



**The Ear and Music:
How Hearing Loss Can Impact Experiencing Music**

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This curriculum unit is recommended for:
(Chorus, 6th Grade)

Keywords: human ear, sound, soundwaves, hearing aids, otic vesicle, membranous labyrinth, cochlea, listening, hearing loss, Ludwig van Beethoven.

Teaching Standards: See [Appendix 1](#) for teaching standards addressed in this unit.

Synopsis: This unit will focus on how the human ear is created during the developmental process and how the hearing mechanisms are used in the hearing process. This unit will also focus on how educators can teach music to students that have hearing loss problems and what kinds of hearing loss devices they might come across or should be familiar with. Students in this unit will be focusing on how the music they listen to should be experienced at a safe level, and what consequences could occur if they were to damage certain structures within the inner, middle, and outer ear. They will focus on the emotional and social impact of having difficulties hearing every day sounds and music. This unit also allows students to be able to create their own hearing mechanisms for individuals that have hearing loss problems. Students will also be creating a hearing loss device that would be appropriate for a famous composer, Ludwig van Beethoven, who suffered complete hearing loss, but was still able to compose music.

I plan to teach this unit during the coming year to 25 students in sixth grade Chorus.

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The Ear and Music

Kristina White

Introduction

Rationale

As a music teacher studying biology, I was worried that I would not be able to create a unit combining these two subjects that I could present to my students. I then realized that creating music, understanding music, our reactions to music, are all biological. We use our bodies to create sounds or to support an instrument; we use our visual, aural, and sometimes physical receptors to perceive music; our brains process music and allow us to have physiological responses to it. We, as humans, are constantly using our brains and ears to experience the joys and emotions that music can spawn.

What does this have to do with children in schools? Everything! Music can improve learning practices, reduce stress, and even “improve cognitive performance”¹. Being in music class allows for all of the subjects to relate to each other and to join forces. Students are constantly discussing history, language arts, and even math within the music classroom and lessons. It became more difficult to find a new topic that would be very relevant and useful for my students, as well as easy to implement. Then, in our seminar, How to Build a Human, we began discussing how our eyes, ears, and brain are formed. I discovered the processes that go into creating certain folds and parts of the ear, and realized this could be pertinent to my students.

Demographics

The school I teach at is Oaklawn Language Academy located close to the heart of Charlotte, North Carolina. Oaklawn is a magnet K-8 school that specializes in Spanish immersion. All kindergarten students are taught in full Spanish immersion, no matter what their background. Through first and fifth grade, students are taught 50/50 in Spanish and English. Math and Social Studies are taught in Spanish while Language Arts and Science are taught in English. Special area classes are taught in English, while also encouraging our dual-language mission. Students in sixth through eighth grade can choose one of two different pathways: students can choose to take advanced Spanish courses that offer high school credit, or stay on the track that continues from elementary school.

¹ Christ, 2013

I teach at a school where 57% of students are Hispanic, 38% are African American, less than 3% are Caucasian and less than 3% are two or more races and other. This allows the blending of different cultures and experiences.

My classroom and students overall range from kindergarteners to eighth graders. I will be teaching two sections of sixth grade chorus during the Spring semester in 2020, which are the students that will be receiving this curriculum unit. Currently, I have a total of twenty-three sixth grade students. This will give the opportunity to work in smaller groups and create experiments for these students to fully understand this unit.

Unit Goals

The goals for this unit are for students to understand “potential health and wellness issues for musicians”². Students will be able to understand the basic structure of the ear, the basic properties of soundwaves, how these soundwaves at constant exposure can affect the mechanisms used to perceive sound (parts of the ear and neurons). I also want my students to understand ways that they can protect their own ears from overexposure and how people use certain devices to assist with hearing issues.

It is important that my students receive the background knowledge of how our ears are formed and how they work in order for them to understand the benefits of protecting our ears. We, as humans, want to be able to appreciate the sounds and music that the world provides. In this paper, I plan to communicate how we start off as cells, and then become diverse and complicated receivers of sound.

Content Research

How Cells Communicate to Form Ears

Before we can discuss how the ear is made during gastrulation, we must discuss how cells communicate and what begins the process of forming the ear. Cells communicate in a variety of ways. Two of the main ways that cells communicate are juxtacrine signaling and paracrine signaling. Juxtacrine signaling occurs when there is communication between cells that are in direct contact with each other, making this a short distance communication. Paracrine signaling occurs between cells that are further away from each other, secreting a protein signal over longer distances³. Cells begin to communicate, then the induction process begins.

² North Carolina Essential Standards

³ Gilbert and Barresi, p. 96

It is important to understand that a growth factor is “a potential agent to target specific tissue reactions because of their regulatory roles in cellular functions”⁴. Essentially, the most spoken of growth factor mentioned during this induction process is the Fibroblast Growth Factor or FGF. FGF is “a representative growth factor which has shown the potential effects on the repair and regeneration of tissues”.⁵ Of course, in order to build tissue within this process, there is a necessity to have a growth factor that encourages the creation of tissues.

FGF and Wnt are commonly seen in the induction process. Wnt and FGFs are activated in the neural ectoderm.⁶ At some point, a structure known as a placode (thickened ectoderm, which is what creates tissue inside our bodies) is formed, which then starts off the morphogenesis. This placode becomes thicker which helps with the mode of proliferation and division. The invagination process then begins, which is when a depression forms on the placode, which eventually becomes so pushed in that it pinches off into its own independent circular structure.⁷ This is the beginning of the otic vesicle. A structure then begins to form out of the vesicle known as the statoacoustic ganglion. This is made up of nerve cells, and is also part of the vestibulocochlear nerve. While three other groups of cells are emerging from the structure, the outer ectoderm (what becomes a different type of tissue) begins to form the outer ear. Ossicles (which will become three tiny bones in the inner ear) begin to separate and the endoderm and ectoderm grow towards each other. This grows bigger and starts to have more structure, eventually creating a ventral and dorsal region. At this point, the structure we are referring to is called the membranous labyrinth. The ventral area will produce the cochlear duct and sacculus, while the dorsal region handles the vestibular systems. The ectoderm becomes thicker and more pronounced and the endoderm grows more to create different areas. One section, which is the ventral section, grows to become a tube that connects to the back of the nose, and the dorsal section becomes the tympanic cavity. We are now seeing the middle ear forming, filled with mesenchymal tissue, which is essentially connective tissue. Now that there is a close association between the endoderm and ectoderm, the tympanic membrane starts to form, also known as the eardrum. If we were to look at the inner ear portion at this point, we would notice that the cochlear duct has begun turning and starting to resemble a coiled structure. The tympanic membrane introduces mesenchyme between the endoderm and ectoderm, which means that your eardrum is made up of three layers. Now the three ossicles mentioned earlier in the middle ear have taken shape: the malleus, incus, and stapes. These are the tiny bones that are located in the middle ear.⁸

⁴ Ye-Rang Yun et al., 2010

⁵ Ye-Rang Yun et al., 2010

⁶ Gilbert and Barresi, 2019

⁷ Sai and Ladher, 2015

⁸ Todorovic and Barton, *Embryology: Development of the Inner Ear*

If we were to look at the formation of the membranous labyrinth, we would see different areas that serve different functions. The two large areas are called the scala vestibuli and scala tympani. Located in the middle of these two sections is another section called the cochlear duct, or scala media. Eventually, the connections between the cochlear duct and scala vestibuli becomes the vestibular membrane and the connection between the cochlear duct and scala tympani is called the basilar membrane. Looking at the cells near the cochlear duct, a group of cells forms two ridges: an inner and outer. This inner ridge of cells is more closely related to the basilar membrane, while the outer ridge is where most of the communication to the brain occurs.⁹

How We Perceive Sound

Now that it is partially understood what happens in utero, what happens after birth when sounds are being heard? When discussing how humans process sound, it is necessary to focus on the entire ear structure rather than just the inner and middle ear. Although it may not seem as if it does much work, the outer ear acts as a portion of the ear that focuses the sound. This is the pinna, which “collects and focuses the soundwave”.¹⁰ The frequency then travels through the ear canal, also known as the auditory canal, then reaches the eardrum, which is also called the tympanic membrane. This membrane vibrates, which causes the very small bones in the middle ear to react and send a signal to the elliptical window, located past the malleus, incus, and stapes. The frequency or soundwave then travels through the circular canals, eventually reaching the cochlea¹¹. Oliver Sacks describes the cochlea as “snail-shaped”, and discusses how “people have compared the cochlea, the spiral organ, to a stringed instrument, differentially tuned to the frequency of notes”¹².

Inside the cochlea, there are three large areas filled with fluid that were mentioned earlier: these are the scala tympani and scala vestibuli, which surround the scala media (also known as the cochlear duct). The fluid within these areas vibrates from the very small bones in the middle ear mentioned earlier, called the ossicles. Once these different fluid-filled areas vibrate, it then activates the basilar membrane, which is essentially a structure that is made up of connective tissue and is located between the scala media and scala tympani. Here in the basilar membrane, different levels of frequency are absorbed in different parts. The frequencies create waves in the basilar membrane, which is transferring the information to the organ of Corti. The organ of Corti sits right on top of the basilar membrane and contains tiny hair cells that are also referred to as receptor cells. These cells have small groupings of more hair cells, referred to as

⁹ Todorovic and Barton, *Embryology: Development of the Inner Ear*

¹⁰ Boundless

¹¹ Boundless

¹² Sacks, 144

stereocilia. The vibrations that eventually make their way into the basilar membrane, then to the organ of Corti cause the stereocilia to submit the neurological information to the brain through the vestibulocochlear nerve, and then the proper process of signaling data to the brain.¹³

The organ of Corti is one of the most important parts of the hearing mechanisms for musicians. Because the organ of Corti contains nearly thirty-five hundred inner hair cells, an average ear can hear around fourteen hundred tones among ten octaves. These tiny receptors allow humans to hear a variety and range of sound, but they are also very delicate and susceptible to damage from loud or overused sounds.¹⁴

Dealing With Hearing Loss

What happens when we have continuous exposure to high decibel sounds? Hearing loss and ringing in the ears (also known as tinnitus) are common side effects.¹⁵ If you are a musician, you are in an environment that produces many loud sounds. For example, a snare drum alone can produce anywhere from 115 to 120 decibels. A typical drum corps can include up to nine snare drummers.¹⁶ This constant, high frequency decibel exposure can have negative effects on our ears. If this is the case, how can musicians protect themselves? The first way is by purchasing hearing protectors. This can include headphones or in-ear monitors that have limitations on decibel levels.¹⁷ Although musicians sometimes do not have the option, it is important to limit how much exposure we receive from these frequencies. It is also important to use common sense and not purposely expose ourselves to high levels of sounds consistently.

Teaching Individuals with Hearing Loss

When an individual has a hearing issue, there is no excuse for them not to learn the same concepts of music. Since music can express different perspectives, music must be taught using different methods. Not only is music taught aurally, it must be taught visually and kinesthetically.

One such method is using vibrotactile cues. Tactile cues are typically something the learner can touch, so vibrotactile cues would allow the learner to feel vibrations in order to gain understanding. This can be done using sound bars, percussion instruments, or even something as simple as sitting close to the instrument or speaker to feel vibrations. Instructors can also use

¹³ Neuroscientifically Challenged, 2015

¹⁴ Sacks, 141

¹⁵ Schupp, 21-22

¹⁶ Schupp, 21-22

¹⁷ Schupp, 21-22

visual cues, such as clapping, flickering lights, and other types of body percussion for visual learning.¹⁸

Types of Hearing Aids

A hearing aid is any type of device that amplifies sound waves to assist with hearing and understanding speech. One of the first types of hearing aids was known as an ear trumpet. These were shaped like funnels and could be made out of different materials, such as wood, silver, animal horns, etc. They collected and strengthened sound for the individual, and created a more focused sound to the eardrum.¹⁹

Hearing aids now are much more complicated, but provide better results. They can either be worn on or in the ear and typically have multiple parts: a microphone to receive the sound, an amplifier or receiver that has some sort of volume control, a miniature speaker, as well as a battery. Sometimes these devices are made with some sort of specifically designed in-ear mold. The sound is taken in through the microphone where it is turned into an electrical signal. The electrical signal is taken through the amplifier where it is either made louder or more intense. The receiver makes the signal from the amplifier into an acoustic sound, eventually making the way towards the ear mold.²⁰

There are three main categories of hearing aids: ear-level aids, on-the-body aids, and bone-conduction hearing aids. Ear-level aids include Behind-the-Ear (BTE) and In-the-Ear (ITE) aids. These types of aids contain all of the necessary components in an enclosure in the ear or near the ear. Ear-level aids are the most commonly used hearing aids in the United States. However, most BTE aids are used with children, while ITE are used more commonly with adults since they are less noticeable. On-the-body aids are used less than ear-level aids, but are mostly used by individuals with more profound hearing loss due to their power. On-the-body aids have a larger battery, and are kept in a case that is typically held in the shirt. This is connected to the inner ear device by a cord. On-the-body aids have been known to be more uncomfortable than other hearing devices. Bone-conduction hearing aids can also be referred to as a Bone-Anchored Hearing Aid (BAHA). These types of aids are used with a surgically placed implant that is put on the actual skull bone. The typically titanium implant causes vibrations to the skull, which is received from an external sound processor.²¹ Bone-Anchored Hearing Aids can be more expensive and more challenging to use, but could cause greater improvements with hearing due to creating inner ear vibrations rather than simply amplifying sound.

¹⁸ Schraer-Joiner, 2014

¹⁹ Schraer-Joiner, 2014

²⁰ Schraer-Joiner, 2014

²¹ Schraer-Joiner, 2014

Ludwig van Beethoven

When it comes to dealing with hearing loss and music, one of the greatest examples of perseverance and adaptation would have to be Ludwig van Beethoven. Beethoven was and is still considered one of the greatest composers of all time. Born in Bonn, Germany in December of 1770, Beethoven was already surrounded by struggling and talented musicians. Beethoven's grandfather was a talented composer and musician, while Beethoven's father was an alcoholic that would abuse young Beethoven while training him on a variety of instruments. Although his first recital was before he was even ten years old, Beethoven was not considered the young savant that his father had hoped for publicly. Eventually, Beethoven began studying with popular and talented musicians from Italy, Germany, and Austria, and developed his own musical abilities.²²

By the late 1700's, Beethoven was entering his late twenties and already starting to develop hearing issues. It began with hearing buzzing and various noises, then lead to losing 60% of his hearing within the next five years. By 1816, Beethoven was 46 years old and had completely lost his hearing.²³ As most people know, Beethoven was said to have been a grumpy individual who was easily frustrated. However, his passion for music was so powerful that he had his methods in which to create his music. Researchers suggest that because Beethoven had gone deaf, he was unable to hear other composer's works. This made it so that he was not distracted by their compositions and was able to create intricate pieces. Researchers also suggest that Beethoven's life-long experience composing gave him the ability to recognize notes and tones from the written notation alone. Beethoven was also known to cut the legs off of his piano in order for him to sense the vibrations from the floor that the piano gave off. These vibrations would help him distinguish which frequencies accounted for which tone and would assist him in constructing his musical works.²⁴

There is still no known diagnosis for Beethoven and his deafness. Researchers have many possibilities, but just like modern hearing loss, sometimes the diagnosis is hard to find.²⁵ What is important to remember is the social impact that the lack of hearing had on Beethoven. Even though he had trouble writing pieces of music, one of his biggest struggles was communicating with individuals in everyday life. Beethoven wrote many letters documenting his depression and isolation that was caused by his deafness.²⁶

²² Biography.com, 2019

²³ Traynor, 2011

²⁴ Traynor, 2011

²⁵ Traynor, 2011

²⁶ Biography, 2019

Beethoven is one of the greatest examples of how music can still be experienced and even written by individuals with hearing loss. Because of his methods and his fantastic works, many individuals with hearing issues can find hope and inspiration in Beethoven.

Instructional Implementation

Teaching Strategies

Using technology in the classroom is going to be one of the biggest strategies in teaching this unit. Technology is what is needed in order for these two subjects to work together. I would love for my students to be able to create a 3D model of the human ear, so that they can see the size and delicacy of the inner workings. I also would like for my students to experience what different levels of hearing loss sounds like. There are some simulators that allow individuals to experience everyday sounds at different levels of hearing loss, such as mild, severe, etc.

Students at our school in grades 6-8 are provided their own Chromebooks to use throughout that day. These Chromebooks are to be kept at school and are the responsibility of that student. With each student having their own personal piece of technology, they will be able to research new ideas on how they can protect their hearing. This will also be a great way for them to be able to document, journal, and take notes on all of the information they are learning. Google Classroom is a tool that I commonly use in my classroom. This allows students to be able to post questions, receive assignments, turn in their work, and even take quizzes on the knowledge they have learned.

My students and I can also create a KWL chart. KWL stands for What I Know, What I Want to Know, and What I Learned. This will be a great graphic organizer for students, and to understand where students are in terms of what they know about the human ear. This can be an ever-evolving list, since students will constantly be learning new information. I believe that this can be done at the beginning of the unit, as well as in the middle of studying the unit. This will help with checking for understanding, as well as seeing what interests the students about this unit.

I also hope to implement cooperative learning into my classroom. Cooperative learning is having students working in smaller groups to allow for more student-student based interaction to improve their own and each other's learning .²⁷ These smaller groups would most likely occur after whole group instruction or discussion, in order for students to understand what information will be important to discuss.

²⁷ Johnson and Johnson

Students should also focus on the emotional and social impact that hearing loss can cause. This is why I am having my students journal about some of the topics that are brought up and discussed. Music can cause many different kinds of emotions, so allowing my students to constantly write about how they feel or what they could feel if they had any hearing issues is important. It will also lead the students to create questions and possible scenarios that could help with some of the activities in the upcoming lessons.

Classroom Lessons/Activities

These lessons will be taught over the course of one to two weeks, depending on the time it takes to complete certain experiments and what students are discussing in large and small groups. These lessons will also be taught to two separate sixth grade chorus groups, each containing thirteen to fifteen students. Each class lasts about sixty-five minutes, so students will also be completing other lessons and assignments during this class time. Since each section of these classes contains a smaller group of students, there will be time to individually hear from each student and their opinions of what will happen with experiments as well as what they experience during the listening activities.

Lesson One: Introduce Parts of the Ear

Duration: 30-40 minutes

Instructions:

- Explain to students that they will be learning about major parts of the ear and what happens during the hearing process. Discuss how the inner ear is made up of small bones that vibrate whenever soundwaves reach this part of the ear.
- Show the students the 3D model of the inner ear. Explain how each part is formed during development.
- Review the parts of the ear on the ear foldable (See Appendix 2). Have students discuss how the sound enters the ear and where it travels to. Have students color each section (outer, middle, and inner ear).
- Cut out the foldable and fold and tape or glue the sections to each other. This can be used as a reference point to students.
- Using the large bowl and plastic wrap, tightly attach the plastic wrap to bowl with the rubber band. Place a small handful of dried rice on the plastic wrap.
- Have students make assumptions about what they think will happen to the rice when it is exposed to loud sounds. Using instruments and objects from around the room, have students conduct an experiment to see what happens to the rice when exposed to different sounds.
- Students should write about how they believe this could affect the inner ear. What happens to

the bones in our inner ear when sound enters? (They vibrate and send signals to the brain.) What long term effects would the inner ears have from constant exposure? What effect would it have from an extremely loud sound?

Lesson Two: Listening Activity with Hearing Loss

-As a warm-up, have students watch and participate in the YouTube video, “How Old Are Your Ears? (Hearing Test)” (See Teacher Resources for YouTube link). Students will discuss the highest pitches they could hear and could not hear. I would typically have the students watch the video first with their normal and expected reactions, and then have the students close their eyes and listen to the video a second time so that they experience it without the reactions from the other students in the classroom.

-Have students listen to different pieces of music, ranging from pop, hip-hop, and classical music. They could also listen to songs related to the time period they are learning at the time, or the songs that they will be performing for their end of year concert. Students will journal and document some of the reactions they had to the music. What did they feel? How did they feel? Did they enjoy any of the pieces?

-Now, have the students listen to the same pieces while they have ear plugs in. Explain to students that this will not completely block out the sound, but will have similarities to how someone with hearing loss would hear the music. Have students document what they heard. What were their emotions this time? How did they feel the second time they listened to the piece?

-Students will then experience the hearing loss simulator. (See Teacher Resources for website information)

-In small groups, have students discuss and document some of the emotional and social problems that individuals with hearing loss could have while listening to music and in everyday life. This topic is supposed to focus on the social issues that could arise, so encourage students to discuss personal experiences and how they can prevent hearing damage.

Lesson Three: Creating Hearing Protection/Hearing Devices

Duration: One to Two Class Periods

-Review with students basic ear structure. Discuss the different types of damage that could occur within the outer, middle, and inner ear.

-Explain to students that different types of ear damage could occur during development or could occur from other external factors.

-Present students with different examples of hearing loss due to different types of hearing damage. (Damage to the inner, outer, or middle ear)

-Explain to students that they will be creating a hearing mechanism for the certain individual that will allow them to improve their hearing. This device can be made with any materials and can

cost any amount of money.

-Explain to students that this device must be comfortable to wear for the individual, and they must take into account personal needs from the individual. (This information can be taken from different case studies or created by the instructor).

-Have students illustrate their designs and write a commentary on the specifics for their product. What materials did they use? How much does it cost? What are the different parts, and how will it allow the individual to hear?

Extension Activity: Create a Hearing Device for Beethoven

After discussing Beethoven's life and music career, discuss some of the possibilities for his degenerative hearing loss. Where do they think that most of this damage occurred? Explain the types of materials and technologies that were existing during Beethoven's time period. Have students create a hearing device or some type of mechanism that could have helped Beethoven hear the music that he wrote. Students are allowed to use ideas that currently exist, however they are only allowed to use materials that they could have found during Beethoven's time period (late 1700's and early 1800's). Students can create these hearing mechanisms using materials found in the classroom or at home, or students can illustrate their designs with commentary. Students can also vote on the best inventions and discuss ways they can improve and adapt their designs.

Appendix 1: Implementing Teaching Standards

North Carolina Essential Standards K-8 Music:

6.CR.1 Understand global, interdisciplinary, and 21st century connections with music.

Clarifying Objectives:

6.CR.1.2 Understand the relationships between music and concepts from other areas.

6.CR.1.3 Understand potential health and wellness issues for musicians.

Students will be able to connect the process of hearing and ear development with how it impacts their own hearing and damage they could cause with loud and constant exposure. Students will be able to understand the impact of hearing loss and how it affects individuals when it comes to experiencing music.

North Carolina Essential Standards 6-8 Science:

6.P.1 Understand the properties of waves and the wavelike property of energy in earthquakes, light and sound waves.

Clarifying Objectives:

6.P.1.3 Explain the relationship among the rate of vibration, the medium through which vibrations travel, sound and hearing.

Students will be able to understand the basic properties of sound waves and how this occurs during the hearing process, as well as what mechanisms in the ear are responsible for the hearing process.

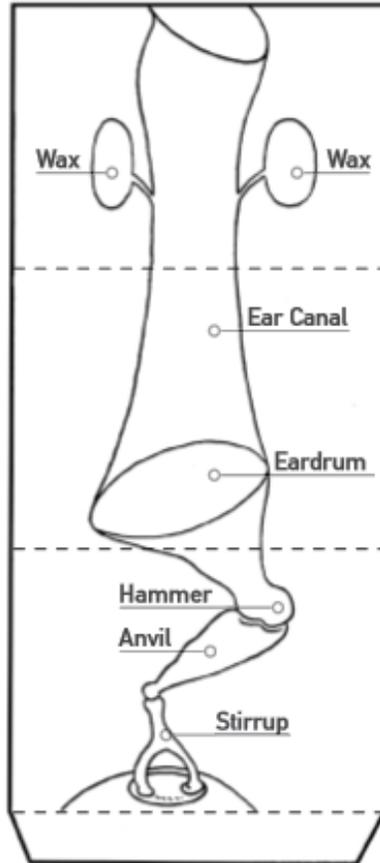
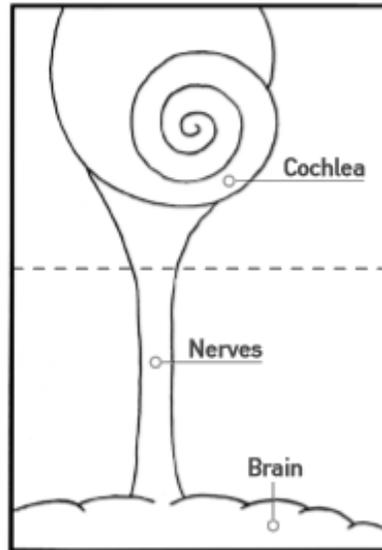
Appendix 2:

Student Worksheet 2

NAME: _____

I'm All Ears

Construct a mini-model of the ear. Cut out the three diagram pieces and tape them together to make one long strip. Fold the strip along the dotted lines so that the ear is facing outward.



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Image found from

<https://www.scholastic.com/browse/article.jsp?id=3757140>

and

http://www.scholastic.com/listencarefully/pdf/starkey_68_imallears.pdf

Appendix 3: Classroom Materials

- Foldable Ear worksheet
- 3D Mold of inner ear (optional)
- Pencils, markers
- Scissors
- Glue
- Large Bowl
- Rubber Band
- Plastic Wrap
- Dried Rice
- Earplugs
- Listening Examples
- Pencils and notebooks

Teacher Resources

AsapSCIENCE. *How Old Are Your Ears? (Hearing Test)*. YouTube. 2013

<https://www.youtube.com/watch?v=VxcbppCX6Rk>

This is a great short clip to show to students at the beginning of a lesson. It has the hearing test with pitches at different decibels and which pitches students should be able to hear based on their age.

Starkey Hearing Technologies: Hearing Loss Simulator

<https://www.starkey.com/hearing-loss-simulator#!/hls/page/1>

This website is a great simulator for students to use to understand the differences between mild, moderate, and severe hearing loss.

Notes

- ¹ Christ, 2013
- ² North Carolina Essential Standards
- ³ Gilbert and Barresi, p. 96
- ⁴ Ye-Rang Yun et al., 2010
- ⁵ Ye-Rang Yun et al., 2010
- ⁶ Gilbert and Barresi, 2019
- ⁷ Sai and Ladher, 2015
- ⁸ Todorovic and Barton, *Embryology: Development of the Inner Ear*
- ⁹ Todorovic and Barton, *Embryology: Development of the Inner Ear*
- ¹⁰ Boundless
- ¹¹ Boundless
- ¹² Sacks, 144
- ¹³ Neuroscientifically Challenged, 2015
- ¹⁴ Sacks, 141
- ¹⁵ Schupp, 21-22
- ¹⁶ Schupp, 21-22
- ¹⁷ Schupp, 21-22
- ¹⁸ Schraer-Joiner, 2014
- ¹⁹ Schraer-Joiner, 2014
- ²⁰ Schraer-Joiner, 2014
- ²¹ Schraer-Joiner, 2014
- ²² Biography.com, 2019
- ²³ Traynor, 2011
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- ²⁶ Biography, 2019
- ²⁷ Johnson and Johnson

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