Physics – Electricity & Magnetism – Headphone Engineering

Culminating Activity – Headphone Engineering			
	Speaker Dissection	**Prototype & Elevator Pitch**	**Headphone Construction and Design Brief**
Student Experience	Students are introduced to the Culminating Activity (if not done at the beginning of unit). Students dissect a speaker and hypothesize the role of each component.	Students experiment with magnets, wire, and paper, plastic, or Styrofoam cups to prototype a single headphone speaker.	Students build headphones using T4T materials. Students prepare design brief defending their design and documenting the engineering design process.
T4T Material	Speaker	2nd Speaker Thin-gauge wire Paper, plastic, or Styrofoam cups or plates	2 speakers (if not already provided) Additional wire (enough for ~35 loops in voice coil in each headphone speaker)
Big Idea	What is required to create a speaker? What does each component do?	Alternating current through a wire produces an alternating magnetic field, and therefore force, acting on the speaker cone. The speaker cone transfers the vibrations from the voice coil to the air, producing sound.	To maximize volume and clarity, speaker cone should be made from a lightweight material (low mass → high acceleration, for a given force). Speaker cone and voice coil assembly must vibrate freely. Mono vs. stereo designs.
Next Generation Science Standards	HS. PS-FM a Asking questions and defining problems.	HS. PS-FM d, e Asking questions and defining problems. Constructing explanations and designing solutions. Engaging in Argument from Evidence	HS. PS-FM d, e PS2.A:b, c Asking questions and defining problems. Constructing explanations and designing solutions. Engaging in Argument from Evidence
Time	One 55-min period	Two 55-min periods	Four 55-min periods, plus time (~1 week) for students to work on projects at home.

CA Standards:

PH5. f.	Students know magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.
PH5. g.	Students know how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.
PH5. h.	Students know changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.

These lessons are not intended to be a complete unit, but rather a guide for the culminating project. Teachers should supplement these lessons with appropriate reading material and problem sets.

Prior Knowledge (* denotes knowledge that is not included in California physics standards):

- Students know that permanent magnets and current-carrying wires are sources of magnetic fields and are subject to forces arising from other magnetic fields.
- Students know that in alternating current (AC), flow of electric charge periodically reverses direction.
- *Students know sound intensity is the rate at which energy is transferred through a unit area perpendicular to the direction of wave motion.
- *Students know that loudness can be expressed as the ratio of the intensity of a given sound wave to the intensity at the threshold of hearing, expressed in decibels (dB).

Culminating Activity – Headphone Engineering ("Beats by ME")

Engage

1. Introduce the Culminating Activity (if not done at the beginning of the unit). Inform students that they are going to play the role of headphone engineers and designers. In order to design and build a commercially successful product, students must experiment with different designs and materials to achieve their desired sound. Headphone aesthetics will also be important in determining commercial viability (what "type" of person would choose to purchase *your* particular brand of headphones?).
2. Show video of Sierra Leonean student Kelvin Doe, who builds DJ and radio equipment from discarded electronics components.
3. Have students brainstorm ideas for novel headphone designs.

Explore and Explain

4. Headphone dissection
    a. Ask students, "How do headphones produce sound? What materials are involved in the construction of headphones? How is electricity converted to sound? Dissect the speaker and hypothesize what each part does!"
    b. Students carry out the dissection and document the speaker components, writing a hypothesis about the role of each part.

Elaborate

5. Prototyping/Iterative Design Process
    a. Students carry out an iterative design process, working towards a speaker with maximum volume and clarity. At this point in the unit, students should be able to articulate, in general terms, how a speaker works. The prototyping process allows students to elaborate on their understanding of physics concepts such as alternating current, magnetic field from a current-carrying wire, magnetic force between two objects producing magnetic fields, the transfer of vibration from the voice coil to the air, and the transfer of the sound through the air to a person's eardrum.
        i. Teacher says to students, "Based on the physics of producing sound from a speaker, how can we *engineer* a speaker that will have the greatest sound?" You can introduce these terms for quantifying speaker performance now or later in the unit: dynamic range (ratio

between loudest and quietest signal, expressed as dB below full scale), frequency response (treble and bass limits), quality (clarity, or lack of buzz/rattle).

ii. "Based on the answer to the question above, iterate (define for students) through at least 3 designs that test different materials, geometries, and construction methods." Students are to use construction materials from the T4T cart, but not decorative materials.

iii. Students create prototypes, improving upon their design with each subsequent iteration. Students must document at least 3 different iterations through sketches, pictures, written notes, or data.

iv. Students give a 30-second elevator pitch to venture capitalist (teacher). Prompt students ahead of time by asking, "Which materials, geometries, and construction methods will you use in order to be successful? Support your explanation by referencing observations, data, and physics theory." The elevator pitch should demonstrate that the student:

1. understands the physics behind headphones
2. has designs for headphones that incorporate insights learned from prototyping with various designs and materials

Evaluate

6. Students gather their materials and construct their headphones. Extra credit may be earned by creating stereo headphones.

7. Teacher instructs students to collect data on the following: treble and bass frequency response, dynamic range, quality, and driver matching. Helpful site: http://www.audiocheck.net/soundtests_headphones.php
   a. Tests
      i. Low frequency limit (10 Hz → 200 Hz test)
         Note: 20 Hz is the lower limit of human hearing
      ii. High frequency limit (22 kHz → 8 kHz test)
         Note: 20 kHz is the upper limit of human hearing
      iii. Dynamic range (full scale volume → 72 dB below full scale)
      iv. Quality (no buzz/rattle→ severe buzz/rattle)
      v. Driver Matching (balanced sound between L and R ears → severe imbalance)

8. Design Brief
   b. Students create a design brief (poster or pamphlet) that documents their headphone development process and explains major design decisions.
      i. To report…
         1. Expected performance (frequency response limits, dynamic range, quality, driver matching) based on previous tests
         2. An explanation of each benchmark (what is being measured, in layman's terms?)
         3. Explanation of how headphones work (emphasize physics concepts)
      ii. To be discussed…
         1. A rationale for the materials, geometries, and construction methods
         2. How the iterative design process led to improvements in each prototype
         3. Demographic to which the headphones will be marketed
         4. Estimated cost of production (materials + labor)
         5. Improvements for future models

Beats by ME–Headphone Engineering

Project Due Date: _____

Recently the consumer market for headphones has exploded with the success of celebrity-endorsed products such as Dr. Dre's Beats and Lady GaGa's Monster earbuds. Headphones have gone from a relatively bland commodity product to a highly personalized object of self-expression. What you wear on your head serves not only to bring sound to one's ears, but also signals to the rest of the world something about your personal values. Your choice in music and musical artists says something about you to the world – your values, what you think is "cool." You wish to start your own headphone company, but in order to get funding (access to materials), you must convince an investor that your company will be successful.

1. Headphone Design

Design your headphones with any school appropriate theme, *as long as it meets these minimum criteria*:

- Your headphones must have *two speakers* that are connected to each other and can be worn on a user's head
- Your headphones must have the audio plug attached, or easily connect to one using alligator clips

2. Approval of Elevator Pitch & Prototype

First, you must build a working prototype of a speaker. It is required that you try 3 different designs (by changing materials, geometries, or construction methods) and document which designs work best, using pictures, sketches, and/or descriptions.

Second, you must give a 30-second "elevator pitch" that convinces a venture capital firm to invest in your startup company. You must convince the venture capitalist (your teacher) that you:

- understand the physics behind headphones
- have designs for headphones that will appeal to a certain demographic and be commercially successful
- are capable of actually producing your planned headphones

When your elevator pitch is presented to the venture capitalist along with your prototype, it will either be **funded or denied**. If it is denied, meaning your elevator pitch was not convincing, you must **re-pitch** *in order to be funded with materials*. The venture capitalist firm will use the following form to fund or deny your company:

The speaker prototype is audible. The elevator pitch convinces the venture capital firm that you understand the physics, are capable of bringing your product to market, and that it will be commercially successful. (10 pts)		
Date pitched:	□ Denied	□ Funded
Re-pitched on:	□ Denied	□ Funded

3. Construction Phase

Upon the funding of your startup company by the venture capitalist (your teacher), you may begin the actual construction of your headphones. Structural materials can include, but are not limited to: cups, cans, small boxes, etc. There will be a few open build workshops after school if you need help. Here are the key points:

- Your headphones will be constructed from recycled magnets, wire, and other recycled materials
- You can earn extra credit by designing stereo headphones (sound can be sent to left and right ear independently)
- You will need access to hot glue, scissors, wire cutters, and other school supplies
- You may **not** use any part that is taken directly from commercially-produced headphones (ex. you can't rip the headband off a set of old headphones to use in your own)

4. Headphone Audio Performance

You want your headphones to sounds great, so it's important that you carry out tests to determine the overall audio quality. The sound of your headphones will be evaluated using the benchmark tests on this site: http://www.audiocheck.net/soundtests_headphones.php, so it is advisable that you test your headphones using the same audio test files. (You may want to download these files onto a phone or MP3 player, if possible. Your teacher will also have a way for you to test in class.)

The following rubric will be used to evaluate the sound of your headphones:

Test	**10 pts**	**8 pts**	**6 pts**	**4 pts**	**2 pts**
Low frequency response	40 Hz or lower	80 Hz	120 Hz	160 Hz	200 Hz or higher
High frequency response	18 kHz or higher	14 kHz	10 kHz	6 kHz	2 kHz or lower
Dynamic range	30 dB below full scale or greater	24 dBFS	18 dBFS	12 dBFS	6 dBFS or less
Quality	No buzzing/ rattling at any audible frequency	Slight buzzing/ rattling	Moderate buzzing/rattling	Pronounced buzzing/rattling	Severe buzzing/rattling
Driver Matching	Sound is centered in middle of head	Slight sound deviation	Moderate sound deviation	Pronounced sound deviation	Severe sound deviation

5. Design Evaluation

In order to determine the design appeal of your headphones, the investors will use this rubric for evaluation:

Area evaluated:	**Description**		
Durability	Headphones are well-built and will withstand everyday use (10 pts)	Headphones lack durability, feel cheap or flimsy to the user (5 pts)	Headphones are extremely fragile and likely to break within first few uses (0 pts)
Style	The style is unique and can be marketed to a particular demographic/age group (10)	The headphones are bland and may be a tough sell. (5)	The headphones do not appear desirable. (0)
Comfort	User is comfortable wearing headphones for long periods of time (over 1 hour of use) (10)	User experiences moderate discomfort wearing headphones (5)	User is extremely uncomfortable wearing headphones (0)
Design Brief	Includes all explanation of how speakers work (the physics), 3 pictures or sketches of prototypes, and an justification of choices for materials, construction, etc. (10)	Some explanation of how speakers work is missing or incorrect. Some missing documentation of prototyping process. Some missing justification of design decisions. (5)	Most information about how speakers work is missing or incorrect. Most documentation of design process is missing. No justification of design decisions. (0)

Final Point Value (score):

Elevator pitch & prototype completed: _____/**10 points**
Audio performance score: _____/ **50 points**
Design Evaluation score: _____/ **40 points**
TOTAL value: ____ /100 points

Name: _____ Period: _____

Headphone Project Rubric

1. Approval of Prototype + Elevator Pitch

The speaker prototype is audible. The elevator pitch convinces the venture capital firm that you understand the physics, are capable of bringing your product to market, and that it will be commercially successful. (10 pts)		
Date pitched:	□ Denied	□ Funded
Re-pitched on:	□ Denied	□ Funded

2. Headphone audio performance (using http://www.audiocheck.net/soundtests_headphones.php)

Test	**10 pts**	**8 pts**	**6 pts**	**4 pts**	**2 pts**
Low frequency response	40 Hz or lower	80 Hz	120 Hz	160 Hz	200 Hz or higher
High frequency response	18 kHz or higher	14 kHz	10 kHz	6 kHz	2 kHz or lower
Dynamic range	30 dB below full scale or greater	24 dBFS	18 dBFS	12 dBFS	6 dBFS or less
Quality	No buzzing/ rattling at any audible frequency	Slight buzzing/ rattling	Moderate buzzing/rattling	Pronounced buzzing/rattling	Severe buzzing/rattling
Driver Matching	Sound is centered in middle of head	Slight sound deviation	Moderate sound deviation	Pronounced sound deviation	Severe sound deviation

3. Design Evaluation

In order to determine the design appeal of your headphones, the investors will use this rubric for evaluation:

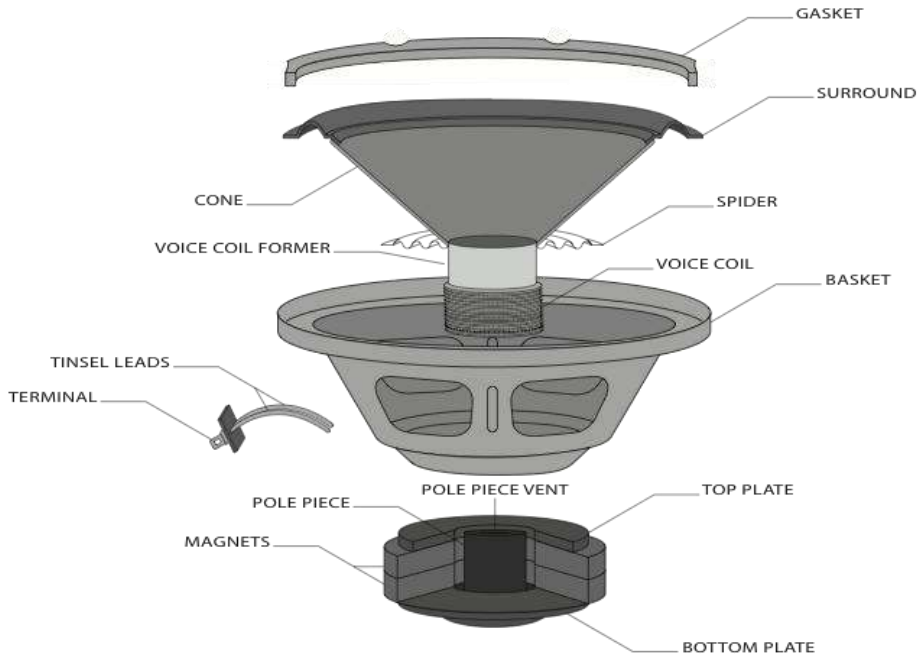
Area evaluated:	**Description**		
Durability	Headphones are well-built and will withstand everyday use (10 pts)	Headphones lack durability, feel cheap or flimsy to the user (5 pts)	Headphones are extremely fragile and likely to break within first few uses (0 pts)
Style	The style is unique and can be marketed to a particular demographic/age group (10)	The headphones are bland and may be a tough sell. (5)	The headphones do not appear desirable. (0)
Comfort	User is comfortable wearing headphones for long periods of time (over 1 hour of use) (10)	User experiences moderate discomfort wearing headphones (5)	User is extremely uncomfortable wearing headphones (0)
Design Brief	Includes all explanation of how speakers work (the physics), 3 pictures or sketches of prototypes, and an justification of choices for materials, construction, etc. (10)	Some explanation of how speakers work is missing or incorrect. Some missing documentation of prototyping process. Some missing justification of design decisions. (5)	Most information about how speakers work is missing or incorrect. Most documentation of design process is missing. No justification of design decisions. (0)

Final Point Value (score):

Elevator pitch & prototype completed: _____/**10 points**
Audio performance score: _____/ **50 points**
Design Evaluation score: _____/ **40 points**
TOTAL value: ____ /100 points

Dissection and Audio Test Info Sheet

Speaker Anatomy:



Headphone Benchmarking Tests: http://www.audiocheck.net/soundtests_headphones.php. The following descriptions were adapted from the website:

1. **Frequency response**: the first two tests are to determine the bass (low frequency) and treble (high frequency) ranges of your headphones. Most humans can hear frequencies as low a 20 Hz, and as high as 20,000 Hz. One of your goals is to design headphones that reproduce sound over the entire range of audible frequencies for humans (20 Hz—20 kHz).
2. **Dynamic range**: Dynamic range represents the ratio between the loudest signal you can hear and the quietest. Dynamic range will help you when benchmarking the isolation offered by your headphone in a noisy environment. The higher the dynamic range reached, the better the isolation offered by your headphones. In general, "closed" headphones and "in-ear" earphones provide more isolation than the "open" type of headsets.
3. **Quality**: Poorly built or extensively worn headphones may start to rattle whenever loud or deep bass content is played. The test file scans bass frequencies and will literally shake your drivers when turning the level up. Adjust the volume in your headphone so that the test is made at a high level: the sweeping tone should remain pure and clear at all frequencies, without any buzz or rattle appearing in one earpiece or the other.
4. **Driver Matching:** This refers to whether or not the sound 'in your head' is centered when both speakers (drivers) are supposed to play identical sounds. If one speaker is louder than the other, the sound will not be balanced in the middle of your head.