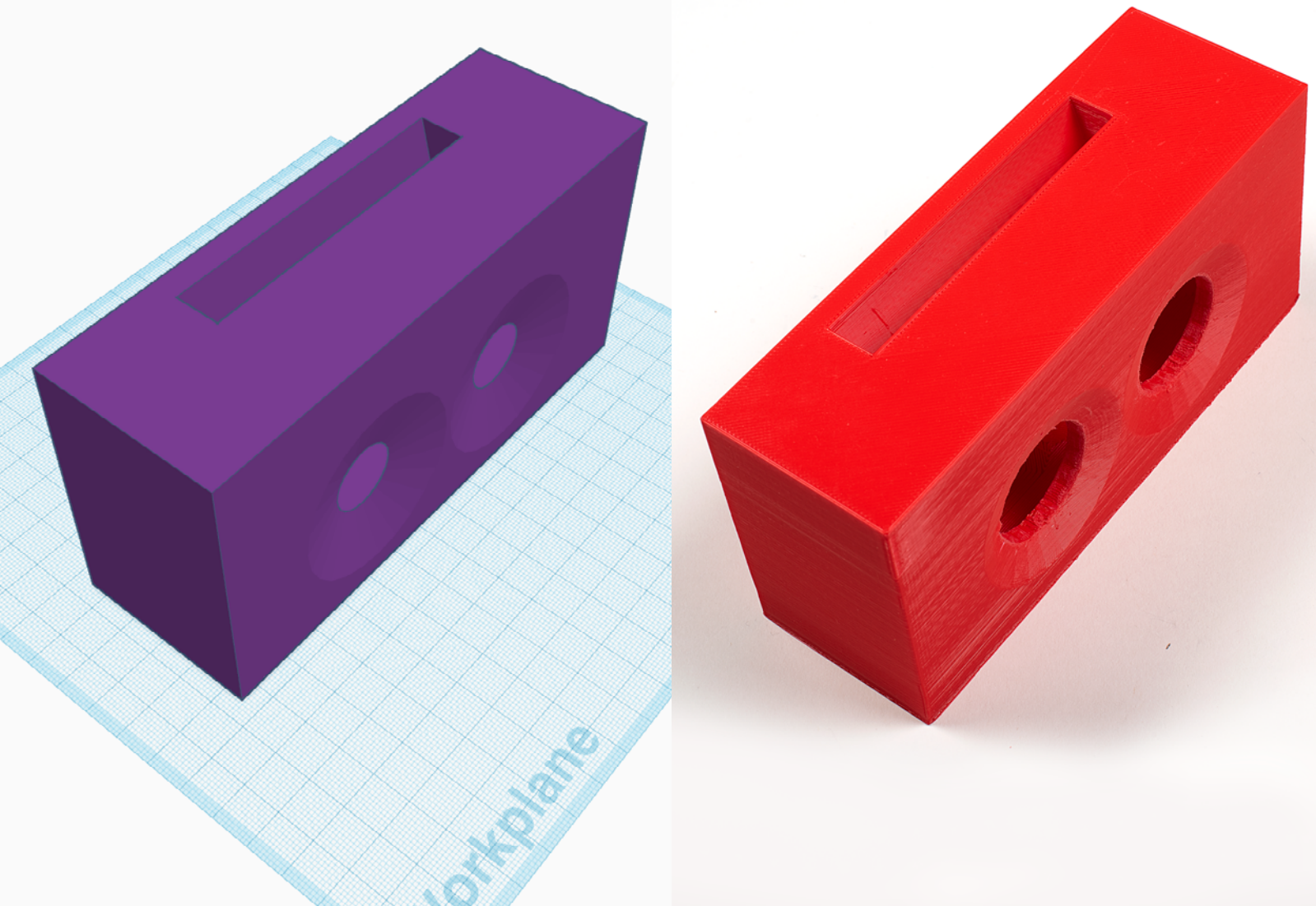


DREMEL[®] DIGILAB

Passive Speaker



Grade Level: 6

Recommended Design Software: Tinkercad

Estimated Class Time: Six 45-minute Class Periods

Estimated Printing Time: Eight Hours

Companion Files: One Example .STL File



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INTRODUCTION

People of all ages have long enjoyed taking their music and other recorded audio content with them, whether to the beach or someplace else. For this challenge, students work in teams to design a passive speaker for a cell phone—today's transistor radio!

? GUIDING QUESTIONS

How did humans amplify sound without electricity in the past?

How does a speaker's design affect its function?

How does the volume of the speaker affect the amplitude of sound?

How does the shape of a passive speaker affect the clarity of sound?

What causes distortion of sound?

How can a passive speaker's design reduce distortion of sound waves?

🎯 LEARNING OBJECTIVES

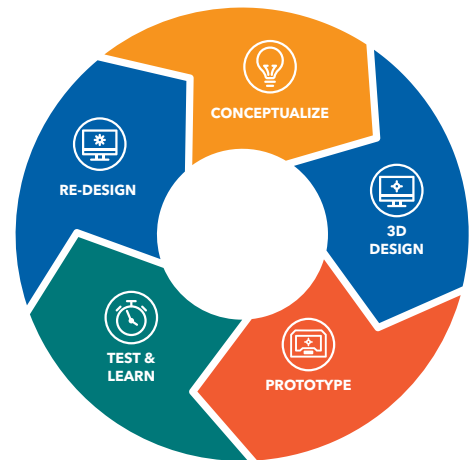
Students will research early means of amplifying sound without electricity.

Students will design and 3D print a passive cell phone speaker.

Students will apply their knowledge of how sound waves behave to their designs to reduce distortion.

Students will apply concepts of volume to develop a speaker which will amplify sound.

Students will evaluate how well their designs meet the project's requirements.



THE DESIGN WHEEL

The Dremel DigiLab Design wheel illustrates the iterative design thinking process using a series of 5 phases.

This process is vital for preparing students with the skills and experience they will need in industry.

Each phase is outlined, color-coded, and described throughout the lesson plan to guide you and your students through the design thinking process.

Education Standards

Common Core Standards

CCSS.ELA-LITERACY.SL.6.1:

Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly.

CCSS.MATH.CONTENT.6.SP.B.5:

Summarize numerical data sets in relation to their context, such as by A) Reporting the number of observations, B) Describing the nature of the attribute under investigation, including how it was measured and its units of measurement, C) Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.

NGSS

MS-PS4-2:

Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

MS-ETS1-1:

Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2:

Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3:

Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Texas Essential Knowledge and Skills (TEKS)

§126.14.c.4.B:

Plan and manage activities to develop a solution, design a computer program, or complete a project.

§126.14.c.4.C:

Collect and analyze data to identify solutions and make informed decisions.

§126.14.c.4.D:

Use multiple processes and diverse perspectives to explore alternative solutions.

§126.14.c.4.E:

Make informed decisions and support reasoning.

Fab I Can Statements

DESIGN.1

I can be responsible for various activities throughout a design process within a group under instructor guidance.

MODELING.1

I can arrange and manipulate simple geometric elements, 2D shapes, and 3D solids using a variety of technologies.

FABRICATION.1

I can follow instructor guided steps that link a software to a machine to produce a simple physical artifact.

SAFETY.1

I can safely conduct myself in a Fab Lab and observe operations under instructor guidance.



Lesson Preparation

You may find the information in this section beneficial to planning and implementing this lesson's classroom activities.

BASIC TIMELINE:

Introduce design challenge - 10 minutes

Research, brainstorming, sketching - 80 minutes

Design speakers in Tinkercad - 90 minutes

3D printing - time will vary

Test speakers - 45 minutes

Presentations - 45 minutes

MATERIALS

Essential:

- 3D printer and sufficient filament
- Computers with access to Tinkercad.com (NOTE: One computer for each student is preferred, but students may also work in pairs or teams at shared computers)
- Graph paper
- Paper
- Pencils, pens, markers, as desired
- Cell phone
- Ruler
- Sound level meter app such as iOS SoundMeter or Android SPL Pro

Optional:

- Calipers for precise measuring of cell phone

PREREQUISITES

This lesson assumes basic experience with the 3D modeling program Tinkercad. For students who have not yet used Tinkercad, consider introducing it to them with the 3D Design Basics in Tinkercad preliminary challenge, which includes links to Autodesk tutorials and other resources for getting started with the program.

If students have no experience working with Tinkercad, have students go to tinkercad.com. There they will create their own accounts. They will also need a class code to create their account. Teachers can create classrooms, and class codes, at tinkercad.com/classrooms. Once they are in their account, they may either go to Learn (if they are to learn through the self-guided tutorial) or Create New Design (if guided by the teacher).

Learn. Tinkercad has tutorials that students can go through at their own pace. Once students are in their account direct them to the upper left corner where it says "Learn." After clicking it students will see tutorials divided into three sections: Starters, Lessons, and Projects. Only the Starter tutorials are required to learn the basics in Tinkercad.

This lesson assumes instructor familiarity with Tinkercad as well. In order to demonstrate how students' sextants will work, it is necessary to have a prototype – feel free to use the files included with this lesson but consider creating your own as well.





CROSS-CURRICULAR CONNECTIONS

This lesson intersects with Physics and Social Studies. In Physics students can relate to sound waves and how they travel through various objects. With Social Studies students can research the history of music recording and playback.

CONTENT REVIEW

A “passive speaker” is an acoustic object that can, through its mass, size, and contours, amplify sound waves, including those from a cell phone’s very small speaker. Placing the phone in a passive speaker serves to channel the sound waves out in one direction, amplifying the sound in much the same way that a megaphone amplifies a voice. At the same time, the open space inside of a passive speaker functions much like the hollow space inside a musical instrument such as an acoustic guitar: Sound waves are reflected, adding depth to the sound. The following resources provide additional information:

Sound waves: <http://www.physics-classroom.com/mmedia/waves/er.cfm>

History and types of loud speakers: <http://www.edisontechcenter.org/speakers.html>

Measuring volume: http://www.helpingwithmath.com/by_subject/geometry/geo_volume.htm.

KEY TERMS

Amplitude - size or magnitude

Decibels - units to measure the intensity of sound based on human hearing

Distortion - compromised audio clarity caused by change in the form of a sound wave during processing

Echo - sound waves that bounce back (reflect) from a hard surface

Passive speaker - an acoustic speaker that will amplify sound without the use of an external power source

Sound waves - energy traveling in a mechanical wave that produces sound

Volume - the amount of space an object or substance occupies

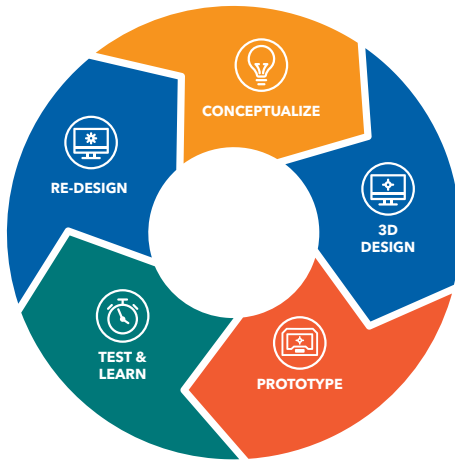
Assessment Rubric

Assessment Category & Criteria	Exceeds requirement	Meets requirement	Does not meet requirement	Teacher Suggestions
Research	All guiding questions are answered, information clearly relates to the guiding question and includes several supporting details and/or examples	Some guiding questions are answered, information clearly relates to the guiding question and includes at least one supporting detail and/or example	One or no guiding questions are answered, information has little or nothing to do with the main topic	
Design	Design is complete and meets all requirements for the project	Design has minor flaws but meets most of the requirements for the project	Design has major flaws and does not meet the requirements for the project	
Function	Superb function—significant amplification with no sound distortion	Adequate function—some amplification with minor distortion	Inadequate function—no amplification	
Critical Thinking	Excellent interpretation of data, strong evidence provided when explaining merits of the design	Adequate interpretation of data, adequate evidence provided when explaining design merits	Misinterpretation of data and/or little or no evidence provided when explaining design merits	
Creativity	All work is original, speaker has unique qualities	All work is original	Work is not original	

Assessment Rubric (continued)

Assessment Category & Criteria	Exceeds requirement	Meets requirement	Does not meet requirement	Teacher Suggestions
Collaboration	All team members contributed equally to the project, completing assigned tasks in an organized and timely manner, all team members participated in respectful and productive discussion	Most team members contributed to the project, completing most tasks in an organized and timely manner, most team members participated in respectful and productive discussion	Most team members did not contribute to the project, most tasks were not completed in a timely manner, and discussion was disrespectful or dominated by conflict	
Communication	Effectively used a variety of communication tools, including verbal and non-verbal, to express thoughts and ideas, consistently listened respectfully to others and was willing to compromise to move the group forward	Adequately used communication tools to express thoughts and ideas, mostly listened respectfully to others and willing to compromise	Failed to effectively use communication tool to express thoughts and idea, generally had difficulty listening to others and compromising, creating difficulty within the group	
Design Modification (if required)	Student provided clear evidence of analysis and refinements based on analytic results	Student provided some evidence of analysis and refinements based on analytic results	Student provided little or no evidence of analysis and refinements	
Design Notebook (if required)	Notebook included complete details of planning, testing, modification plans with rationale, and reflection about the strategies and the results	Notebook included mostly complete details of planning, testing, and modification plans with rationale, some reflection	Notebook included little or no detail about planning, testing, and modification plans with rational, no reflection	

Procedure



PHASE 1 CONCEPTUALIZE

DAY 1

**No computers needed
(45 minutes)**

Introduce the following design challenge.

You and your friends are going to be at a summer camp where you will not have modern conveniences such as electricity. Your group will be allowed to play music for two hours each evening, when the camp counselors will make a few cell phones with music on them available. The problem is, the phones' volume won't be loud enough for everyone to hear the music well.

Design a speaker that will amplify a cell phone's sound, producing the loudest sound that is possible without distortion.

(MS-ETS1-1)

DESIGN REQUIREMENTS

General:

The speaker must be stable, able to hold the phone securely with no danger of falling over.

The speaker must be able to amplify the sound by a minimum of 10 decibels while maintaining clarity.

No external power sources may be used.

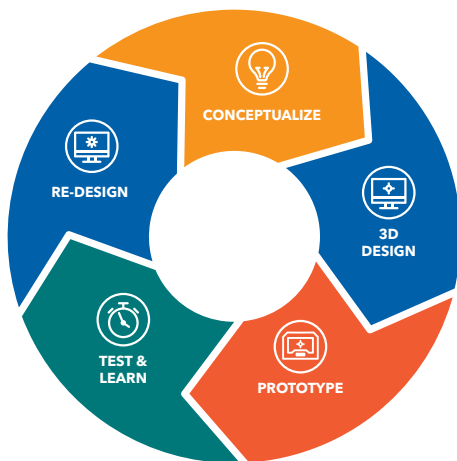
Component:

The speaker must be printed in one piece, requiring no assembly.

The speaker's size may not exceed the capabilities of the printer.

Next, have students research on how passive speakers work. What might work best for their design? Have students record their answers to be used in their brainstorming on Day 2.





PHASE 2

3D DESIGN

DAY 2

**No computers needed
(45 minutes)**

Invite students to brainstorm solutions and sketch designs, labeling all components, including measurements.

(NOTE: An option at this point is to have student groups report and discuss their preliminary design ideas. Additionally, you may want to require students to submit their drawings for your approval before they begin working in Tinkercad.)

(MS-ETS1-2, §126.14.c.4.D,
§126.14.c.4.E)

Make sure their design follows all general requirements.



DAYS 3 & 4

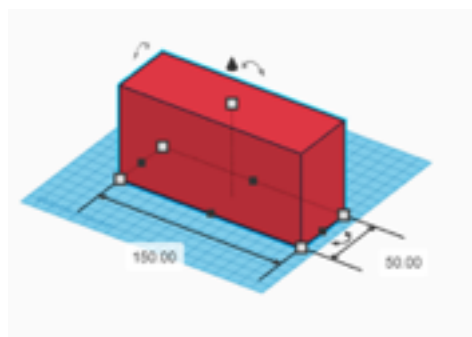
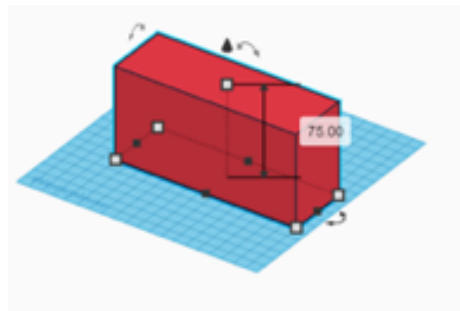
**Computers with access
to Tinkercad needed
(45 minutes)**

The design of a passive speaker can take many shapes and students can research on line and experiment in Tinkercad with shapes and sizes keeping in mind the limitations of 3D printing.

(§126.14.c.4.B)

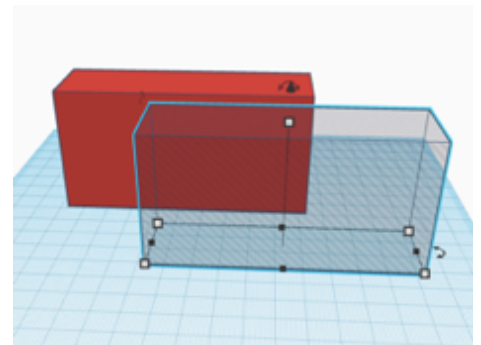
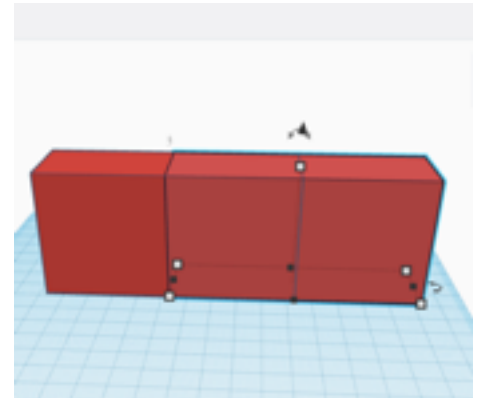
This design is a simple rectangular box but will demonstrate the techniques needed to design a passive speaker. The example design is using measurements for an iPhone 6S.

Start with a Tinkercad primitive box, make the box 75 mm high , 150 mm wide and 50 mm deep. (the dimensions are dependent on the cell phone that the student is making the passive speaker for).



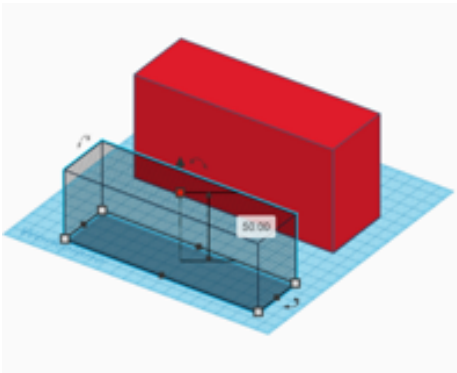
Next make the main cavity in the bottom half of the passive speaker:

Select the box and copy and paste, with the second box make it a hole.



Take the hole and change the size of the hole. (50 mm high).

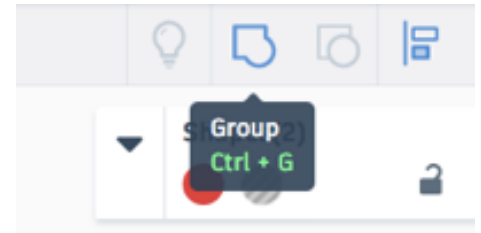
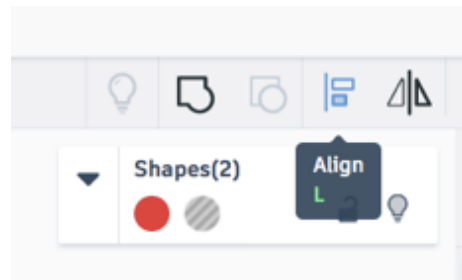
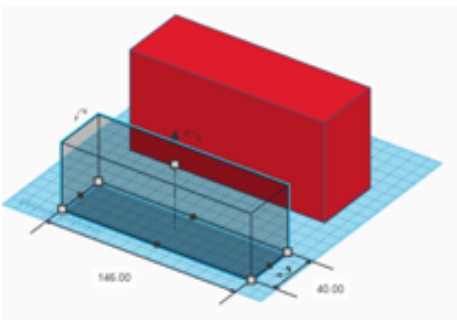
And then make the width and depth smaller by 2 X the size you want for the walls of the speaker. (in this example the walls will be 2 mm on the sides and 8 mm in the front and 2 mm in the back (so the width needs to be 146 mm and the depth needs to be 40 mm).




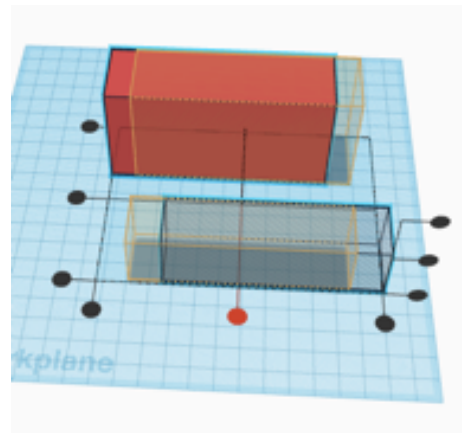
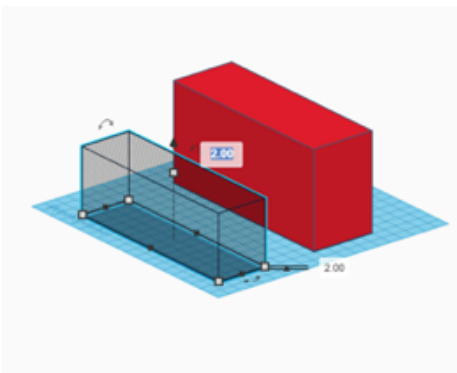
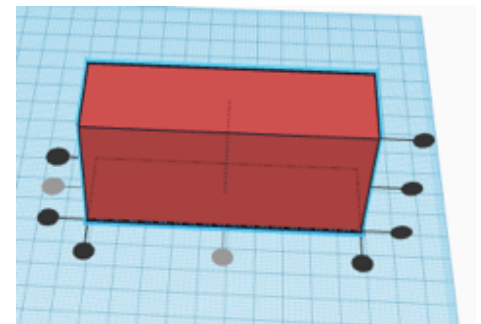
Align the hole (Center on both side axis) with the box and then group them.

Select both the box and the hole and use the alignment tool - leave the height off of the work plane alone while aligning the width and depth to the center.

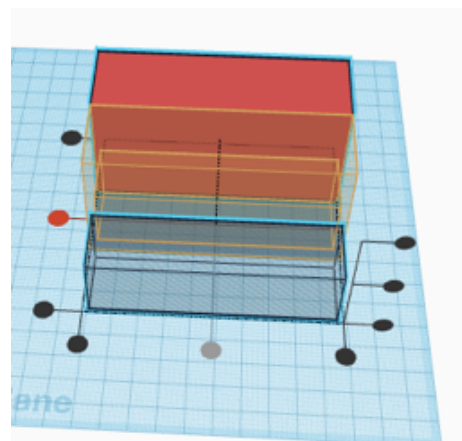
While both are selected group them - you will no longer see the hole. (but you can zoom in and see the inside of the hole - or you can take a hole and temporarily slice the box in half to check out the inside cut out)



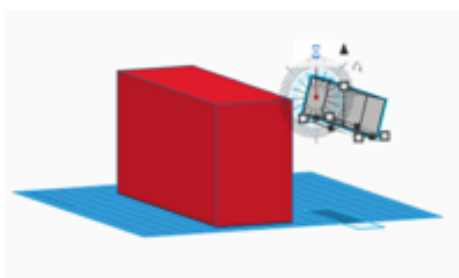
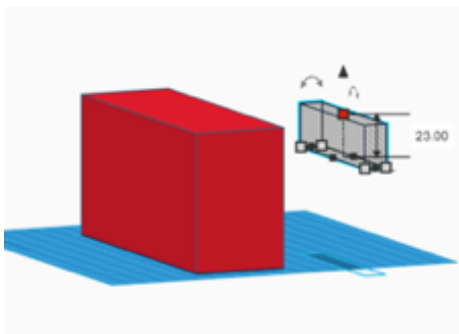
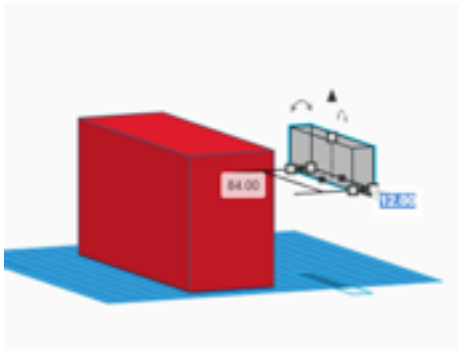
To have a bottom to the speaker the hole needs moved up on the workspace. click on the  (tree) on the top of the hole and move the hole up 2 mm.



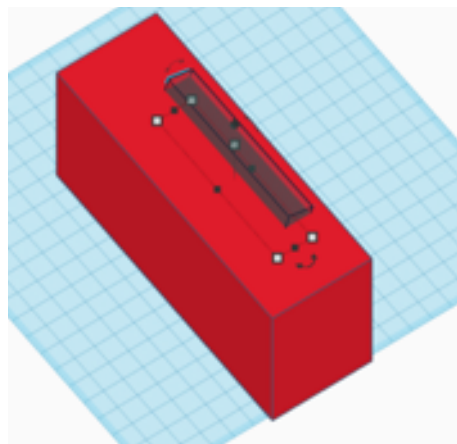
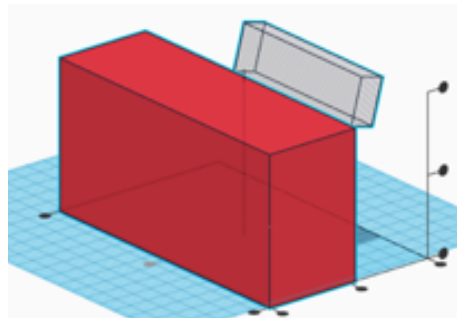
Next create the hole that the phone will sit in (the dimensions will be dictated by the measurements that the student will make on the phone to use the speaker. - Students can get creative and make the hole at an angle for the phone to sit at an angle instead of straight up and down).



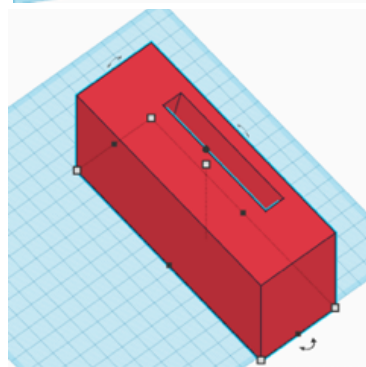
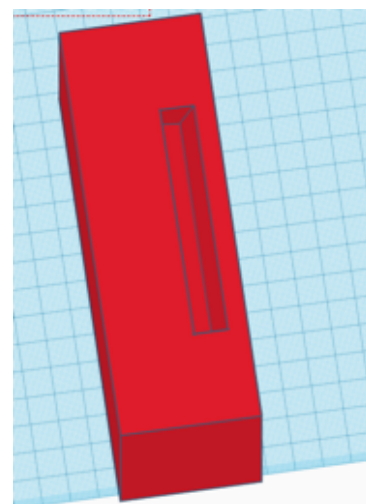
Start with a cubic hole primitive and resize it to 23 mm high, by 84 mm wide by 12 mm deep. (these measurements are for an iPhone 6S with a case. As an option you can make the hole lean 15 degrees to allow the phone to lean back.



Select both the hole and box and use the alignment tool to align the hole to the position of centered on the top of the box. Then use the arrow keys to move the hole into the top as far as you want it.



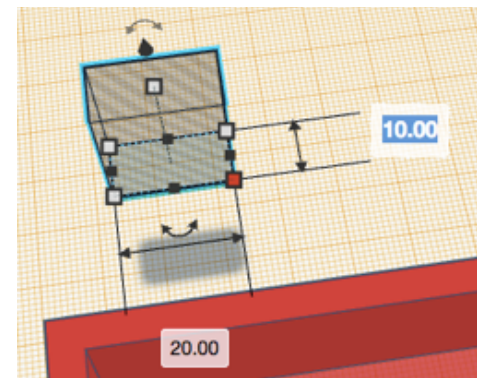
Group to create the slot that the phone will fit in.



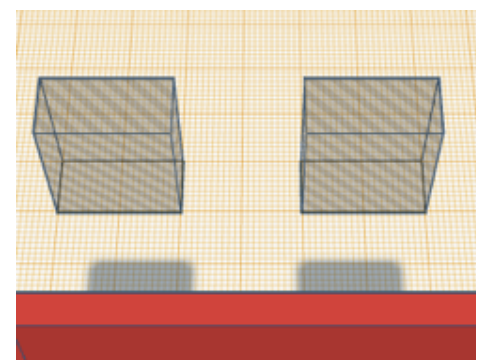
Next place the holes for the phone speakers inside on the ledge that was created by the prior step.

Measure the speakers and the space between them if there are two and make holes that will align to the phone speakers.

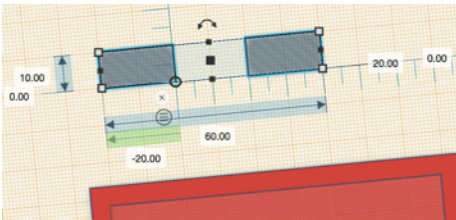
For this example, the phone has 2 speakers that are 20 mm wide by ~ 8 mm deep. Using a cubic hole primitive resized to cut holes in the ledge between the bottom chamber and the phone holding slot.



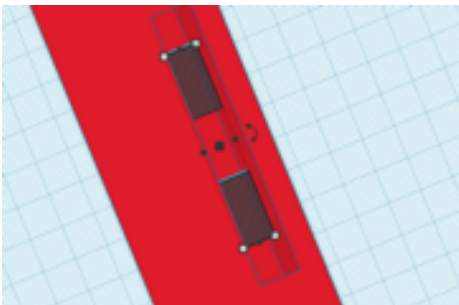
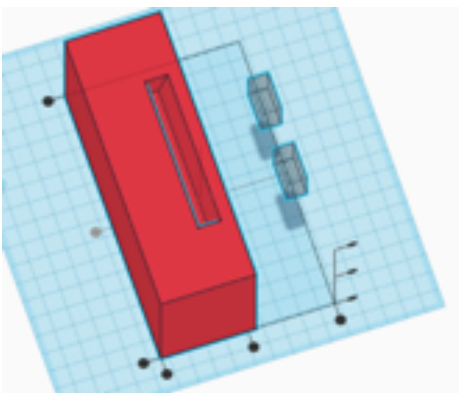
In this example the phone has 2 speakers, so two holes (we don't care about the height as long as it is tall enough to cut through into the chamber below).



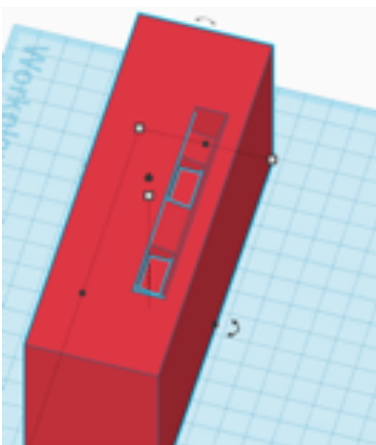
Using the ruler and grid to measure the distance between the two holes. (20 mm holes with a 20 mm space between them)



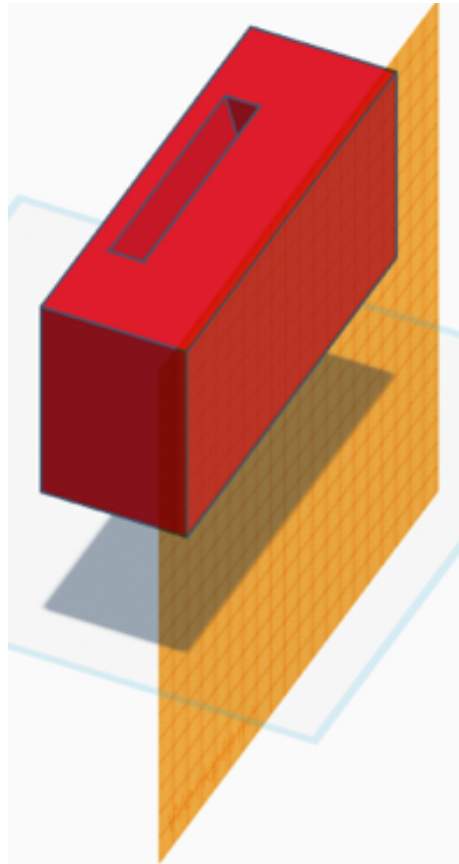
Group the 2 holes so that you can align them in to the phone slot with the alignment tool and arrow keys.



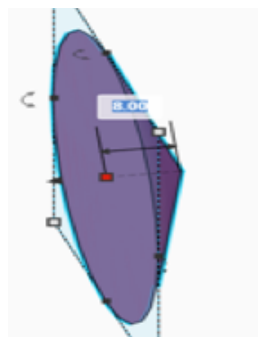
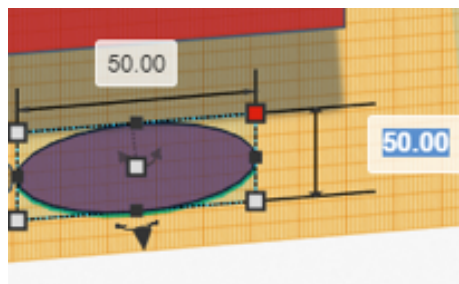
Group to cut through to the bottom cavity. (you can now see the original hidden hole!)



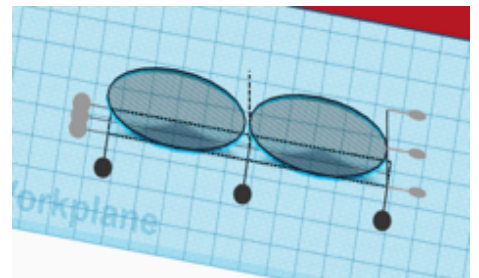
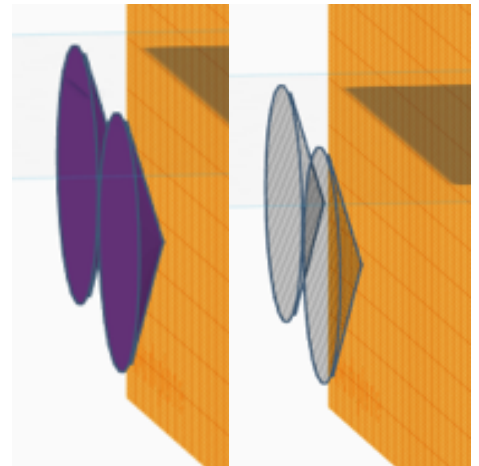
Start by using a workplane on the front side of the speaker.



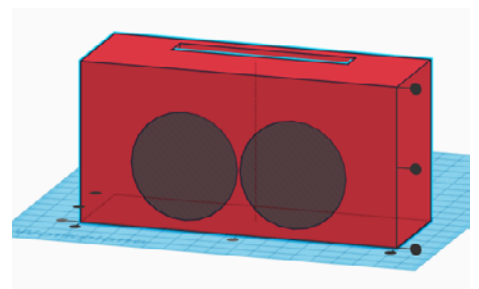
On this workplane use a cone primitive changing its size to 50mm X 50mm X 8mm deep:



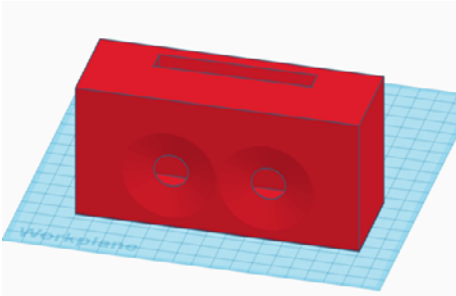
Copy and paste a second speaker shape, then make them both holes, then align them with each other (after aligning Grouping them helps with the next step):



Move the speaker shaped to align with the lower section of the passive speaker box - by centering and keeping it to the front:

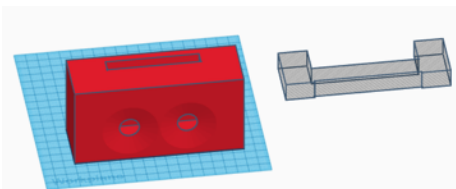


Then group:

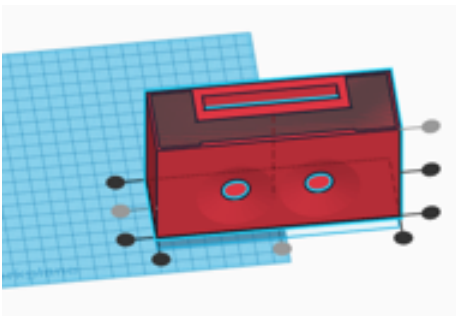


This is a completed Passive Speaker, but in thinking about 3D printing and printers you may want to add a hole in the solid top section to save print time and filament.

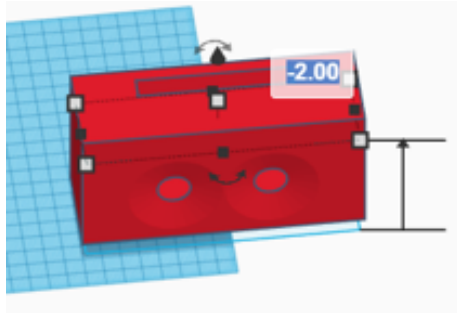
First step is to make a hole in the shape and size of the space you want to eliminate:



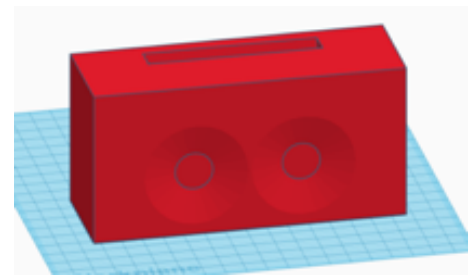
Align this hole centered and to the top:



Then move it down into the piece by the amount of the wall width. (remember you will still have scaffolding inside this section but it will use less filament and less time to print).

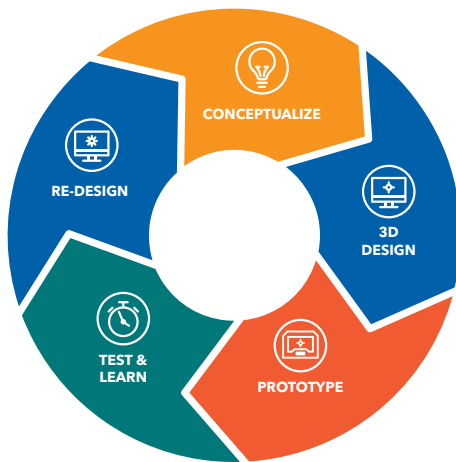


Remember to group your speaker before exporting as an STL.



(DESIGN.1, MODELING.1)





PHASE 3 PROTOTYPE

DAY 5

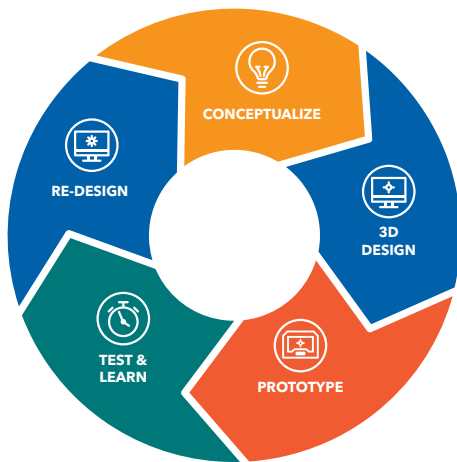
Computers with access
to TinkerCad needed
(45 minutes)

Between days 4 and 5 set aside time for each group to 3D print their project. Typically these projects take 8 hours, but times may vary depending on your specific 3D printer. Below are some general tips for 3D Printing.

(FABRICATION.1, SAFETY.1)

GENERAL 3D TIPS AND GUIDANCE

- 1. PREPARATION:** Before any fabrication can occur, check to make sure that enough correct filament is loaded. Also make sure the print bed is clear of debris and level, and that the nozzle height (Z Gap/Axis offset) is properly set.
- 2. ORIENTATION:** Some objects have more successful prints in different orientations. For objects that are long, it is optimal to print them on their side. This ensures the material has more time to cool so the next layer will adhere more successfully.
- 3. EXTRA COPIES:** If time permits and the object is delicate, place a few on the same build plate in case one is broken during removal.
- 4. BED ADHESION:** Delicate and flat objects may warp or curl on the build plate. Enable a raft in the slicing software to prevent any deformation.
- 5. GRAIN:** Like wood, 3D prints are stronger in some orientations. Identify where the stress will come from and adjust accordingly.
- 6. PROTOTYPE:** Initial prints can be made at lower resolutions (such as 200-micron layers) to test proper fit and function. This will save material and time. Save higher resolutions for the final print.
- 7. TEMPERATURE:** Keep the doors of the 3D printer closed and ensure the room the printer is in will not have drastic temperature fluctuations. Strong drafts or changes in HVAC systems can cause problems in the 3D print.
- 8. REMOVAL:** Only remove the object once the printer and build plate have cooled (usually 10-15 minutes). Carefully remove the build plate and apply force with the object removal tool. For more details on object removal and more 3D printing tips, go to <https://digilab.dremel.com/service-3d45-print-quality>



DAY 6

**No computers needed
(45 minutes)**

Once all files have been printed, invite students to test the effectiveness of their speakers using a sound level meter to record decibels.

To test their speakers, students should choose a song with volume that is as consistent as possible.

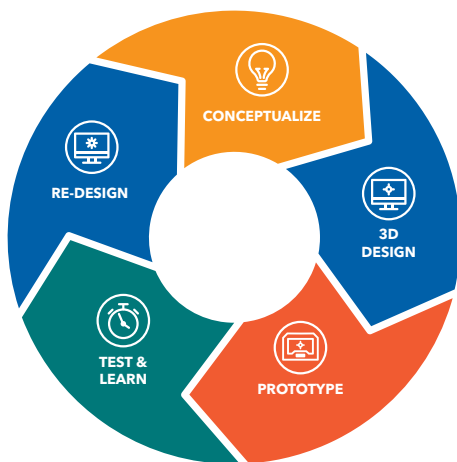
Have students complete a data table as well as starting an outline for their presentations on Day 6.

(NOTE: An option at this point is to have students graph the results. Final preparation for presentations should be assigned as homework.)

(CCSS.MATH.CONTENT.6.SP.B.5, MS-PS4-2, MS-ETS1-3, §126.14.c.4.C)

PHASE 4 TEST & LEARN





PHASE 5 RE-DESIGN

DAY 7

**No computers needed
(45 minutes)**

Students present results and ideas for design changes that will improve the speakers' performance.

Once everyone has presented, start a class discussion on the overall workflow of this product. Show an example of the Design Wheel and have students describe what they did for each section.

If time permits continue the discussion by asking the following questions. If no time is available these questions can also be assigned as reflection work.

(CCSS.ELA-LITERACY.SL.6.1)



Passive Speaker Design Challenge

YOUR CHALLENGE

You and your friends are going to be at a summer camp where you will not have modern conveniences such as electricity. Your group will be allowed to play music for two hours each evening, when the camp counselors will make a few cell phones with music on them available. The problem is, the phones' volume won't be loud enough for everyone to hear the music well.

Design a speaker that will amplify a cell phone's sound, producing the loudest sound that is possible without distortion.

? GUIDING QUESTIONS

How did humans amplify sound without electricity in the past?

How does a speaker's design affect its function?

How does the volume of the speaker affect the amplitude of sound?

How does the shape of a passive speaker affect the clarity of sound?

What causes distortion of sound?

How can a passive speaker's design reduce distortion of sound waves?

DESIGN REQUIREMENTS

General:

The speaker must be stable, able to hold the phone securely with no danger of falling over.

The speaker must be able to amplify the sound by a minimum of 10 decibels while maintaining clarity.

No external power sources may be used.

Component:

The speaker must be printed in one piece, requiring no assembly.

The speaker's size may not exceed the capabilities of the printer.

Assembly: N/A

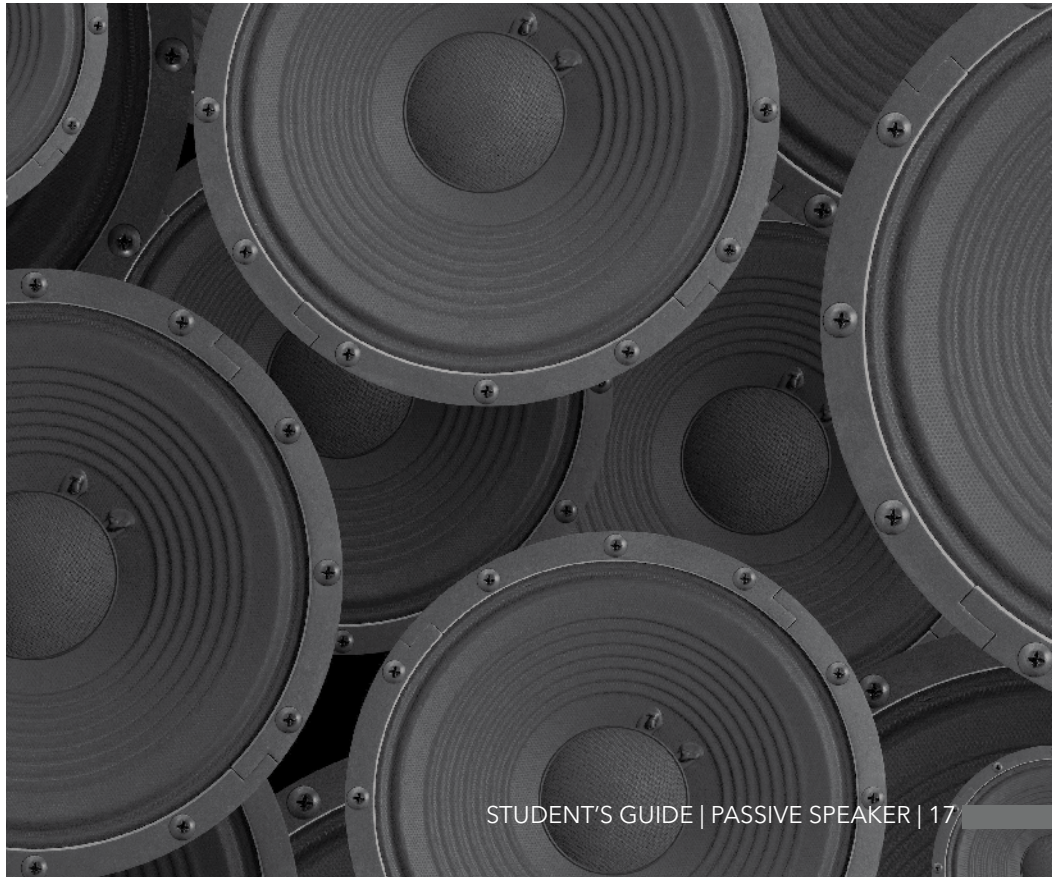
MATERIALS

Essential:

- 3D printer and sufficient filament
- Computers with access to Tinkercad (NOTE: One computer for each student is preferred, but students may also work in pairs or teams at shared computers.)
- Graph paper
- Pencils, pens, markers, as desired
- Cell phone
- Ruler
- Sound level meter app such as iOS SoundMeter or Android SPL Pro

Optional:

- Calipers for precise measuring of cell phone



TIPS FOR SOLVING THE DESIGN CHALLENGE

- Do some background research to be sure you know what factors to address in your design. See “Guiding Questions” for help with this step.
 - Brainstorm details of the design and where you think there may be problems. Thinking about possible problems before they happen is one of the best ways to avoid these problems.
 - Document your work. Keep a record of ideas (even rejected ones!), decisions about component dimensions, time required for design in Tinkercad and 3D printing, and anything else that you or your group does to create the prototype. This information will help with troubleshooting, improve your production techniques, and show how you approach a design problem.
- Use the following workflow:
 - Review the design challenge
 - Background research
 - Brainstorm design solutions, and select the best ideas
 - Prepare an outline drawing of your model to guide creation of the model in Tinkercad
 - Create the design in Tinkercad and save it as an .stl file
 - Prepare the .stl file for printing on the 3D printer
 - Print the file as a 3D shape
 - Test the prototype
 - Identify options for design improvements
 - Prepare a presentation of your or your group’s results
 - Present results and ideas for improvements



TESTING

After your speaker has been printed, test its performance:

- a. Using the cell phone that the speaker was designed for, select a song with a consistent decibel level for the verse or chorus being tested. This should be predetermined by selecting a verse or chorus and testing with the decibel meter for 10 – 15 seconds. Your goal is to find a segment of the song that gives consistent decibel measurements within a 2 decibel variation. Holding the sound level meter 3 inches from the phone, measure the decibel level from the phone. Record in data table.
- b. Place the phone in the speaker. Holding the sound level meter 3 inches from the speaker, measure the decibel level from the phone. Record in data table.

Repeat steps a and b for two additional songs with different types of genres of music (for example, rap, jazz, country, classical), demonstrating different decibel levels at the same volume. Complete the data table.

DATA TABLE

Trial	Music Genre	Decibels 3 inches from phone’s speaker	Decibels 3 inches from passive speaker	Difference
1				
2				
3				
Mean Difference				

REFLECTION

Answer the following questions:

Did your original design work? _____ If not, what caused problems?

What was the mean increase in decibel level for your speaker?

How does your model's performance compare to the models produced by other teams? Compare the data from each team.

Consider the speaker that provided the greatest amplitude of sound.
How is it different from other speaker classmates designed?