proper and timely delivery of vaccinations to remote areas around the world. It might even reduce the cost involved in the delivery of vaccinations.

To summarize, **immunity** plays a vital role in keeping us safe from being sick. Major types of immunity include:

1. **Active immunity** is acquired either through exposure to the disease where the immune system produces antibodies to combat the pathogen or through vaccinations. [10] This type of immunity is sometimes life-long.
2. **Passive immunity** is acquired through the antibodies that are generated in another host, for example from a mother to an unborn baby or to a newborn baby through breast milk.
3. **Herd immunity** applies to situations where enough people in the community are exposed to the pathogen and this, in turn, slows down the spread of the pathogen.

Design Thinking:

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[11] The foundation of the Design Thinking mindset involves creating "human-centric" solutions to problems. This process incorporates 5 phases: empathize, define, ideate, prototype, and test to create individualized solutions. Though the phases do not necessarily follow a pattern. However, the end goal of this process is to acquire a deeper understanding of the product and the user, and ultimately create a product that will cater to the needs of the user. Throughout this process, the focus remains on understanding who that they are going to help, why they are creating solutions, and how their design will make that person's life better.

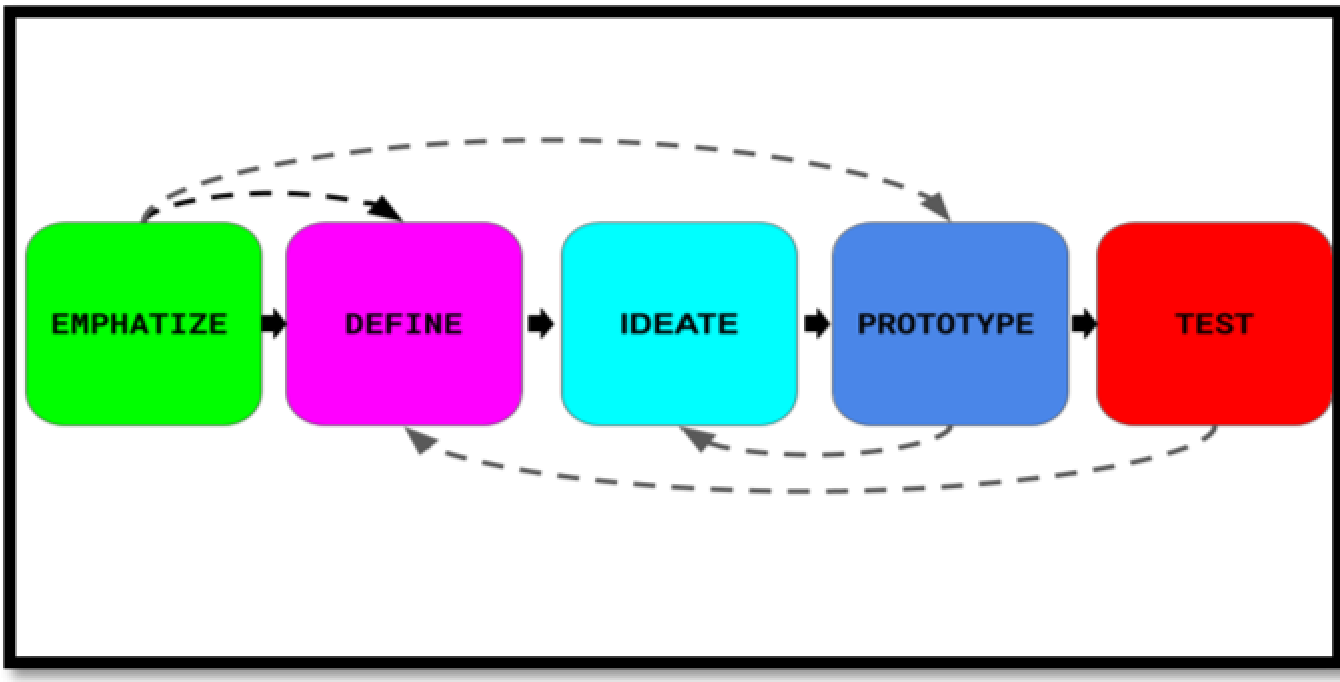

Figure 5: The Five Phases of Design Thinking*Adapted from Interaction Design Foundation*

The first phase is **empathizing**, which gives the researcher an opportunity to set their assumptions aside, understand the problem someone is facing, and think from the point of view of the person who they are trying to help. For example, during this process, students will work in pairs, conduct interviews, listen attentively about the problems their classmate is facing, understand the emotions and gain insight about their needs. This is the information collection/background research phase. During the next phase, the researcher will **define** the problem that they identified from the empathizing phase. This phase will give students an opportunity to not only identify the problems and needs of the classmate they interviewed but also create "human-centered" problem statements that they are going to investigate. The third phase is **ideating**. During this phase, the students will rely on the information that they gathered from the first two phases, challenge their own assumptions, come up with several "outside the box and radical", solutions to the problem statements that they created. During the fourth stage, the researcher creates prototypes of the best possible solutions to the problems that they identified. The main goal of this rapid **prototyping** is to create several versions of solutions using inexpensive and easy to acquire materials. During this phase, the students could use easily acquired materials such as paper, pencils, crayons, flashcards, pipe cleaners, beads, foil, and other inexpensive materials. The prototypes are replicas of the solutions that they are planning to create and could include the potential features that are in the final product. Finally, Lastly, the prototypes thus created are put to **test**, meaning they are shared with the customers for whom they have been created and obtain their feedback. This is a crucial but iterative phase where the prototypes thus created undergo several changes and modifications to ensure that they are addressing the problems they were designed for.

In summary, **Design Thinking** includes 5 phases: empathize, design, ideate, prototype, and test. Design Thinking is a process that could be used to design “human-centered” solutions to an individual’s problems. Through this process, students will be able to learn the importance of empathy, sharpen their listening skills, think out of the box, work collaboratively, create prototypes, accept failure, and design individualized solutions. In conclusion, this unit covers the importance of vaccinations, the crucial role of the immune system and how it protects us from infections and keeps us healthy, and lastly how the Design Thinking mindset could be used to help students design human-centered solution to real-world problems.

Classroom Activities

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1. The history of vaccinations. (1 block / 90 minutes)

Students will answer the following “do now” question: What are vaccinations and how do they keep you healthy?

Learning objectives

Students will be able to (SWBAT) create storyboards about the history of vaccinations. This activity will introduce them to the timeline as well as the inventions of Edward Jenner and Louis Pasteur.

Materials and teacher-developed resources

Paper, color pencils, storyboard templates, Chromebooks/cell phones

Learning activities

For the first 10 minutes of class, the students will do warm-up activity. Then they will turn and talk to the student next to them and explain their answer. Students will then watch a video about vaccinations. During the last half of the block, they will work in groups of 3 or 4 and create storyboards. The teacher will circulate throughout the room, checking their progress as well as asking them questions about vaccinations, their history, and contributions of Jenner and Pasteur.

2. Understand the Role of the Immune System (1 block)

Students will answer the following “do now” question: Define the following in your own words: antigen, antibody, immunity, antibiotic.

Learning objectives

SWBAT understand the importance of the Immune System, their role in fighting pathogens and keeping you healthy.

Materials and teacher-developed resources

Computer, LCD projector, paper, colored pencils.

Learning activities

Students will watch the Crash Course Biology videos about the Immune System. They jot down important information and ask relevant clarifying questions. They will then draw the process of phagocytosis, B cells, T cells, and antibody-antigen interactions.

3. The Design Thinking Process (1 block)

Students will work on the following “do now” question: What is empathy? Think about a time when you showed empathy to someone else. Share it with the person next to you.

Learning objectives

SWBAT understand the major components of the Design-Thinking Process (empathy, design, ideate, prototype, and test). They will be given opportunities to apply this process to solve problems.

Materials and teacher-developed resources

Paper, pencil, Chromebooks/cellphone, partner, colored pencils.

Learning activities

Talk to the person next to you and find out if they have a school-related problem that they would like to talk about. For example, time management, juggling academics with after-school activities, and completing homework on time and so forth. Students will write down the problem that their peers mentioned about, try to come up with procedures/solutions that might be able to address their classmates problem. They will then share their solutions to their peers. This activity will introduce “empathy” to the students.

4. Create a model of the “child-friendly and needle-free” Vaccine Administration System (2 blocks)

Students will work on the following “do now” question: Write down the different types of vaccine administration systems that you are familiar with. Turn and talk and share your information with the person next to you.

Learning objectives

SWBAT apply the Design Thinking Process (empathy, design, ideate, prototype, and test), and create a model of a “child-friendly and needle-free” vaccine administration system for children.

Materials and teacher-developed resources

Paper, pencil, Chromebooks/cellphone, colored pencils, colored paper, pipe cleaners, aluminum foil, tape, play dough or clay.

Learning activities

Students will work on this activity for two blocks.Day 1, they will create sketches/diagrams of the “child-friendly and needle-free” vaccine administration system. They should be able to incorporate empathy, design, and ideate (who they are going to help and why. How will their invention attend to or help solve the problem in question)Day 2, they will create models/sketches of the “child-friendly and needle-free” vaccine administration system. They will create prototypes of their design and test them.

5. Culminating Activity: Invention Convention Expo (2 blocks)Learning objectives

SWBAT participate in the Invention Convention as well as role-play as future parents.

Materials and teacher-developed resources

Rubrics for judging the projects and provide feedback

Learning activities

Day 1: The class will be divided into two groups (group 1 and 2). Students from group 1 set up their booth and display their “child-friendly and needle-free” vaccine administration system and provide detailed sketches and explanations about their invention. Students from group 2 will role-play as future parents and visit the booth and investigate various needle-free systems displayed. They will also have a chance to critique the inventions and provide constructive feedback.Day 2: The Invention Convention Expo continues. Students from group 2 set up their booth and display their “child-friendly and needle-free” vaccine administration system and provide detailed sketches and explanations about their invention. Students from group 1 will role-play as future parents and visit the booth and investigate various needle-free systems displayed. They will also have a chance to critique the inventions and provide constructive feedback.Day 2: **The Invention Convention Expo** continues. Students from group 2 set up their booth and display their “child-friendly and needle-free” vaccine administration system and provide detailed sketches and explanations about their invention. Students from group 1 will role-play as future parents and visit the booth and investigate various needle-free systems displayed. They will also have a chance to critique the inventions and provide constructive feedback.

Resources for students

Crash Course Biology, Immune System part 1: https://youtu.be/GIJK3dwCWCw

Crash Course Biology, Immune System part 2: https://youtu.be/2DFN4IBZ3rI

Crash Course Biology, Immune System part 3: https://youtu.be/rd2cf5hValM

Design Thinking Process:
https://dschool-old.stanford.edu/groups/k12/wiki/956b6/Design_Thinking_Projects_and_Challenges.html

Demo: A needle-free vaccine patch that's safer and way cheaper (Mark Kendall | TEDGlobal 2013)
https://www.ted.com/talks/mark_kendall_demo_a_needle_free_vaccine_patch_that_s_safer_and_way_cheaper?utm_source=tedcomshare&utm_medium=email&utm_campaign=tedspread

Storyboards: https://www.storyboardthat.com/

Resources for teachers

An Educator’s Guide to Design Thinking.
https://dschool-old.stanford.edu/sandbox/groups/k12/wiki/55b9c/attachments/dec28/An%20Educator%27s%20Guide%20to%20Design%20Thinking.pdf?sessionID=8cbdfc6129ceb041dbad2247ffc9d0112fd0ebce

Where Good Ideas Come From by Steven Johnson

NHPS Mastery Scoring Criteria:
http://newhavenscience.org/NGSSCurriculum/NHPSScienceMasteryScoringCriteria.pdf

NOVA, Vaccines Calling the Shots: https://www.pbs.org/video/nova-vaccinescalling-shots/

NOVA, Immunity and vaccinations explained:
https://www.pbs.org/video/nova-immunity-and-vaccines-explained/?continuousplayautoplay=true

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"Adaptive Immunity." Khan Academy. Accessed June 29, 2019.
https://www.khanacademy.org/test-prep/mcat/organ-systems/the-immune-system/a/adaptive-Immunity

Afzal, Hina Ahmad, Khadija Ahmad Zahid, Qurban Ahmad Ali, Kubra Ahmad Sarwar,Sana Ahmad Shakoor, Ujala Ahmad Nasir, and Idrees Ahmad Nasir. "Role of Biotechnology in Improving Human Health." Journal of Molecular Biomarkers & Diagnosis. Accessed June 24, 2019.
https://www.omicsonline.org/peer-reviewed/role-of-biotechnology-in-improving-human-health-82443.html.This review sketches improvement of human health by the use of biotechnological advances in molecular diagnostics, medicine, vaccines, nutritionally enriched genetically modified crops and waste management.

"All Timelines Overview." Timeline | History of Vaccines. Accessed June 24, 2019.
https://www.historyofvaccines.org/timeline/all.This timeline offers a detailed history of vaccinations dating back to 1000 CE. This timeline category holds nearly all of the entries for the subject-specific timelines. A few of the entries have been left out in order to provide a broad overview.

"An Educator’s Guide to Design Thinking." https://dschool-old.stanford.edu/sandbox/groups/k12/wiki/55b9c/attachments/dec28/An Educator's Guide to Design Thinking.pdf?sessionID=8cbdfc6129ceb041dbad2247ffc9d0112fd0ebce.This document is an excellent guide to educators and it provides details about the Design Thinking Methodology. It also includes tips and strategies for bringing design thinking into the classroom, how to apply design thinking mindsets at your school and more.

"Immune Systems." In BSCS Biology: *A Molecular Approach*, 603-29. 8th ed. Blue Version. Columbus, OH: Glencoe/McGraw-Hill, 2001.

Children's Hospital. "Types of Immunity." The Children's Hospital of Philadelphia. April 16, 2019. Accessed June 24, 2019. https://www.chop.edu/centers-programs/vaccine-education-center/human-immune-system/types-immunity.

"Connecticut Next Generation Science Standards (NGSS-CT) — A Toolkit for Local School Boards." CONNECTICUT NEXT GENERATION SCIENCE STANDARDS (NGSS-CT). Accessed June 15, 2019. https://portal.ct.gov/-/media/SDE/Science/NGSS_Boards.pdf?la=en.This document compares the 2015 Next Generation Science Standards (NGSS) with 2004

State Connecticut Science Standards. It also explains the NGSS and potential to transform science education across the State of CT.

"Defense Against Infectious Diseases." In *Glencoe Science: Reading Essentials for Biology, The Dynamics of Life*, 504-13. Columbus, OH: Glencoe/McGraw-Hill.

Giudice, E., and J. Campbell. "Needle-free Vaccine Delivery☆." *Advanced Drug Delivery Reviews* 58, no. 1 (2006): 68-89. Accessed May 2019. doi:10.1016/j.addr.2005.12.003.

Glynn, Ian, and Jenifer Glynn. The Life and Death of Smallpox. Cambridge University Press, 2004.This book provides a detailed history of smallpox, one of the deadliest infectious diseases known to mankind. The book details how smallpox spread across the world, its eradication, and how it could be used in biological warfare.

"Healthcare Professionals | Intramuscular Influenza Vaccination Infographic | CDC." Centers for Disease Control and Prevention. Accessed June 24, 2019. https://www.cdc.gov/vaccines/hcp/infographics/you-call-the-shots-intramuscular-flu-vaccination.html.This infographic provides detailed information about the proper administration of the Intramuscular injection.

"How Vaccines Work to Keep You Healthy." Queens College Health Fair. Accessed June 29, 2019. https://eportfolios.macaulay.cuny.edu/qchealthfair/vaccinations/how-vaccines-work-to-keep-you-healthy/.

"Immunizations: Vaccine Administration." AAP.org. Accessed June 29, 2019.

https://www.aap.org/en-us/advocacy-and-policy/aap-health-initiatives/immunizations/Pages/Immunizations-home.aspx.

Johnson, Steven. *Where Good Ideas Come From*. London: Penguin, 2011.The author takes the reader on a journey through centuries. The main focus of this book is to investigate the environments that lead to unusual levels of innovation and creativity across the world. The author stresses the importance of collaboration and how it leads to innovation.

Kendall, Mark. "Demo: A Needle-free Vaccine Patch That's Safer and Way Cheaper." TED. June 2013. Accessed June 24, 2019.
https://www.ted.com/talks/mark_kendall_demo_a_needle_free_vaccine_patch_that_s_safer_and_way_cheaper?>utm_campaign=tedspread&utm_medium=referral&utm_source=tedcomshare.Informative video about needle-free vaccine delivery. An excellent source to students, who are planning to design their own versions of needle-free vaccine delivery systems.

"Module 2: Types of Vaccine and Adverse Reactions." Vaccine Safety Basics. 2019. Accessed July 02, 2019. https://vaccine-safety-training.org/route-of-administration.html

"Movie: Immune System (for Kids)." KidsHealth. Accessed July 11, 2019.
https://kidshealth.org/en/kids/ismovie.html?WT.ac=en-k-htbw-main-page-f.Kids Health provides valuable information to students. The information is offered in audio, video, and print format.

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The Centers for Disease Control and Prevention (CDC) has a plethora of information on immunity, infectious diseases, and vaccinations.

"What Is Design Thinking?" The Interaction Design Foundation. Accessed July 11, 2019. https://www.interaction-design.org/literature/topics/design-thinking.This website details the Design Thinking Process. It highlights the 5 phases of the process that include: Empathize, Define, Ideate, Prototype, and Test.

Notes

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[1] https://www.ted.com/talks/hans_rosling_the_good_news_of_the_decade?utm_campaign=tedspread&utm_medium=referral&utm_source=tedcomshare

[2] http://www.nfid.org/about-vaccines/vaccine-science/vaccine-science-infographic.pdf

[3] https://www.ted.com/talks/mark_kendall_demo_a_needle_free_vaccine_patch_that_s_safer_and_way_cheaper?utm_campaign=tedspread&utm_medium=referral&utm_source=tedcomshare

[4] https://portal.ct.gov/-/media/SDE/Science/NGSS_Boards.pdf?la=en

[5] https://www.historyofvaccines.org/timeline/all

[6] The life and death of smallpox Authors: Ian Glynn, Jenifer Glynn Publisher: Profile Books, London; 2004

[7] https://www.cdc.gov/vaccines/vac-gen/immunity-types.htm

[8] https://www.mydr.com.au/travel-health/vaccination-and-antibodies

[9] https://www.cdc.gov/vaccines/hcp/infographics/you-call-the-shots-intramuscular-flu-vaccination.html

[10] https://www.cdc.gov/vaccines/vac-gen/immunity-types.htm

[11] https://www.interaction-design.org/literature/topics/design-thinking