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